Atnarko Sockeye Recovery Plan

Nuxalk Nation

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Nuxalk Nation

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Atnarko Sockeye Recovery Plan

Final Report

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Glossary

Anadromous	Fish that mature in seawater but migrate to fresh water to spawn.
Benchmark	A standard point of reference against which condition can be compared.
Brood year	The year that a cohort of salmon spawned.
Carrying capacity	The maximum population size that can be sustained indefinably in the absence of harvest. Carrying capacity can refer to specific habitats (e.g., a sockeye nursery lake) or over the life of a species (e.g., integrated across all life stages).
Conservation Unit (CU)	A geographically, ecologically and genetically distinct population of wild Pacific salmon. A CU can contain one or more populations (see definition below).
Escapement	The number of mature salmon that pass through (or escape) fisheries and return to fresh water to spawn.
Exploitation rate	The proportion of a population that is removed by harvest (e.g., commercial and recreational fishing).
Fry	The free-swimming life stage of juveniles, which includes the period between emergence from the gravel to the smolt life stage, where the fish start migrating seaward.
Kalman Filter	A modeling approach used to separate long-term, low-frequency or persistent changes in productivity (the "signal" that is often of greatest interest) from "noise" introduced by measurement error and random, high-frequency environmental influences on survival from year to year.
Life history stage	An arbitrary age classification of salmon into categories related to body morphology, behaviour and reproductive potential, such as migration, spawning, egg incubation, fry, and juvenile rearing.
Population	A group of interbreeding salmon that is sufficiently isolated (i.e., reduced genetic exchange) from other populations such that persistent adaptations to the local habitat can develop over time.
Productivity	The ratio of adult returns (recruits) to the number of spawners that produced them. This ratio reflects the combination of survival rates across the entire life span, i.e., both the freshwater and post-juvenile stages.
Recruitment	The process where juvenile organisms survive and are added to a population of interest. In salmon management, recruitment usually refers to the pre-fishery abundance of adults. Thus recruitment is calculated based on the sum of all catches, estimates of pre-spawn mortality and post-release mortality (if fish are captured and then released), and the escapement.
Stock-recruitment relationship	The relationship describing how the number of fish in one generation (i.e., recruits: adult fish that returned to the coast, including those captured in fisheries, summed across all age classes) varies with the number of fish in the parental generation (i.e., stock: the number of spawners). As the number of spawners increases the number of recruits produced per spawner is predicted to decline as a result of, for example, competition for food and spawning habitat.
Smolt	A juvenile salmon that has completed rearing in freshwater and migrates into the marine environment.
Status	Condition of a metric relative to a defined benchmark.

Executive Summary

> **“I believe the salmon is the heart of everything – the heart of our culture, the heart of our traditions and the heart of our traditional economy”**
>
> Nuxalk Nation 1998

The Atnarko River watershed is located in Nuxalk Ancestral Territory on the Central Coast of British Columbia approximately 55 km east of the community of Bella Coola. The river flows 43km through a series of five connected Sockeye salmon nursery lakes (Elbow, Rainbow, Tenas, Lonesome, and Stillwater) before joining the Talchako River to become the Bella Coola River. Atnarko Sockeye have been observed spawning in and between all five lakes as well as downstream of Stillwater Lake. Sockeye from the Atnarko appear to exhibit three distinct life-history types that differ in the amount of time they rear in freshwater before migrating to sea.

Sockeye returning to the Atnarko have supported Nuxalk food and social fisheries for millennia. In the 1970s and 80s, returns of Sockeye to the Atnarko River supported a fishery for all user groups in excess of 30,000 fish with an average of 30,000 fish also making it to the spawning grounds. However, beginning in the late 1990s, the number of Sockeye returning to the system collapsed and the abundance of spawners has remained severely depressed ever since. From 2005 to 2015, an average of only 2,500 fish have returned to the spawning grounds each year, and productivity was below replacement during seven of the past 10 brood years. The status of Atnarko Sockeye is unequivocally in the “red zone” when assessed against Fisheries and Oceans Canada Wild Salmon Policy biological benchmarks, indicating the need for urgent conservation and management intervention.

The collapse of Atnarko Sockeye, and their failure to recover, has led to cultural and economic hardship for the Nuxalk Nation and has also impacted non First Nation communities that historically benefitted from a directed commercial fishery. As a result, there has been interest in developing a recovery plan that lays out prospects for recovery and actions to support it. A recovery-planning workshop was held in Bella Coola in the fall of 2015 to review available data, identify factors potentially limiting survival and productivity (by life stage) and determine actions to promote recovery. A Nuxalk food fisher workshop was also held to understand how Nuxalk food fisheries have changed in response to the Atnarko Sockeye decline. This report is a product of these efforts and is intended as a framework to guide activities promoting the recovery of Atnarko Sockeye.

The pronounced declines observed in abundance and survival are not unique to the Atnarko River. Sockeye populations across the southern part of their range, from Southeast Alaska to Washington, have exhibited shared downward trends in survival over the past two decades. Information on habitat conditions and trends for Atnarko Sockeye are sparse and incomplete. However, the available information suggests that changes in oceanographic conditions and the abundance of competitors at sea, coupled with acute freshwater events including forest fires and severe flooding, likely contributed to the currently depressed state of Atnarko Sockeye.

The Atnarko Sockeye recovery goal is to

> **...reverse the decline of Atnarko Sockeye salmon and re-establish self-sustaining, natural spawning populations for the benefit of future generations and the surrounding ecosystem while ensuring the preservation of the unique biological characteristics of Sockeye from the Atnarko watershed.**

Accordingly, the recovery committee identified and prioritized actions related to immediate and long-term objectives to support this goal.

Consideration of recovery potential, and activities to support recovery, must recognize broader scale declines in Sockeye survival on the Central Coast and across British Columbia. These broader-scale regional declines suggest that common mechanisms operating at sea, and thus beyond the reach of freshwater-focused recovery actions, likely have contributed to the depressed state of Atnarko Sockeye. Specific recommendations that emerged from the recovery planning workshop include improving the understanding of life history and ecology of Atnarko Sockeye (to inform appropriate scale of management and limiting factors), freshwater habitat assessment (to identify any freshwater factors that may need intervention), and assessment and synthesis of existing data from over 10 years of conservation enhancement efforts (to optimize conservation hatchery efforts moving forward). In combination, these actions should help to minimize the genetic and ecological risks of small population size and ensure Atnarko Sockeye are in the best position possible to take advantage of improved marine conditions when they occur. In addition, because harvest management is a central component to any recovery strategy, additional work focused on improving estimates of Atnarko Sockeye harvest in marine and freshwater fisheries is recommended to ensure incidental and directed harvest does occur at a level that could jeopardize recovery.

1 Background

Sockeye from the Atnarko River have been harvested by the Nuxalk for millennia. These fish have played an important role in the Nuxalk culture but declines in Atnarko Sockeye abundance over the past several decades have threatened their cultural significance. In response, the Nuxalk Fisheries Department along with Fisheries and Oceans Canada (DFO) staff from the Snootli hatchery have attempted to stop the decline and promote recovery. However, Atnarko Sockeye have remained at very low levels of abundance. In the spring of 2015, the Central Coast Indigenous Resource Alliance secured funding from the Aboriginal Species at Risk Fund to support working with the Nuxalk Nation's Stewardship Office and DFO to develop an Atnarko Sockeye recovery plan. The goals of the recovery planning process were to:

1. compile, update and synthesize existing data on Atnarko Sockeye;
2. hold a workshop with recovery plan committee members (see Appendix 1) to critically review the available data to identify potential factors limiting Atnarko Sockeye survival and productivity (by life stage) and actions that could be taken to promote recovery;
3. use traditional knowledge information from a food fisher workshop to document how and when Nuxalk food fisheries have changed in response to the Atnarko Sockeye decline; and
4. draft a recovery plan that synthesizes available information, identifies the most likely factors limiting productivity, outlines prioritized recovery activities, evaluates habitat and restoration prospects and recommends additional management actions to promote recovery.

Recovery planning efforts for Pacific salmon can be extensive (and expensive) processes involving detailed population viability analyses, numerous workshops and broad jurisdictional and stakeholder engagement, all over multiple years (e.g., Cultus Sockeye Recovery Team 2005, Sakinaw Sockeye Recovery Team 2005). In contrast, this recovery plan was developed with a modest amount of resources over a short period of time and with a single opportunity to bring the recovery planning committee together. However, it should be noted that the majority of the recovery planning team has worked together on Atnarko Sockeye for many years and so it was felt that what was primarily needed was someone to lead the compilation and synthesis of information and data so that a prioritized set of actions could be identified to help recover Atnarko Sockeye.

This document details the results of the recovery planning process and is modelled after recovery plans developed for other Sockeye populations in British Columbia (BC) including Lakelse Lake (Lakelse Watershed Society *et a*l. 2005) and Kitwanga (Cleveland *et al.* 2006) Sockeye.

1.1 Geographic setting

The Atnarko River watershed is located in Nuxalk Ancestral Territory, also known as part of the Central Coast of British Columbia, approximately 55 km east of the community of Bella Coola (Figure 1). The Atnarko River, most of which lies within the southern end of Tweedsmuir Provincial Park, originates from the Chilcotin Plateau near the Monarch Glacier. The river flows from Charlotte Lake through a steep-sided valley in a landscape characterized by a complex geology of volcanic activity, sedimentary folding and granite intrusion (BCWCS 2007). The river flows through and connects a series of five Sockeye salmon nursery lakes (Elbow, Rainbow, Tenas, Lonesome, and Stillwater) before joining the Talchako River to become the Bella Coola River.

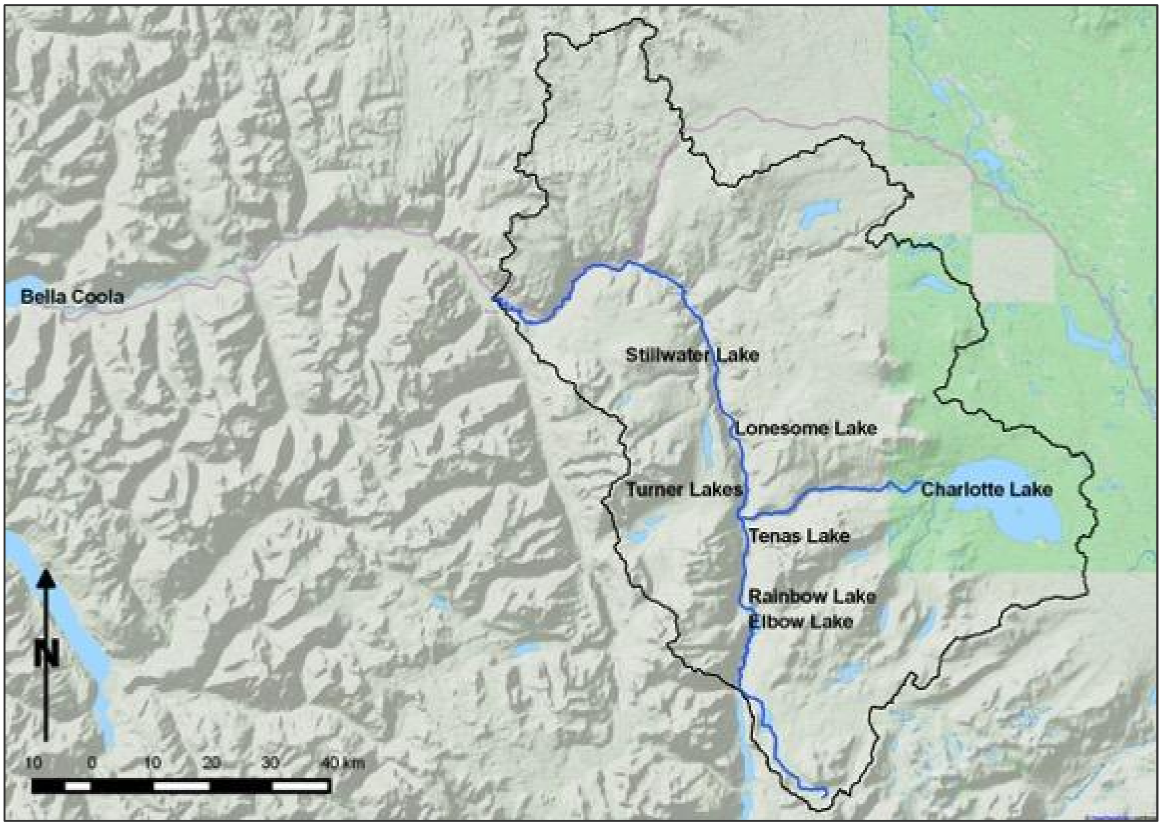

Figure 1: The Atnarko River watershed and Sockeye salmon nursery lakes (note Charlotte and Turner lakes are not nursery lakes).

1.2 Species biology and population structure

Sockeye salmon are one of five species of Pacific salmon and are anadromous – they reach maturity in the ocean but return to freshwater to reproduce. The Atnarko River stock typically spawns in late September, within and between all five nursery lakes (Figure 1), as well as in the Atnarko River itself below Stillwater Lake. As is typical of Pacific salmon, eggs are deposited in nests constructed by the female, fertilized by an adult male or opportunistic precocious male, and then subsequently covered with gravel by the female (Burgner 1991). Eggs incubate in the gravel through the winter, with incubation duration and the timing of fry emergence from the gravel (mid-April to mid-May) mediated by ambient temperatures (Burgner 1991).

Following emergence from the gravel, juvenile Atnarko Sockeye appear to exhibit three distinct life history strategies: rearing in a nursery lake, rearing in the river, or migrating directly to sea. Juveniles exhibiting the “lake-type” life history migrate to a nursery lake soon after emergence and rear there for one or two winters before migrating to sea. Juveniles exhibiting the “river-type” life history rear in the sloughs and back channels of the Atnarko and Bella Coola rivers for one or two winters before migrating to sea. Juveniles exhibiting the “ocean-type” life history migrate to sea in the same year they emerge from the gravel and likely rear in the estuary and North Bentinck Arm for a longer period of time than for other life histories, as is common in other Sockeye populations with an ocean type life history (Tucker *et al*. 2009; Beamish *et al*. 2013; Beamish *et al*. 2016). The presence of all three life history types within a single watershed the size of the Atnarko is uncommon.

Evidence for each life history type comes from freshwater growth patterns read from the scales of Atnarko Sockeye that have returned to spawn (Wood 2000, 2007). It has generally been thought that adults spawning below Stillwater Lake exhibit river and ocean life history types while those that spawn in and between the lakes above Stillwater exhibit the lake life history type. However, there is some, albeit limited, evidence that adults spawning above Lonesome Lake also exhibit the ocean life history type (Wood 2007). It is not known what proportion of the total Atnarko Sockeye complex are made up of each life history type, or how it has varied over time, though it has been suggested that as much as 30% of historic spawner abundance was made up of river and ocean life history types (Cox-Rogers 2011). Sockeye from other sockeye spawning tributaries of the Bella Coola River (Snooka Creek, Sallompt River, Nusgulch River) may also produce stream type or ocean type juveniles.

Lake and river type Atnarko Sockeye smolts are thought to migrate to sea in the spring and move northward from the Bella Coola estuary along the coast. During their first summer at sea, juvenile Sockeye remain in a band relatively close to the coast and by July can be found moving northwestward in the Gulf of Alaska within 40 km of shore (Tucker *et al*. 2009; Beacham *et al*. 2014). Limited sampling in the North Pacific Ocean suggests that by early fall, juvenile Sockeye are still distributed primarily inshore and that offshore movement typically occurs in late fall or winter (Burgner 1991). The timing of ocean entry for ocean type Atnarko Sockeye is unknown, but in other ocean type populations (e.g., Harrison Rapids in the Fraser watershed) migration to sea occurs over the late spring and summer and juveniles may reside in coastal areas for a prolonged period (Tucker *et al*. 2009; Beamish *et al*. 2013; Beamish *et al*. 2016).

Atnarko Sockeye reside in the North Pacific Ocean for one to three years before they mature and return to freshwater. Based on historic Food, Social and Ceremonial (FSC) catch in the lower Bella Coola River, and confirmed by the observations of Nuxalk food fishers, the timing of Atnarko Sockeye migration from the ocean into freshwater has shifted by approximately one week over the past 4 decades and typically peaks in early to mid-July (Figure 2).

These fish then hold in nursery lakes for varying amounts of time before spawning. See BCWCS (2007) for a summary of all documented Atnarko Sockeye spawning locations.

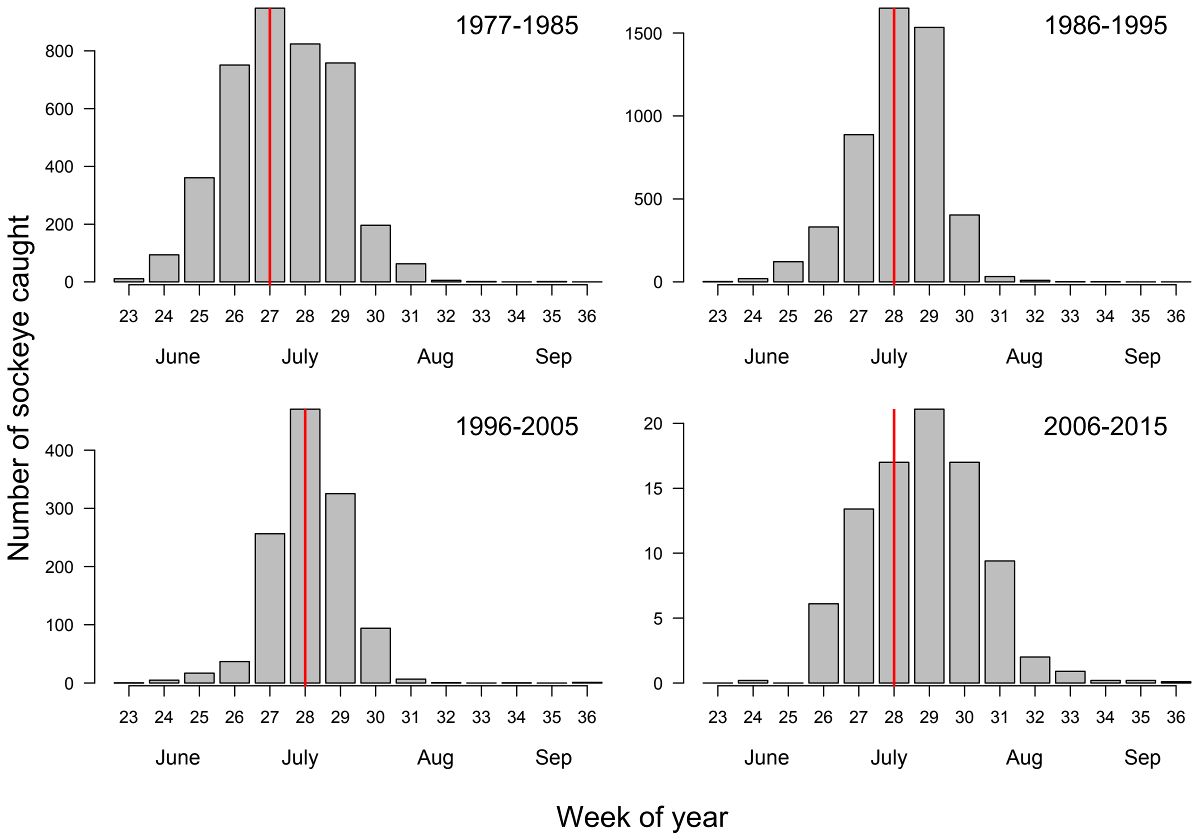

Figure 2: Atnarko Sockeye run timing as inferred from average annual Nuxalk FSC harvest by week of year in the lower Bella Coola River over four decades. Vertical red lines indicate the point at which 50% of the average cumulative catch per year occurred. Note the y-axis range varies by panel and week 28 corresponds to approximately the second week of July. Data provided by DFO.

Historic estimates of age at maturity come from biological samples taken from FSC harvest or from fish in the spawning grounds. The available data on age composition suggest that, at least in years with data, most Atnarko River Sockeye mature at age 4 and to a lesser degree age 5, although males (commonly referred to as “jacks”) can also mature at age 3 (Figure 3).

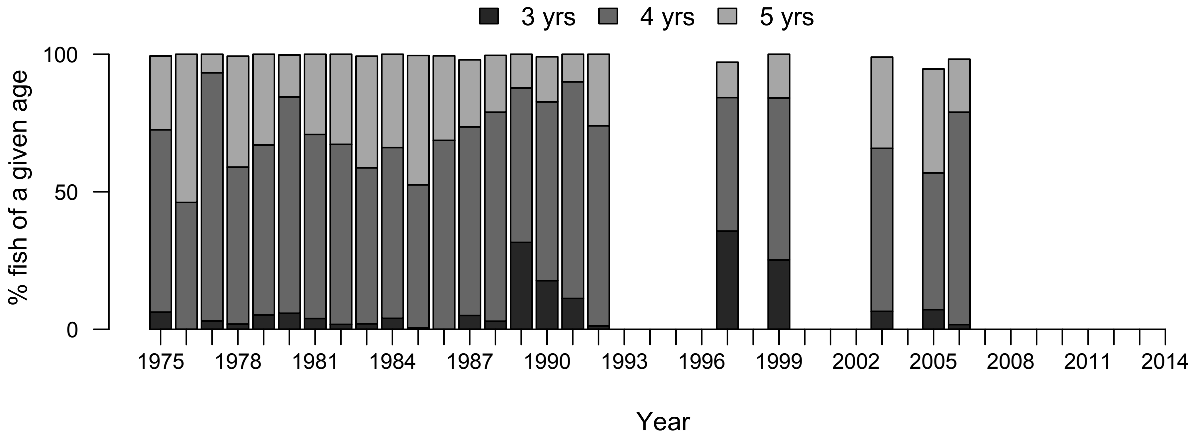

Figure 3: Atnarko Sockeye age structure, by brood year. Estimates are derived from biological samples taken from fish on the spawning grounds or harvested in FSC fisheries (minimum 100 samples). Years with no FSC or escapement samples are left blank. In some years column does not add up to 100% because older age classes are not plotted. Data provided by DFO.

The timing and duration of spawning in the Atnarko system appears to be very compressed relative to other Sockeye populations, which are often on the spawning grounds for 3 to 8 weeks. Based on field observations, Atnarko Sockeye spawning is thought to occur over the course of approximately two weeks in mid September. This very short window of spawning is both a blessing and a potential curse. From an assessment perspective the short window of spawn timing means that estimates of spawner abundance (see next section) based on a single point count are relatively precise compared to those in systems with longer spawning times. However, having all spawners mate and deposit eggs in a short period increases vulnerability to natural disturbance events while spawning.

Canada's Wild Salmon Policy (WSP; Fisheries and Oceans Canada 2005) provides a blueprint to monitor, manage and conserve salmon in order "*to restore and maintain healthy and diverse salmon populations*" in Canada. At the heart of the WSP is the management of salmon at the scale of individual Conservation Units (CUs), which are geographically, ecologically, and genetically distinct populations of wild salmon. The WSP identifies CUs based on ecotypic (e.g., life history), timing and genetic information and has preliminarily proposed two Atnarko Sockeye CUs: Atnarko river and ocean type Sockeye belonging to the "Rivers-Smiths Inlets (RSI-R12)" CU based on their life history and lake type Sockeye from the Atnarko belonging to the "South Atnarko Lakes (L-16-1)" CU based on genetic distinctness from other lake type Sockeye in the region (Holtby and Ciruna 2007). These CU classifications should be considered preliminary as molecular work investigating population differentiation among the Atnarko life history types has been very limited. For the purposes of this recovery plan the Atnarko sockeye population is treated as an aggregate population because these two population units have not been historically managed or monitored separately, and because the contribution of each life history type to total estimated abundance is unknown. As detailed in Section 4.4, this is an important knowledge gap that needs to be filled as part of the recovery planning process.

2 Stock Status

2.1 Spawner surveys and escapement estimates

The abundance of spawning Atnarko Sockeye (also referred to as escapement) has been estimated by a combination of approaches almost continuously since the early 1970s (see recent description in Cox-Rogers 2011). From the early 1970s to the mid 1990s an index of escapement was typically estimated by stream walks between the five rearing lakes coupled with boat-based surveys of Rainbow Lake (to enumerate beach spawners) and Stillwater Lake (to enumerate holding fish). The sections of the river below Stillwater Lake were then walked and floated to enumerate remaining fish. This assessment program was typically completed in a single day and followed up with a community celebration known as the “Atnarko Bash”. In 1995 the methodology changed and escapement was estimated via a single helicopter survey (1995-1997) or 2 fixed-wing aircraft overflights (1998-2006) at or near the assumed peak-timing of spawning. Since 2006, escapement has been estimated by a combination of helicopter, fixed-wing aircraft, and/or foot surveys. In 2010, escapement could not be estimated due to flooding and, in recent years, escapement has only been estimated above Stillwater Lake.

To generate a total estimate of spawner abundance in a given year, estimates of the number of observed Sockeye are typically expanded by those who conducted the counts to account for unobserved sections of the river and the reliability of the methodology used. As a result of the changes in assessment methodologies over time, and unknown methodologies for expansion of counts, historic estimates of spawner abundance should be considered of relatively poor quality (compared to enumeration programs for Sockeye in other parts of BC) and likely underestimates true spawner abundance.

Nuxalk Fisheries staff have occasionally participated in the fixed wing and helicopter flight surveys (2002-2013) as well as the recent enumeration walks with DFO Assessment (2011-2015). Bio-sampling above Lonesome Lake has also been a working relationship between the Nuxalk Fisheries and DFO Assessment and their field staff on the spawning grounds (2005-2015). In addition, since 2005 Nuxalk Fisheries staff have conducted annual river drifts in September along the Tote Road for brood stock collection as part of the Nuxalk Sockeye Recovery Project (see Section 2.6 for further details on enhancement efforts).

The Atnarko Sockeye spawning population collapsed in the early 2000s (Figure 4). From the mid-1970s to the early 2000s spawner abundance averaged approximately 30,000 fish but since 2004 has averaged approximately 2,500 spawners. This pronounced decline in spawner abundance was preceded by an earlier decline in run size beginning in the mid-1990s (see Section 2.3) and was mirrored in commercial and FSC catch.

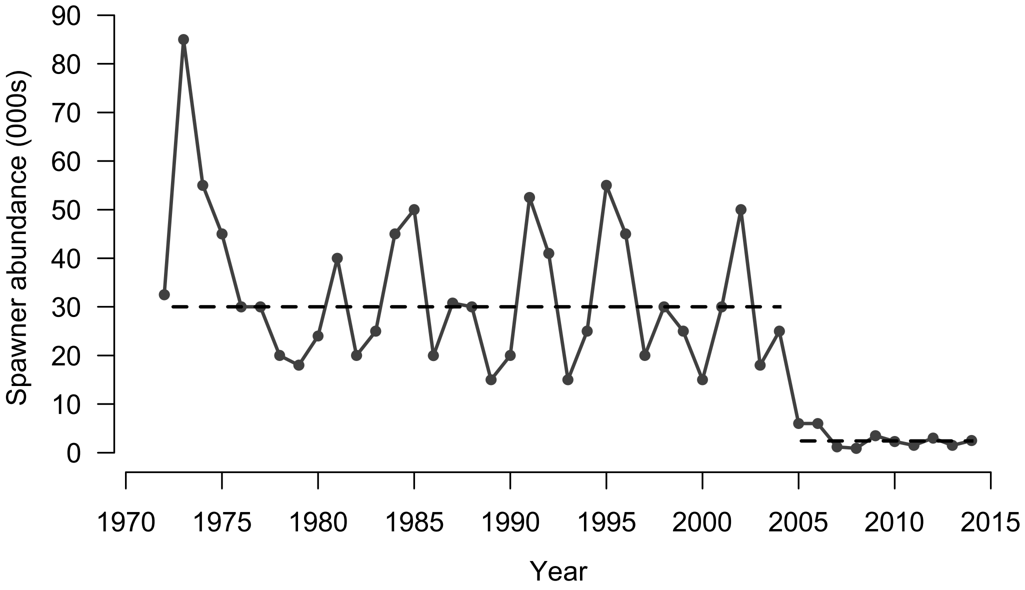

Figure 4: Estimated Atnarko Sockeye spawner abundance. Dashed lines indicate the 1972-2004 (32,780 fish) and 2004-2014 (2,840 fish) averages. Data provided by DFO.

The Atnarko Sockeye escapement from 2015 is estimated at 7,500 spawners. In addition, Sockeye were observed in tributaries of the Bella Coola River (e.g., Thorsen, Noosgultch, and Necleetsconay) for the first time in many years.

2.2 Juvenile surveys

Assessments of juvenile Sockeye abundance in Elbow and Lonesome lakes were conducted in 2007. Abundance and density estimates for populations of pelagic fish, including Sockeye, were generated from these surveys using hydroacoustic and midwater trawling techniques developed for juvenile Sockeye salmon (MacLellan and Hume 2011). Sockeye were the dominant species present in Elbow Lake and comprised most of the biomass in the lake, while in Lonesome Lake the only species present was juvenile Sockeye (Table 1). Other species present in Elbow Lake included northern pikeminnow, sculpins and juvenile Coho.

Table 1: Estimated abundance and biomass of juvenile Sockeye and dominant competitor fish species in Lonesome and Elbow lakes in the fall of 2007. From MacLellan and Hume (2011).

Lake	**Juvenile Sockeye density (n/ha)**	**Juvenile Sockeye size (mean; g)**	**Juvenile Sockeye biomass (kg/ha)**	**Dominant competitor species**
Lonesome	496	1.9	0.937	none
Elbow	153	5.7	0.864	northern pikeminnow, sculpin, and Coho

In addition to juvenile assessments, limnological surveys of Elbow, Lonesome and Rainbow lakes were conducted in 1999 and 2007 (Shortreed and Hume 2008; MacLellan and Hume 2011). These surveys characterized lake temperature, conductivity and chemistry along with the zooplankton community. A habitat-based model using data from these surveys was used to convert estimates of the photosynthetic rate of the lake into the predicted number of juvenile Sockeye the lake can support and the number of Sockeye salmon spawners (S_{MAX}) required to produce them. Based on initial limnetic surveys in 1999, S_{MAX} for Elbow, Lonesome and Rainbow lakes was estimated as 2,000, 11,000, and 3,000 spawners, respectively (Cox-Rogers 2011). However, these estimates were based on a single lake survey in September and did not account for the limnetic fish community (e.g., competitors). Shortreed and Hume (2008) re-surveyed the three lakes in 2007 after accounting for the limnetic fish community updated estimates of S_{MAX} for Elbow, Lonesome and Rainbow lakes to 2,200, 14,500, and 4,600 spawners, respectively. Based on these updated estimates of S_{MAX} and the juvenile assessments in 2007 (Table 1) fall fry densities were approximately 8% and 14% of maximum lake rearing capacity for Elbow and Lonesome lakes, respectively.

2.3 Fisheries and harvest

Atnarko Sockeye have been harvested by the members of the Nuxalk Nation for millennia. These sockeye, along with Chinook, Coho, Pink, Chum and Steelhead are essential components of the food fish that maintain the health and structure of each Nuxalk family and are central to the traditional culture of the Nuxalk Nation.

> **To a lot of people, salmon's just salmon. Some people don't have it. Sockeye is more important here and spring salmon, but in other places it's different. They're both similar in that they're most used. For one thing, you get slaq'k [dried fish] out of spring salmon, and canned fish out of sockeye; other ones you do are coho and dog salmon. Humpies/pink salmon, they use it. They use all of it.**
>
> (0020, Nuxalk Fisher) (Winbourne, 1998)

Sockeye were historically harvested using a diversity of methods including stone traps, weirs, and dip nets (McIllwraith 1948). Colonization and technological advances have meant that most of these traditional methods are no longer used. Today, most fishing is done using drift or set nets in the Lower Bella Coola River or offshore using commercial gillnet fishing boats. Beginning in the early 1900s, commercial fisheries began to target Sockeye from the Atnarko River and a cannery began operations in Tallheo, the location of a former village of the Nuxalk known as Talyu. The cannery closed in the 1960s with the advent of faster and larger packers and improved ice-making technology.

Contemporary estimates of catch in Pacific Fisheries Management Area 8 commercial fisheries are available from the mid-1970s to present. This Area includes Atnarko Sockeye as well as other local stocks (e.g., Kimsquit, Namu, and Koeye) and likely Sockeye bound for the Rivers and Smiths inlets in large return years. Catch in Area 8 historically averaged 100-150 thousand fish (Figure 5; estimates from the early 1950s to 1970s indicate a similar level of average harvest) but declined dramatically in the early-1990s and remained around 2,000 fish until the mid-2000s when all directed commercial harvest of Sockeye in Area 8 was closed. The commercial fishery has remained closed ever since, with regulations specifying no Sockeye retention in Pink and Chum seine fisheries since 2005 and release of all live Sockeye in gillnet fisheries since 2007.

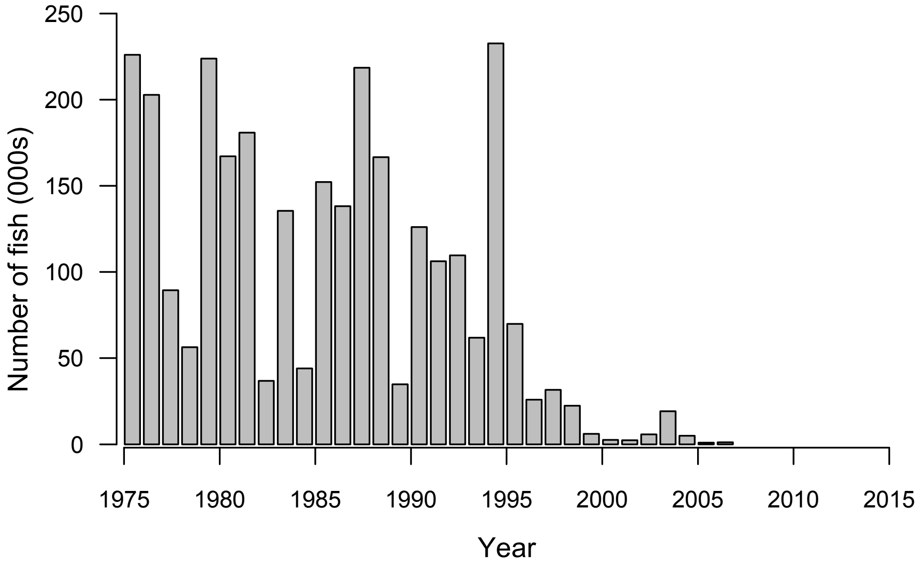

Figure 5: Historic estimates of Sockeye harvest in Area 8 commercial fisheries. Data provided by DFO.

The proportion of Area 8 catch that consists of Atnarko Sockeye is difficult to estimate because information on catch composition by stock is extremely limited. A single year of stock composition data from FSC catch in Area 8 (Fisher Fitz-Hugh Sound) is available from 2003 based on genetic stock identification of 64 fish (Cox-Rogers 2011). These samples suggest that the Atnarko component of Area 8 catch was 13% and 6% for lower and upper Fisher Fitz-Hugh Sound, respectively. Catch of Sockeye from other regions in Area 8 including Burke Channel, Labouchere Channel, South Bentinck Arm, and North Bentinck Arm are likely to be comprised primarily of Atnarko Sockeye, with a small, but unknown contribution from Sockeye returning to the Kimsquit River in the Dean Channel.

When historic estimates of Atnarko Sockeye catch are reconstructed from the overall Area 8 catch history, based on the assumptions above and estimates of FSC catch in the lower Bella Coola River drift net fishery, a pattern similar to that observed with total Area 8 catch emerges (Figure 6). Estimated average annual catch of Atnarko Sockeye dropped by an order of magnitude in the mid 1990s (i.e., from ~30,000 to 2,000 Sockeye). These reconstructed estimates of Atnarko Sockeye harvest corresponded to exploitation rates that exceeded 50% in many years prior to the mid-1990s before dropping to an average of 5-10% ever since (Figure 6).

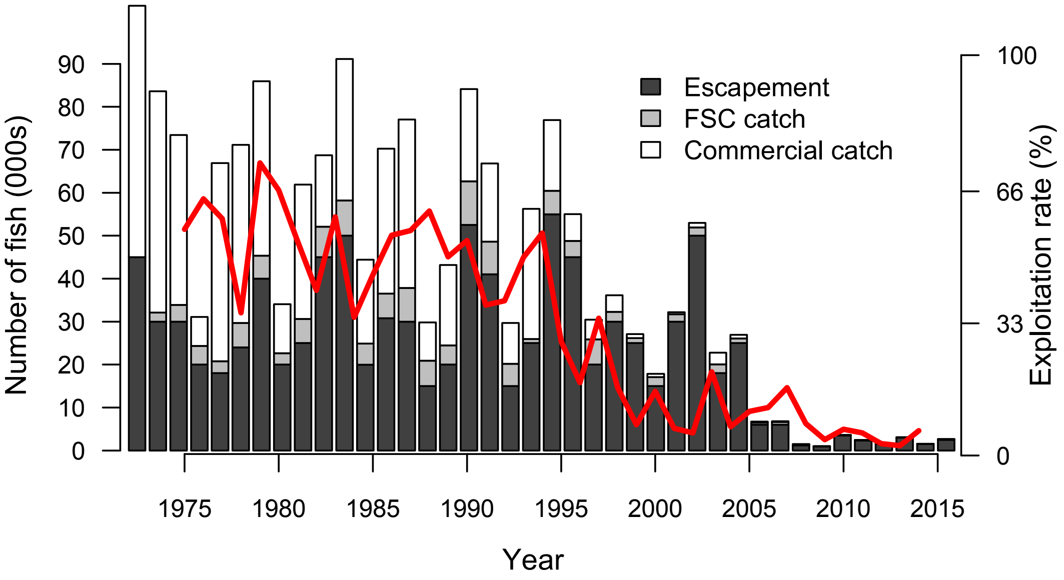

Figure 6: Atnarko Sockeye run size (bars including commercial and FSC catch and escapement) and exploitation (red line). Data provided by DFO.

The Lower Bella Coola Nuxalk drift net food fishery catch averaged 3,500 Sockeye through the mid-1990s before mirroring earlier declines in marine harvest and dropping to an average of less than 100 fish since 2005 (Figure 2, Figure 6). In the late 90's interviews were conducted with Nuxalk community members about salmon by graduate student Janet Winbourne. During these interviews, participants reported "dramatic declines in sockeye and steelhead in the last ten to fifteen years."

> **The sockeye's becoming so limited that… we don't eat that much sockeye now. We're sort of stretching it out a little bit. About ten years ago, we would never think of doing that, because they were plenty then, but now it's becoming less we're conserving it our own way. [My husband] was able to go fishing about three times down the river and we'd have our winter supply. But now he has to go down very often to get enough for our winter supply**

(0033, Nuxalk Fisher) (Winbourne, 1998)

These observations indicate that beginning in the late 1980's food fishers were observing Sockeye declines and by the late 1990's these declines had become drastic. Lower Bella Coola River food fishers no longer target Atnarko Sockeye by driftnet and those that are harvested are caught in set nets or incidentally in the targeted Chinook drift net fishery. This is because of both the depressed abundance of Atnarko Sockeye and the increased abundances of Chum whose run timing through the lower river appears to have increased in overlap with Atnarko sockeye run timing in recent years. These Chum, which are not typically targeted because of their condition, are so abundant that it makes targeting Sockeye unfeasible. The apparent shift in the timing of the Chum return has coincided with hatchery enhancement of Chum stocks (see Section 3.2). The very limited window for harvest of Sockeye in the lower river has resulted in increased drift and set net effort in the mid Bella Coola River.

2.4 Stock-recruitment relationship and productivity

With estimates of run size and age composition, the total production of adult Atnarko Sockeye salmon from a given brood year (i.e., year that a cohort of salmon spawned) can be estimated. The resulting brood table, which tracks the total adult salmon that returned to spawn or were captured in fisheries (recruits) by brood year, can then be used to calculate total life-cycle survival and to infer the relationship between the abundance of spawners and the number of adult salmon they produce (i.e., the stock-recruitment relationship). The number of adult Atnarko Sockeye recruits produced per spawner historically fluctuated around two prior to declining in the mid-1990s and then dipped below replacement for seven of the past ten brood years (Figure 7).

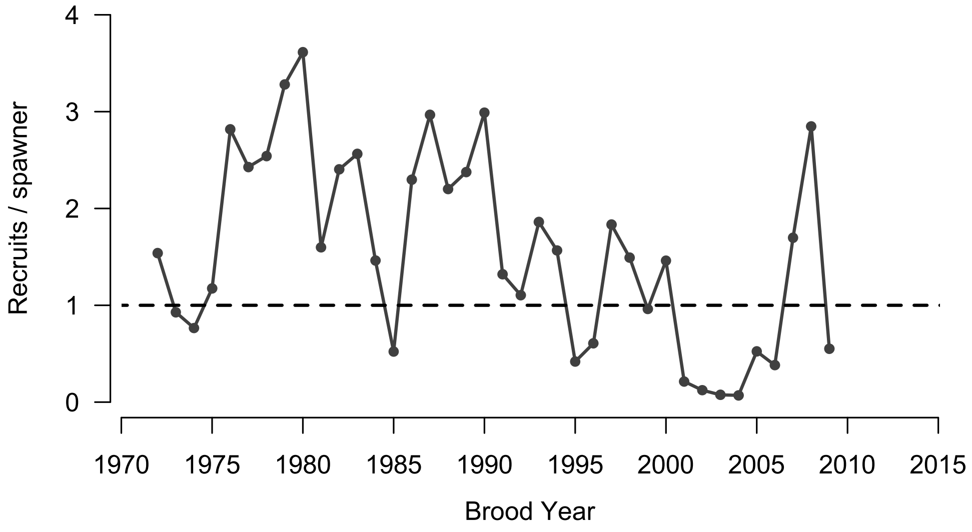

Figure 7: Estimated adult recruits (catch plus escapement) produced per spawner for each Atnarko Sockeye brood year with corresponding data. The dashed line indicates replacement. Data provided by DFO.

Fitting a model of the stock-recruitment relationship to observed spawner and resulting recruitment pairs, allows one to estimate the average recruitment that is expected from a given number of spawners. Such relationships typically assume that the number of recruits produced per spawner declines as the spawning population increases as a result of, for example, competition for spawning or rearing habitat. Stock-recruitment relationships are fundamental to fisheries ecology and management (Walters and Martell 2004). The shape of the stock-recruitment relationship can be used to estimate the carrying capacity of the stock (i.e., the largest population that could be sustained by the environment over the long term), the average survival of individuals when the population is small and within-population competition is expected to be lowest (i.e., productivity), and the spawner abundance that is predicted to maximize surplus production that could be harvested (i.e., maximum sustainable yield).

To generate a brood table for Atnarko sockeye, we assumed that ages at return followed those in Figure 3 and in years without data we assumed age at return was the average of those years with empirical estimates. The resulting Atnarko Sockeye stock-recruitment relationship is characterized by a “shot gun” scatter of spawner-recruitment data points that is typical of salmon (Figure 8). Assuming a Ricker stock-recruitment relationship (Ricker 1975; see Section 2.5 for approach used to estimate parameters), which is common for Pacific salmon, the estimated carrying capacity of the Atnarko system for Sockeye is 38,089 individuals (range 25,557 - 44,382). The stock-recruitment relationship is clearly very uncertain, as evidenced by the wide credible intervals (grey region around solid black line in Figure 8).

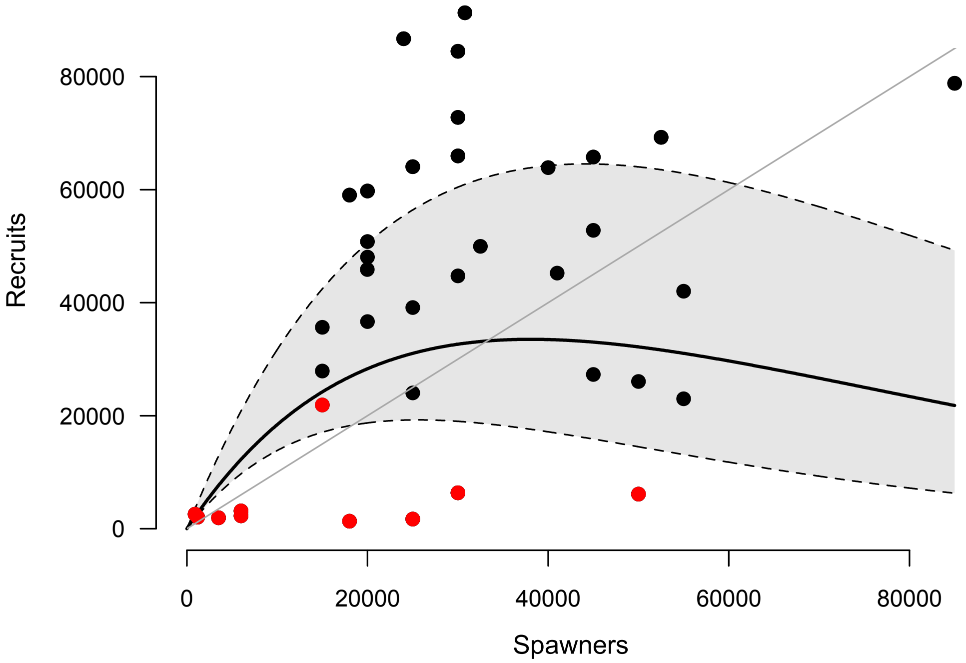

Figure 8: Atnarko Sockeye stock-recruitment relationship. The solid black line is the median predicted relationship between spawners and the number of recruits they produce while the dashed lines represent 95% credible intervals. Red points are spawner-recruitment pairs since the 2000 brood year. The solid grey line is the 1:1 replacement line. Data provided by DFO.

The relationship in Figure 8 is based on an assumption of stationarity over the entire period of record, meaning that there is no persistent upward or downward trend in productivity, no persistent change from one mean level to another, and no change in magnitude of variation over time. However, there is evidence that productivity has been much lower in recent years than in the past (see color coded points in Figure 8), and a plot of the residuals of the fit of the stock-recruitment relationship over time suggests that productivity has changed in a persistent manner, declining precipitously beginning around the mid-1990s (Figure 9). An alternative way to estimate change in productivity over time is to use a Kalman filter (Peterman 2003) to remove high-frequency year-to-year variation in productivity (i.e., to smooth the time series), thereby making any long-term trends that may exist in the time series easier to see. Kalman filter estimates of productivity further highlight a downward trend in productivity (Figure 9). As a result of what appears to be persistent and directional change in productivity, the management and conservation advice derived from the historical stock-recruitment relationship should be interpreted with considerable caution.

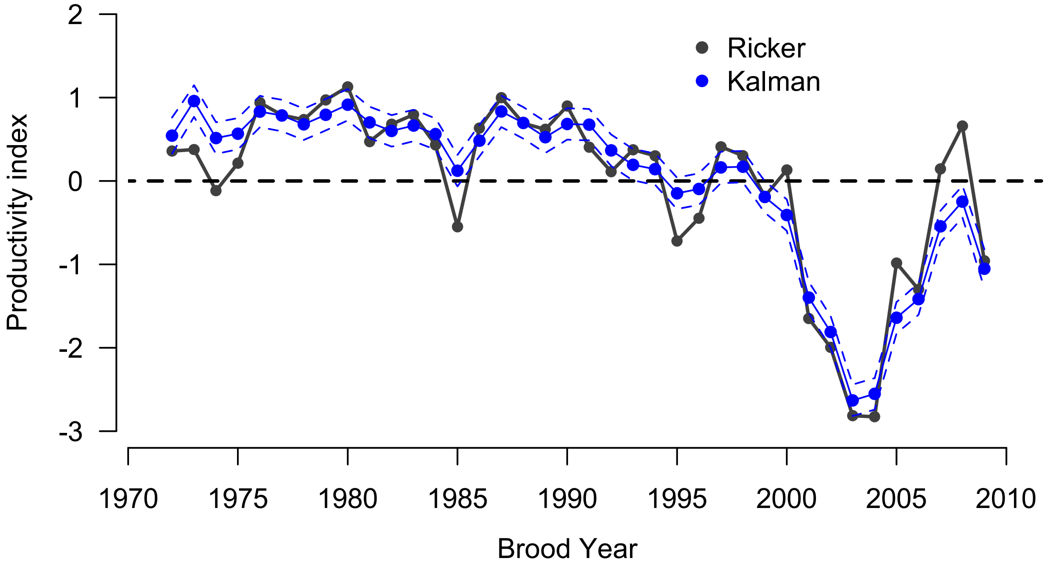

Figure 9: Atnarko Sockeye productivity indices. The points labeled 'Ricker' were derived by taking the difference between the points shown in the stock-recruitment curve (Figure 8) and subtracting the predicted value (solid line) for the corresponding x-value (note that this occurs on the $\log_e$ scale). The points labeled 'Kalman' are standardized estimates of time varying productivity. The mathematical details of the Kalman filter estimation method are described in the appendices of Peterman *et al*. 2003 and Dorner *et al*. 2008. Data provided by DFO.

2.5 Status assessment

A recovery plan is predicated upon the notion that a population or species is at risk and revolves around two questions: (1) what is the current status of population? and (2) what is the recovery goal?. Quantifying the current status of a population is the focus of this section.

A typical salmon recovery goal is a naturally self-sustaining population(s) with sufficient spawners to have a high probability of long-term persistence (e.g., 100 yrs) and resilient enough to withstand variability in survival due to natural changes in the environment (e.g., floods and variation in marine productivity). Population viability analysis and consideration of genetic effects at small population sizes are typical inputs into establishing a formal recovery goal. Such analyses are beyond the scope of this report and so we assume a general recovery goal in Section 4.2.

Canada's Wild Salmon Policy provides a framework through which the conservation and biological status of Atnarko Sockeye can be assessed. The first strategy of Canada's Wild Salmon Policy (DFO 2005) states that salmon CUs should be assessed against specific biological benchmarks, for indicators such as spawning abundance or fishing harvest rate, in order to assess their conservation status. For each CU, a higher and a lower benchmark are to be defined so as to delimit 'green', 'amber', and 'red' status zones. As numbers of spawning salmon decrease, a CU moves towards the lower status zones and the extent of management actions directed at conservation should increase (Figure 10). The status of an indicator does not dictate that any specific action must be taken, but instead serves to guide management decisions in conjunction with other information on habitat, ecology, and socioeconomic factors.

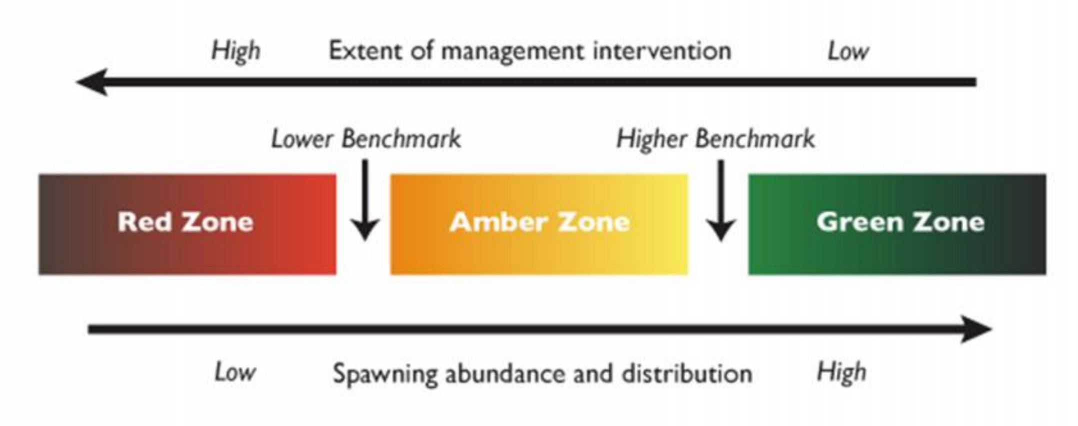

Figure 10: Benchmarks and biological status zones to be determined for each Conservation Unit under the Wild Salmon Policy. From DFO (2005).

To quantify the conservation status of Atnarko Sockeye, we compared six metrics from three classes of indicators (Table 2) against benchmarks that have been proposed to delineate levels of conservation and management concern in Pacific salmon (e.g., Holt *et al*. 2009). Many of these benchmarks have been identified based on simulations that have quantified extinction and recovery probabilities (Holt and Bradford 2010; Holt and Folkes 2015).

Table 2: Classes of indicators and corresponding metrics for assessing Atnarko Sockeye conservation status.

Indicator	Metric	Reference(s)
current abundance	historic abundance (percentile)	DFO (2013); Clark *et al.* 2014
	stock-recruitment relationship	Holt and Bradford (2011)
	habitat capacity	Cox-Rogers (2012)
trends in abundance	rate of change over recent generations	Holt *et al.* (2009); COSEWIC (2014)
fishing mortality	stock-recruitment relationship	Holt (2010)

The individual metrics used to assess status have both strengths and weaknesses. For example, historic abundance benchmarks require the least amount of data and underlying assumptions but are sensitive to past conditions, such as exploitation rates or carrying capacity (Clark *et al.* 2014; Holt and Folkes 2015). Stock-recruitment benchmarks are the most biologically-based but are sensitive to assumptions about temporal variation in age structure and productivity (Holt and Bradford 2011). Habitat capacity based benchmarks do not require estimates of spawner abundance but assume that freshwater nursery habitat limits population size (Cox-Rogers 2012). Trend-based benchmarks are commonly used to assess the status of organisms across the animal kingdom but can be sensitive to variability in the data (Connors *et al*. 2014, d'Eon-Eggertson *et al*. 2014). Given these trade-offs, we assessed status against as many benchmarks as possible, thereby capturing coherence (or lack thereof) in the picture that emerges for the status of Atnarko Sockeye.

For historic spawner abundance based benchmarks we used the 60th and 20th percentile of historic abundance (from 1972 to present) as upper and lower benchmarks (Table 3). These percentiles were chosen because they have been shown to be reasonable proxies for stock-recruitment based benchmarks (see next paragraph) when there is insufficient information to derive them (Clark *et al.* 2014).

To identify upper and lower stock-recruitment based benchmarks we fit a Ricker stock-recruitment relationship to the spawner and recruitment data in a Bayesian estimation framework[1]. From this relationship we then calculated the spawner abundance predicted to correspond to the maximum sustainable yield (S_{MSY}) as the upper benchmark and the spawner abundance predicted to result in recovery to S_{MSY} in one generation in the absence of fishing under equilibrium conditions as the lower benchmark (S_{gen1}; Holt *et al.* 2009) (Table 3).

For benchmarks based on habitat capacity we use 55% and 15% of S_{MAX} as the upper and lower benchmarks, where S_{MAX} is the spawner abundance that is expected to produce the maximum number of juveniles that the rearing habitat can support, based on models of rearing habitat capacity (Cox-Rogers 2012) (Table 3). We based our overall estimate for the system as a whole on data from Shortread and Hume (2008), who estimated S_{MAX} for Elbow, Lonesome, and Rainbow Lakes at 2,200, 14,500, and 4,600 spawners, respectively. If the other two nursery lakes (Stillwater and Tenas) are considered, and their rearing capacity is assumed to be equivalent to the average of the other lakes, S_{MAX} for the Atnarko lakes is ~ 25,000 spawners (Cox-Rogers 2011).

We used a 15% and 25% decline over 3 generations (15 years) as upper and lower benchmarks for the trends in abundance indicator (Holt et al. 2009) (Table 3). To estimate

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[1] For this analysis we used a uniform prior on the Ricker *a* parameter (uniform [0.5,10]) and an informative prior on the Ricker *b* parameter based on the habitat-based estimates of capacity in the system (lognormal [$1/S_{MAX}$,1/0.3]). A total of 100,000 MCMC iterations on three chains were run to estimate the posterior probability distribution for each parameter. The final posterior probability distributions were based on retaining every 5th value after discarding the first 5,000 simulations.

the rate of change, we smoothed spawner abundance using a 5-year running average prior to estimating rates of change on a natural logarithmic scale. Such smoothed data have been shown to be a more statistically reliable metric to detect population decline with salmon than unsmoothed abundance (d'Eon-Eggertson *et al*. 2014). The rate of change was estimated in a Bayesian estimation[2] framework that regressed smoothed spawners on a natural logarithmic scale against time.

Lastly, we estimated the exploitation rate that maximizes long-term fishing yield (U_{OPT}) as a benchmark against which to assess status based on current harvest rates (Holt 2010) (Table 3). A population that is consistently harvested at rates above U_{OPT} is being overfished.

For those benchmarks with estimates of uncertainty (stock-recruitment and rate of change) we estimated the probability that spawner abundance over the last 5 years, or rate of change, is above, in between, and below the upper and lower benchmarks. For the exploitation rate benchmark we estimated the probability that the average exploitation rate over the past 4 years fell above U_{OPT} (red status) or below U_{OPT} (green status).

Table 3: Current values for a range of status metrics and their corresponding upper and lower benchmarks. 95% credible intervals are provided in brackets for those benchmarks with estimates of uncertainty.

Indicator	**Metric**	**Upper benchmark**	**Lower benchmark**
current abundance	historic abundance	30,000	6,000
	stock-recruitment relationship	14,572 (8,209-24,584)	3,798 (2,540-4,399)
	habitat capacity	13,750	3,750
trends in abundance	rate of change over recent generations	15% decline	25% decline
fishing mortality	stock-recruitment relationship	38% (32-56%)	

The Atnarko has averaged 2,160 Sockeye spawners over the past five years. As a result, the current status of Atnarko Sockeye across the spawner abundance and trend in spawner abundance metrics we considered was consistently and unequivocally in the 'red' zone (Figure 11), a region of high conservation concern and extent of necessary management intervention according to the WSP. That status was consistently assessed in the red zone,

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[2] These were run as described for the Bayesian stock-recruitment analysis but with uninformative priors.

despite high uncertainty in the stock-recruitment and trends in spawner abundance benchmarks, highlights the degree of conservation concern in this system. In contrast, the harvest rate over the same time period has averaged 5% (Figure 6) well below the exploitation rate based benchmark indicating that Atnarko Sockeye are not currently at risk of being overfished.

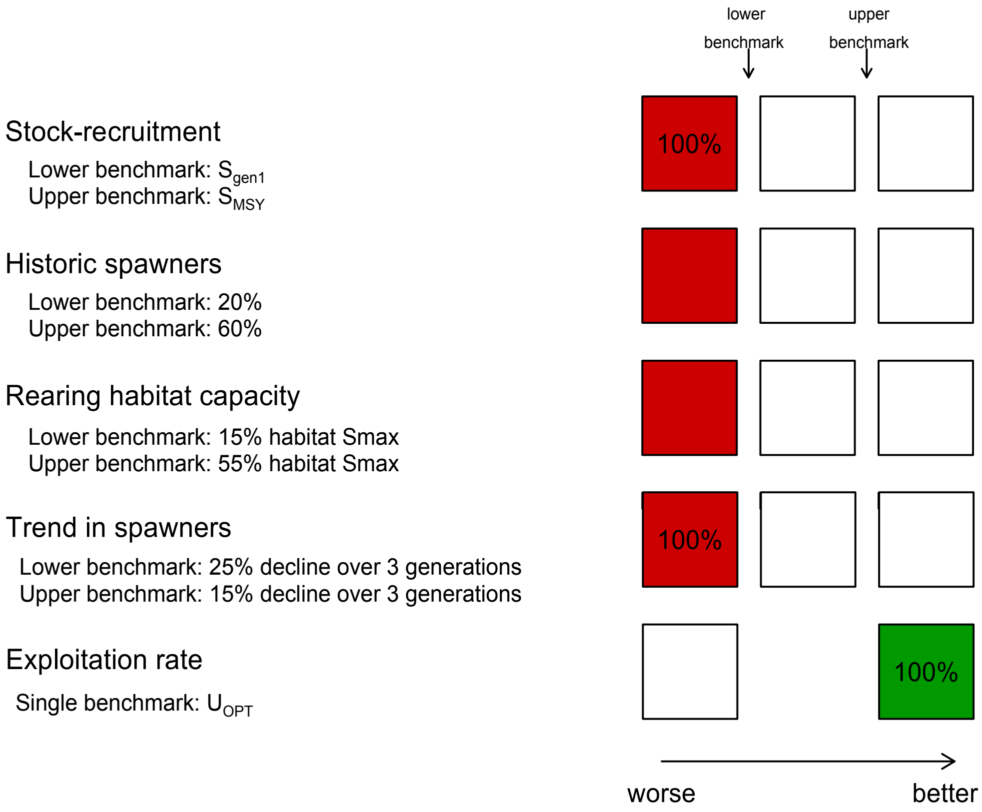


Figure 11: Current status of Atnarko Sockeye for a range status metrics and corresponding benchmarks (left) with results summarized in a colour−coded display (right). Numbers within the squares show the % chance of being a given status, when estimates of uncertainty for benchmarks are available.

Numerous uncertainties and assumptions underlie the estimates of spawner abundance, age-structure, exploitation, resulting brood tables and associated benchmarks we used to assess status. Significant sources of uncertainty, as well as the way in which the uncertainties may lead to biases, include:

<u>Errors in estimates spawner abundance</u>: There have been numerous changes in the way Atnarko Sockeye spawner abundance has been estimated over time (e.g., by foot, boat, helicopter, fixed wing aircraft) and each of these methodologies will have some degree of uncertainty associated with it. As a result these spawner estimates should be considered no more than an index of abundance, and one that has likely declined in quality in recent years. This can lead to an "errors-in-variables" problem where errors in estimates of

spawner abundance lead to the appearance that recruitment does not depend on spawning stock size (Walters and Martell 2004). This in turn is predicted to lead to overestimates of productivity and magnitude of density dependence (and hence overestimation of U_{OPT} and underestimation of lower abundance benchmarks like S_{gen1}).

Uncertainty in age-composition due to a lack of year-specific age-at-return data. We estimated age-composition from FSC catch in most years which may bias estimates of age-structure towards older fish (if the FSC fishery is size-selective) and dampen true variation in age-structure. In the remaining years (with the exception of a couple with estimates from spawners) a weighted average of all years with data was used. This assumes age-structure is not variable, which is almost certainly not the case. In cases where a stock is not dominated by a single age class (like the Atnarko, at least in years with data) assuming a fixed age-structure can lead to overestimation of U_{OPT} and underestimation of lower abundance benchmarks like S_{gen1} (Zabel and Levin 2002).

Uncertainty in Atnarko Sockeye harvest rates. Our baseline brood table reconstruction (Section 2.4) assumes that all harvest in Burke Channel, Labouchere Channel, South Bentinck Arm, and North Bentinck Arm is comprised of Atnarko-bound Sockeye. We further assume that the proportion of Atnarko sockeye in Heiltsuk FSC fisheries (Fraser-Fitzhugh region) in a single year (2003) is representative of all years and apply this proportion to all reported FSC and commercial catch in the area to estimated Atnarko Sockeye catch in each year. These are likely both gross simplifications as some harvest in Burke Channel, Labouchere Channel, South Bentinck Arm, and North Bentinck Arm has likely been made up of Kimsquit River sockeye and FSC harvest of Atnarko Sockeye in the Fraser-Fitzhugh region likely varies from year to year as a result of variation in run size and timing among regional Sockeye stocks. If these assumptions overestimate Atnarko harvest then they would also overestimate productivity (and hence overestimation of U_{OPT} and underestimation of lower abundance benchmarks). If they tend to underestimate harvest then these assumptions would have the opposite effect.

Non-stationarity and unrepresentative data. Our estimates of productivity and density-dependence based on the stock-recruitment relationship assume that productivity is stationary over the entire period of record, meaning that there is no persistent upward or downward trend in productivity, no persistent change from one mean level to another, and no change in magnitude of variation over time. When the assumption of stationarity is not valid, e.g., because of a persistent time trend in productivity, estimates of productivity and density dependence may be overestimated with the same consequences as above. A plot of residuals from the recruitment relationship over time indicate a declining slope, suggesting that there has been a persistent decline in productivity, and fitting a Kalman filter stock recruitment model provides, not surprisingly, strong evidence for a decline in productivity over time (Figure 9).

One possible solution to the issues of error and bias in estimates of spawner abundance, age-structure, harvest and non-stationarity is to fit a state-space stock-recruitment model with time-varying productivity to the data (e.g., Fleishchman *et al*. 2012). Such an approach can incorporate uncertainty in age-structure and catch and attempt to account for and separate observation error from underlying true variation in recruitment over time. While such a modelling approach can be powerful, particularly when combined with extensive sensitivity analyses, it is also beyond the scope of this recovery plan.

To explore the sensitivity of our stock-recruit parameters and potential bias in estimates of spawner abundance, age-structure and harvest, we conducted a simple simulation exercise that bookended the range of uncertainty that is likely present in the data. Specifically, we considered 4 scenarios consisting of the possible combinations of alternative assumptions about estimates of spawner abundance and harvest estimates while simulating variation in age-structure for years in which it was missing (Table 4). For each of the four scenarios we ran 1,000 Monte Carlo trials where in each trial we (1) estimated age-structure in brood years with missing data by taking a random draw from a multivariate logistic distribution (Holt and Folkes 2015) with variation equal to that from the years with data, (2) generated a brood table based on the simulated escapement, catch and age-structure, (3) estimated the stock-recruitment and percentile benchmarks, and (4) estimated status against the benchmarks. We then summarized status across the Monte Carlo trials by estimating the proportion of trials where status was in the red, amber and green zones for the stock-recruitment and percentile benchmarks.

Table 4: Alternative scenarios used to evaluate sensitivity of Atnarko Sockeye status to assumptions about parameter values.

Variable	**Alternatives considered**
Spawner abundance	Baseline (i.e., as reported) or 2-fold expansion of estimated spawner abundance in each year
Harvest	Either double or half the estimated proportion of FSC and commercial catch in Fitzhugh Sound that consisted of Atnarko Sockeye in 2003 (i.e., 6 and 13% in lower and upper Fraser-Fitzhugh sound, respectively) applied to all year with catch estimates

The predicted biological status of Atnarko Sockeye was consistently in the ‘red zone’ across all four combinations of alternative assumptions about Atnarko Sockeye spawner abundance and harvest estimates, and when age-structure in missing years was simulated based on historic proportion and variation in age-structure (Table 5). This corroborates, with a high degree of confidence, that Atnarko sockeye are of high conservation concern.

Table 5: Biological status of Atnarko Sockeye across four combinations of alternative approaches to estimating escapement and harvest ('Scenario' column; see Table 4 for details). Status is calculated as the proportion of 1000 Monte Carlo trials in which status was assigned to a given zone (red, yellow, green; see Table 2) when age-structure in years with missing data is simulated based on multivariate logistic variation.

Scenario		**Status (stock-recruitment)**			**Status (historic abundance percentiles)**		
Spawner abundance	Catch	'red'	'yellow'	'green'	'red'	'yellow'	'green'
1x	*0.5x*	0.99	0.01	0	1	0	0
2x	*0.5x*	1	0	0	1	0	0
1x	*2x*	1	0	0	1	0	0
2x	*2x*	0.99	0.01	0	1	0	0

2.6 Enhancement

The enhancement of Atnarko Sockeye was first considered in the 1990s when pilot projects investigated the feasibility of creating and managing a large harvestable surplus of Sockeye salmon by outplanting Sockeye fry from Atnarko River broodstock into Charlotte Lake (Wood 2000a). However, the feasibility work was discontinued because (1) it would very difficult to segregate adult returns reared in Charlotte Lake from the original Atnarko population and (2) interbreeding could threaten genetic adaptations in the original Atnarko population because of divergent natural selection in Charlotte Lake (Chris Wood, personal communication).

In response to continued depressed returns in the mid 2000s, the Nuxalk Fisheries Department, in partnership with DFO (Snootli Hatchery), led efforts to explore opportunities for conservation enhancement. Since 2005, brood stock have been collected from spawning fish below Stillwater Lake, and since 2007 between Stillwater and Lonesome lakes, and eggs and fry have been incubated and reared in Snootli hatchery. Approximately 50 thousand fry have been released annually from both Lonesome Lake and Atnarko River brood stock since 2007 (Table 6). It is currently unknown what return rates of these marked fish have been since 2010 when the first four-year-old hatchery reared fry would have been expected to return.

Table 6: Summary of Atnarko Sockeye conservation enhancement program 2005-2014.

Broodstock location	**Year**	**Number of female broodstock**	**Total live eggs** (eyed count)	**Percent survival** (eyed to release)	**Total released fry**	**Mark** (AD=adipose, LV=left Ventral, RV=Right Ventral)
Atnarko River	2005	13	40,434	73%	29,634	0
Atnarko River	2006	14	38,756	84%	32,405	AD = 27360
Atnarko River	2007[1]	30	102,468	87%	88,636	AD = ~ 35000
Lonesome Lake	2007[1]	22	60,955	49%	29,917	RV
Atnarko River	2008	18	53,792	105%	56,452	AD = 55225
Lonesome Lake	2008	21	41,633	58%	24,253	LV = 181 RV = 21285
Atnarko River	2009	21	83,966	62%	51,819	AD = 51413
Lonesome Lake	2009	13	28,903	66%	19,040	0
Atnarko River	2010	23	65,612	72%	47,215	AD = 42655
Atnarko River	2011	6	16,301	88%	14,377	0
Lonesome Lake	2011	30	82,052	78%	63,723	0
Atnarko River	2012	27	83,014	75%	61,983	0
Atnarko River	2013	27	72,136	94%	67,521	0
Lonesome Lake	2013	20	38,276	91%	34,839	0
Atnarko River	2014	20	41,855	89%	37,157	AD = 36975
Lonesome Lake	2014	9	13,964	91%	12,702	AD = 12639

[1] Data from 2007 are subject to revision by DFO at a future date once the system they are stored in has undergone repairs.

Information on the recovery of marked fish as adults, along with scale and otolith samples has been collected by the Nuxalk Fisheries Department and DFO. With information on the recovery of marked fish as adults it would be possible to estimate and compare fry-to-adult survival by broodstock source, release timing and year. With scale and otolith samples from recovered marked adults it would be possible to relate fry-to-adult survival to interannual variation in growth increments in freshwater and the marine environment as well as the life history exhibited by the fish recovered. These data could be used to help inform and optimize conservation enhancement practices and improve our understanding of the ecology of Atnarko sockeye and factors that may be contributing to low survival and abundance.

3 Habitat Status

3.1 Habitat setting and critical Sockeye habitat requirements

The Atnarko watershed is a 6th order drainage with a catchment area of approximately 1,800 km^2 (BCWS 2007). The climate in the watershed is cold in the winter and warm in the summer. Precipitation is at a maximum during late spring and early summer and so discharge in the Atnarko River is dominated by a combination of snowmelt and rainfall during this time (Figure 12). Discharge through the winter is low when most precipitation falls as snow.

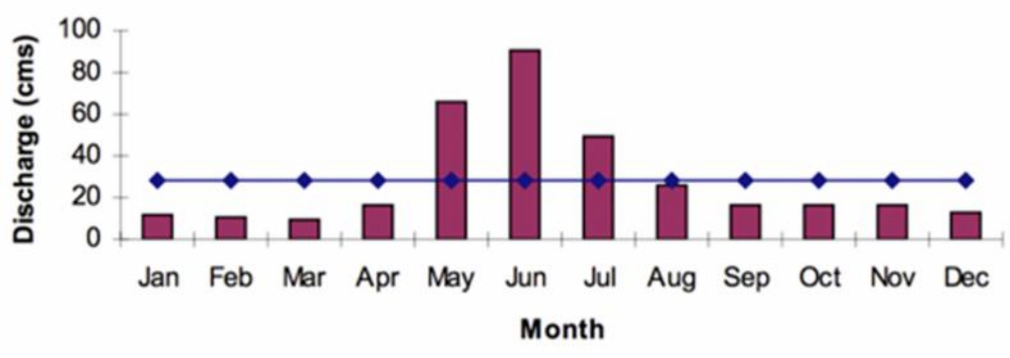


Figure 12: Mean monthly discharge (bars; 1965-2007) and mean annual discharge (blue line) at the mouth of the Atnarko River (Water Survey of Canada station 08FB006; From BCWS 2007)

The headwaters of the Atnarko originate from the Chilcotin Plateau, specifically Charlotte and Hotnarko lakes and Young Creek. From these headwaters the Atnarko flows down through a series of lakes before joining the Talchako River to form the Bella Coola River. Upper Atnarko watershed stream channels tend to be lower gradient in high elevation plateau areas with steep sections dropping to valley floors (BCWCS 2008). Lower watershed areas have varied gradients and stream morphology but are relatively stable due to the lake fed nature of the system.

As an anadromous species that migrates from freshwater to marine habitat and back again to complete its life cycle, Atnarko Sockeye use and require a diversity of habitats. The minimum extent and configuration of habitat necessary to provide a high probability that this population will persist indefinitely can be defined as “critical” habitat (Cleveland *et al.* 2006).

Critical freshwater habitat requirements for incubating eggs include suitable substrate (1-10 cm with < 10% fine sediment by weight; Quinn 2005), flows (low enough to minimize scour; Quinn 2005) and water quality (e.g., temperature and dissolved oxygen) in and between the five Atnarko nursery lakes as well as the Atnarko River downstream of Stillwater Lake. Following incubation, emergent lake-type fry require nursery lakes with suitable water quality (e.g., temperature) and quantity (flow low enough to minimize displacement) as well as food to sustain rearing juveniles. River and ocean type fry also require suitable water quality and quantity and adequate food as well as cover and riparian vegetation to grow and rear. Once Sockeye begin their migration to sea they require safe and unimpeded passage conditions with appropriate water temperatures, flows and cover as well as unrestricted ocean corridors and feeding grounds of appropriate temperature and productivity. Upon their return migration Atnarko Sockeye require safe and unimpeded passage conditions with appropriate water temperatures, flows and cover through the lower Bella Coola River up to holding areas in nursery lakes and spawning grounds within the Atnarko watershed. Critical spawning habitat requires appropriate water temperatures (typically below 18^{o}C; Rand *et al*. 2006), flows and substrate (as above for incubation) in the areas in and between the five Atnarko nursery lakes as well as the Atnarko River downstream of Stillwater Lake.

3.2 Sockeye habitat status and trends

Land-use practices

Land use within the Atnarko sub-basin is diverse, including ranchland, recreational properties, commercial logging in headwater areas, and conservation and protected areas (BCWCS 2008). Atnarko Sockeye freshwater habitat occurs primarily within Tweedsmuir Provincial Park (Figure 13), which has limited land use, and so the watershed is relatively free from many of the sources of human-caused habitat degradation (e.g., sedimentation from linear development and nutrient input from agriculture) that have contributed to Sockeye declines elsewhere. Human activity within the watershed is restricted to a modest amount of logging activity in the eastern margins of the watershed (Figure 13).

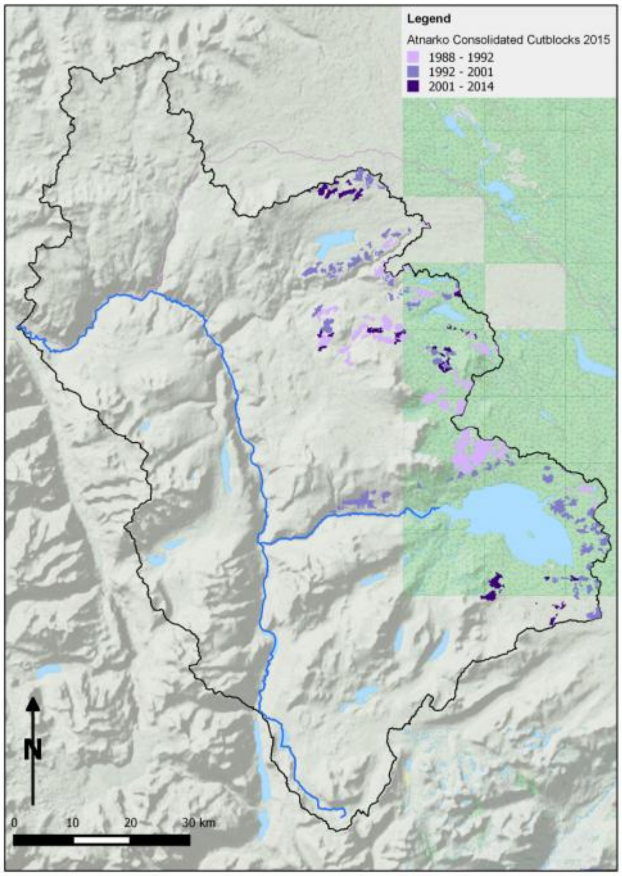


Figure 13: Logging history in the Atnarko watershed as indexed by consolidated cutblocks 1988-2015. Data from BC vegetation resources inventory database.

Natural disturbance

While human activity within the watershed has been relatively minimal, natural events in recent years may have contributed to the currently depressed abundance of Atnarko Sockeye. Significant wild fires in the mid and late 2000s (Figure 14b), and mountain pine beetle kill (Figure 14a) has impacted hillside and riparian vegetation and likely led to increased erosion and sediment input into nursery lakes and streams. Extreme flooding in 2010 and 2011 may have exacerbated these sedimentation issues which may have had negative consequences for spawning habitat and water quality. For example, in September of 2010, Bella Coola received 262 mm of rainfall over four days, one of the largest precipitation events in its history. While preliminary evaluation after the flooding in 2010 suggested spawning and rearing habitat conditions within the watershed may have deteriorated dramatically, detailed habitat assessments have not occurred.

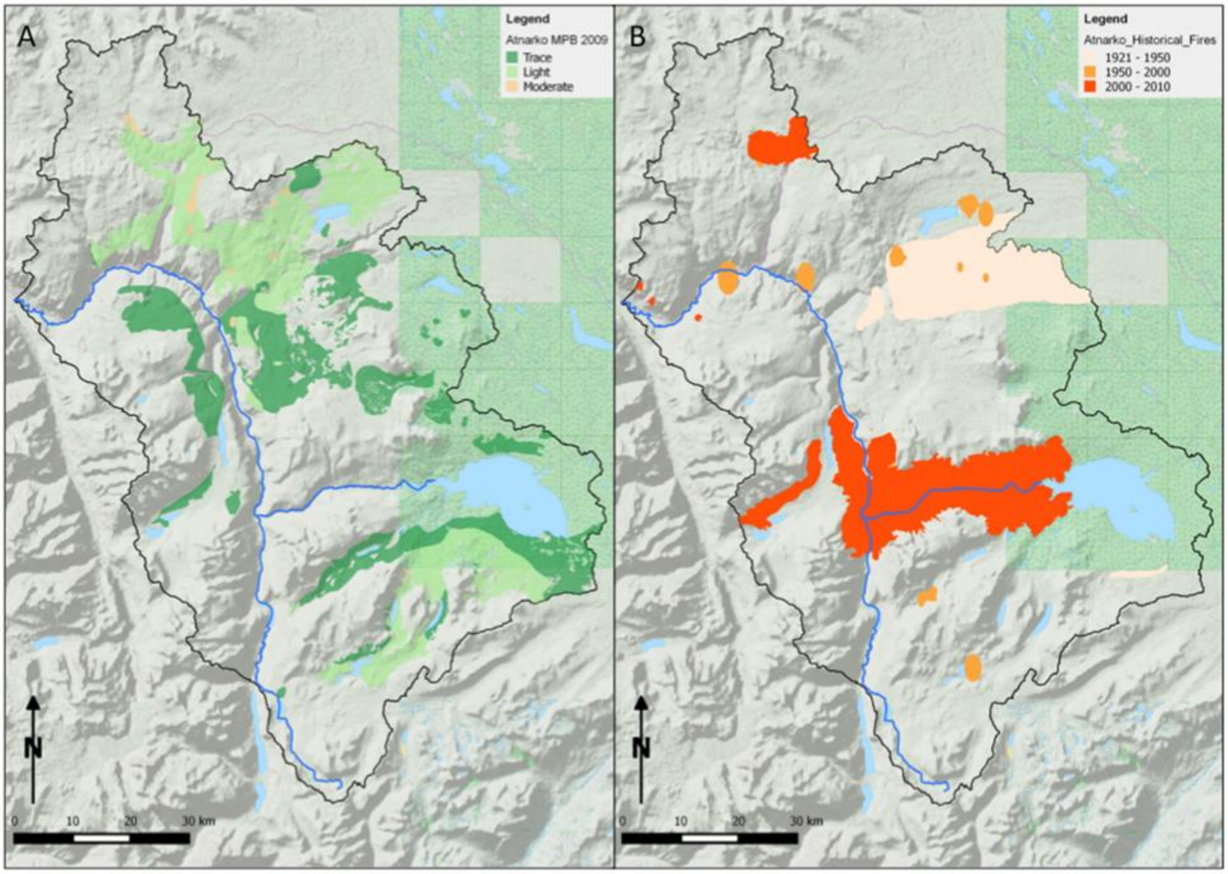


Figure 14: Mountain pine beetle (A) and forest fire disturbance (B) in the Atnarko watershed. Data from BC vegetation resources inventory database.

Lake and river conditions

Elbow, Lonesome and Rainbow Lakes have been subject to limnological surveys to characterize Sockeye habitat conditions. Lonesome lake is the largest of the three lakes at 4.1 km^2 followed by Rainbow (1.7 km^2) and then Elbow (1.4 km^2). All three lakes have extensive shallow water habitat, and are moderately oligotrophic, with Lonesome and Rainbow Lake having higher macrozooplankton and *Daphnia* biomass (a prime food source for Sockeye) than Elbow lake, which has a higher relative abundance of copepods resistant to sockeye predation (Shortreed *et al*. 2001; MacLellan and Hume. 2011). Based on these surveys both Elbow and Lonesome lakes are considered to have favourable physical habitat conditions for juvenile Sockeye. With extensive shallow water habitat it is currently unknown if Rainbow Lake can provide juvenile Sockeye with the physical environment needed year round (Shortreed *et al.* 2001). These lake habitat characterizations are based on only a few lake surveys prior to the significant fire and flooding events of the late-2000s and so current habitat conditions in the lakes are largely unknown.

Data on discharge in the Atnarko River is available from a Water Survey of Canada station at the mouth of the Atnarko River (08FB006) from 1965-2012. These data highlight general, though variable, declines in average flows in the spring, summer and fall from the late 1960s and early 1970s to the mid-2000s before increasing to some extent from the mid-2000s to early 2010s (Figure 15). In contrast, average winter flows have remained relatively stable since the early 1970s (Figure 15).

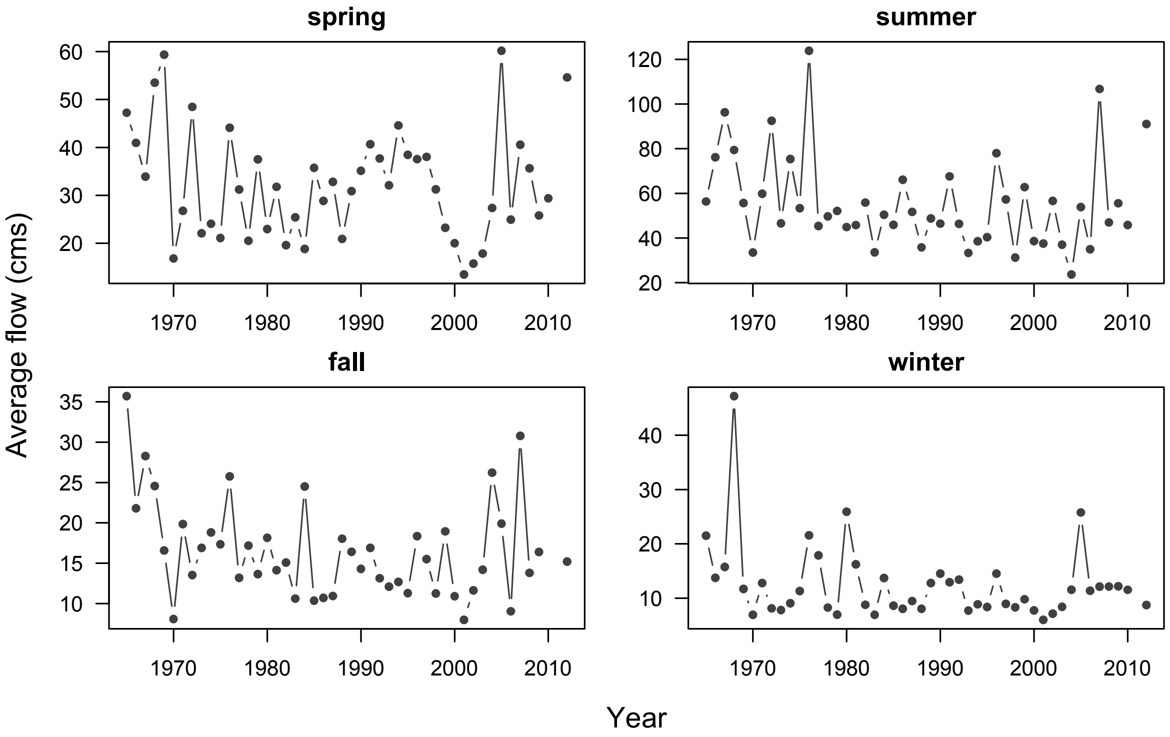


Figure 15: Average annual spring (March-May), summer (June-July), fall (September-November) and winter (December-February) discharge at the mouth of the Atnarko River from 1965 to 2012. Note there are no discharge readings for the fall of 2010 or any of 2011. Data from Water Survey of Canada.

Data on temperature in the Atnarko River are available for a 6-year period from 1998 to 2004 (Sandie MacLaurin pers. comm.). These data were collected with temperature loggers set to record temperature every 1.5 hours and were located in the Upper Atnarko above the canyon and Young Creek. Over this admittedly limited time period, interannual variation in temperature was low and temperatures followed a predictable pattern where they were typically lowest in January and February and highest in July and August (Figure 16). On average, these temperatures are below those known to affect adult Sockeye physiology and survival (18-19 ^{o} C; Martin *et al.* 2011, 2012), however, temperatures exceeding 18^{o} C were often recorded on a couple of days in July or August of each year.

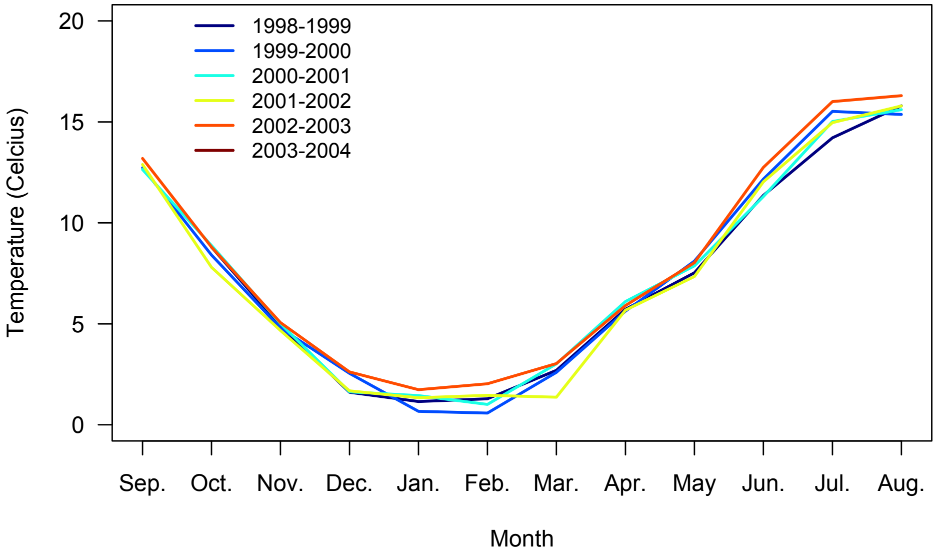


Figure 16: Average monthly water temperature in the Atnarko River from 1998 to 2004. Data from Sandie MacLaurin.

Several species of fish and birds are known to consume sockeye in freshwater, including: Coho and Chinook salmon; Rainbow, Steelhead, Cutthroat and Bull trout; Common mergansers and Double-crested cormorants (reviewed in Christensen and Trites, 2011). Coho and Steelhead abundance has declined across the Bella Coola watershed in recent decades while Chinook abundance has remained relatively stable. Trends in the abundance of other potential predators of Atnarko sockeye are not well known. As a result we have little information upon which to assess the influence of predation on Atnarko Sockeye at the juvenile life stages. However, in other regions there is no evidence that any of these predators consume sufficient numbers of juvenile Sockeye to pose a significant threat to Sockeye salmon (Christensen and Trites 2011).

Marine conditions

In general the distribution and movement of immature Sockeye salmon at sea is the least well understood of all life history phases (McKinnell *et al.* 2011). For Atnarko Sockeye in particular, habitat conditions and use in the Bella Coola River estuary, Burke Channel and the broader Central Coast region are poorly understood. Despite these gaps fish ecologists generally believe that abiotic and biotic conditions during early marine life can be important determinants of overall marine survival. Evidence suggests that salmon mortality during early marine life is related to fish size suggesting that bottom up processes affecting prey resources may be critical to early marine growth and survival (Farley *et al.* 2007; Duffy and Beachamp 2011). The phenology and overall production of the spring bloom may be important components of bottom-up forcing pathways and sockeye productivity tends to be lower in years with early spring blooms (Malick *et al.* 2015). Data on the timing of the spring bloom in the Central Coast from 1998-2010 indicate that the bloom has occurred as early as the beginning of February in some years (e.g., 2005) and as late as early May in others (e.g., 2007). There is no evidence of persistent changes in the timing of the spring bloom over this time period (M. Malick pers. com.).

One index of oceanographic conditions during early marine life that extends over a longer time period is sea surface temperature (SST). SST is a proxy for physical and biological conditions and has been shown to be inversely related to Sockeye productivity in the southern part of their range including the Central Coast (Mueter *et al*. 2002a, 2002b, 2005; Pyper *et al*. 2005). SST is a stronger predictor of Sockeye salmon productivity than large-scale climate anomalies associated with the Pacific Decadal Oscillation (PDO; Mueter *et al*. 2002a). SST has increased slightly over time on the Central Coast and Atnarko Sockeye productivity is inversely related to it (Figure 17) suggesting that changes in physical and biological conditions experienced by Atnarko Sockeye during early marine life may have contributed to their currently depressed abundance.

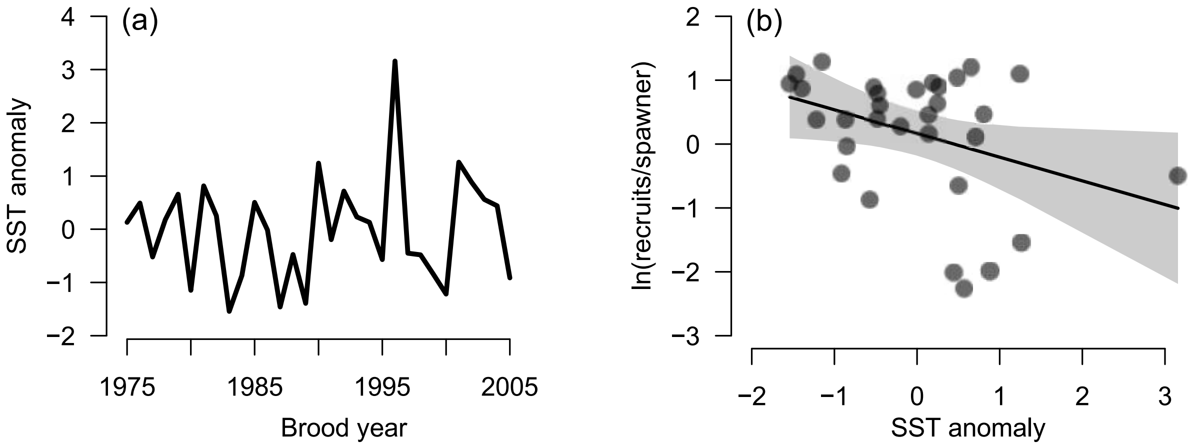


Figure 17: (a) Average coastal sea surface temperature (SST) anomaly (from 1950 to 2010 average) in January through May for Atnarko Sockeye. (b) Relationship between Atnarko Sockeye productivity and SST ($y = 0.16 - 0.37x$, *p-value* = 0.04, R^2 =0.13). SST data from Ruggerone and Connors (2015).

In the ocean and on their return migration Sockeye are prey for a number of species. Primary predators in the open ocean may include salmon sharks and daggertooth fish (Christensen and Trites 2011) while marine mammals including orcas, sea lions and harbour seals are known predators during Sockeye return migrations in coastal environments. Available data indicate that Sockeye salmon are not a preferred prey of these marine mammals (Christensen and Trites 2011). Nonetheless within Burke Channel, North Bentinck Arm and the lower Bella Coola River, harbour seals have increased in abundance since the late 1970s when a bounty on seals (~$2 dollars per nose) ceased. These increases likely mirror those that have been observed coastwide where harbour sea abundance has increased from a low of ~10,000 seals in the early 1970s to over 100,000 seals in the late 2000s (Olesiuk 2008).

In addition to predators, competition for food with other salmon at sea, in particular with abundant Pink salmon, is believed to influence the diet, growth, distribution, age at maturation, and survival of Pacific salmon including Sockeye (Ruggerone and Nielsen 2004; McKinnell and Reichardt 2012; Ruggerone and Connors 2015). Sockeye may be especially vulnerable to competition with Pink salmon because they share common prey at sea (Davis *et al*. 2005) and pink salmon abundance has increased dramatically over the past 50 years. As with other Sockeye in the southern part of their range, Atnarko Sockeye productivity is inversely related to Pink salmon abundance (Figure 18) suggesting that increased competition for food at sea with Pink salmon, particularly in odd years when Pinks are exceptionally abundant, may have contributed to their currently depressed abundance.

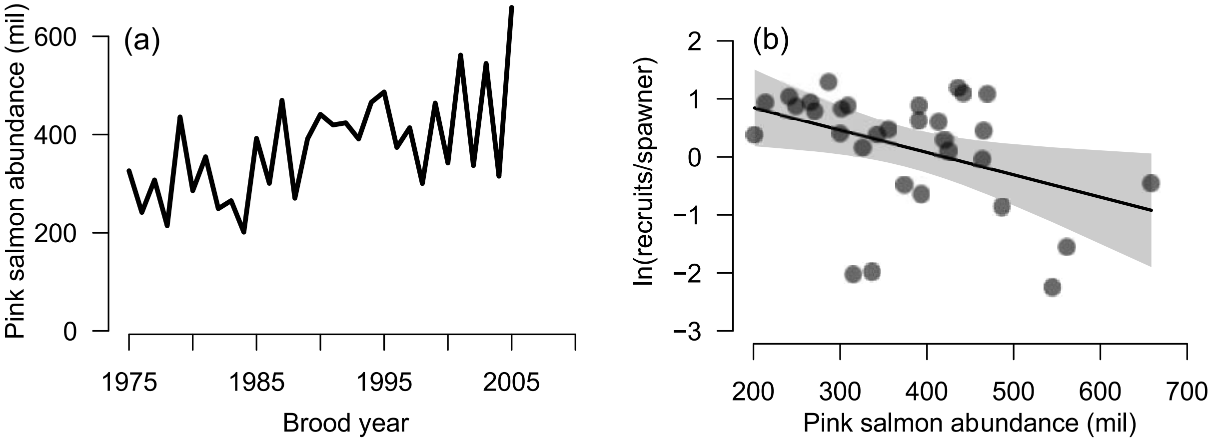


Figure 18: (a) The sum of adult Russian, Alaskan, and Canadian Pink salmon abundances in the North Pacific Ocean as an index of potential competitors with Atnarko Sockeye for food at sea. (b) Relationship between Atnarko Sockeye productivity and the abundance of Pink salmon ($y = 1.62 - 0.004x$, *p-value* = 0.02, $R^2 = 0.17$). Pink salmon data from Ruggerone and Connors (2015).

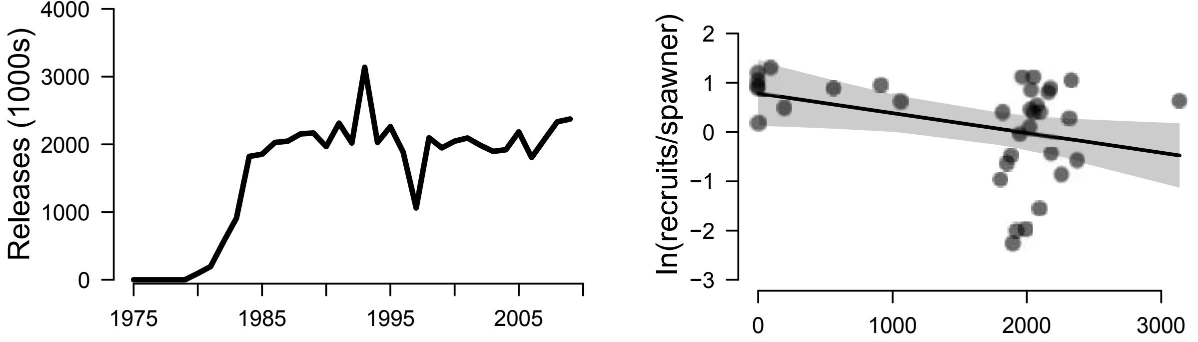
Enhancement

The Bella Coola system has been the focus of significant salmon enhancement efforts for over 30 years. Beginning in the late 1970s and early 1980s the Snootli hatchery began releasing Chum, Coho and Chinook fry and smolts into the Bella Coola River (Figure 19).

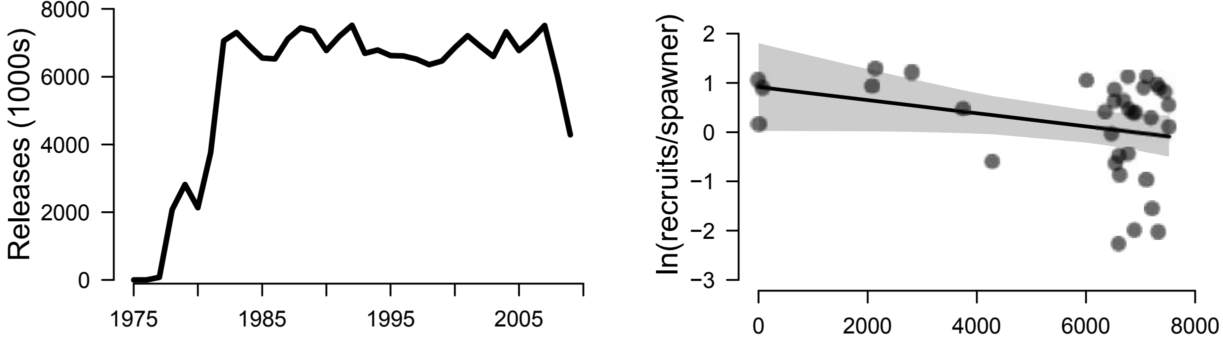
There is relatively little information on interactions between Coho, Chum, Chinook and Sockeye in freshwater and the early marine environment. However it is possible that high abundances of hatchery-reared Chum and Chinook salmon, released at the same time as Atnarko Sockeye are migrating to sea, could lead to reduced prey availability, changes in foraging behaviour, or shifts to lower quality foods if food resources are limiting and hatchery fish directly or indirectly compete with wild Sockeye.

The extent to which competitive or predatory interactions between hatchery reared Chinook, Chum and Coho and Atnarko Sockeye occur will depend on the spatial and temporal overlap between them and the size of enhanced fish at release. Enhanced Chinook are typically released at ~ 5 g in early June in the upper and lower Atnarko River, enhanced Chum are released at ~ 1 g in mid to late March in lower Bella Coola tributaries, and enhanced Coho are released at ~ 20 g in mid May in lower Bella Coola tributaries. The size and timing of sockeye smolt outmigration has not been studied in the Atnarko but in other nearby systems outmigration typically occurs in May at a size of ~ 5 g (e.g., Owikeno Lake; Ajmani 2011).

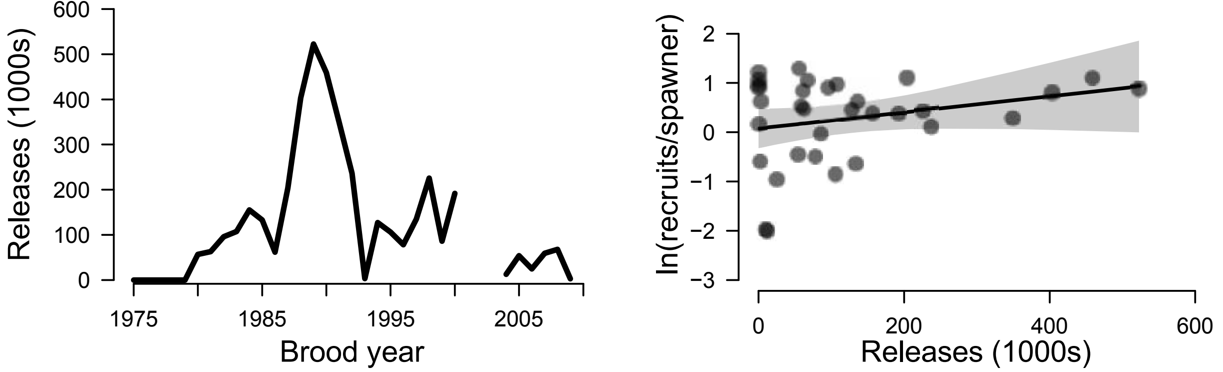
There is weak evidence of an inverse relationship between the number of Chinook and Chum salmon released from Snootli hatchery (but not Coho) and Atnarko Sockeye productivity (Figure 19). However, there is very little contrast in the time series of releases and so the appearance of an inverse relationship could simply arise from the fact that hatchery production increased around the time Atnarko sockeye productivity started to decline.



(a) hatchery Chinook releases



(b) hatchery Chum releases



(c) hatchery Coho releases

Figure 19: Releases of (a) Chinook, (b) Chum and (c) Coho fry and smolts from Snootli hatchery by Atnarko Sockeye brood year (data provided by DFO) and their relationships with Atnarko Sockeye productivity. Productivity is lagged by 2 years to correspond to the year Sockeye migrated to sea (assuming a lake-type life history; Chinook: y = 0.786 - 0.0004x, *p-value* = 0.03, R^2 =0.13; Chum: y = 0.915 - 0.0001x, *p-value* = 0.07, R^2 =0.09; Coho: y = 0.077 - 0.0016x, *p-value* = 0.142, R^2 =0.07). Data from DFO.

4 Recovery Strategy

4.1 Feasibility of recovery

In considering the feasibility of recovery, the current status of Atnarko Sockeye needs to be placed in a broader context of the status of Sockeye populations throughout the southern part of their range. Though the current status of Atnarko Sockeye is of high conservation concern, this depressed productivity and abundance is not unique to Atnarko Sockeye. The productivity of Sockeye populations from southern BC through Southeast Alaska is known to covary positively (Figure 20) and declining trends in productivity across the region appear to have intensified and become more synchronous in recent decades (Peterman and Dorner 2012). These shared declines in productivity suggest that mechanisms operating at a large multi-regional scale at sea (like the climate and competition effects discussed in Section 3.2) are, at least partially, responsible for the depressed state that Atnarko Sockeye currently experience.

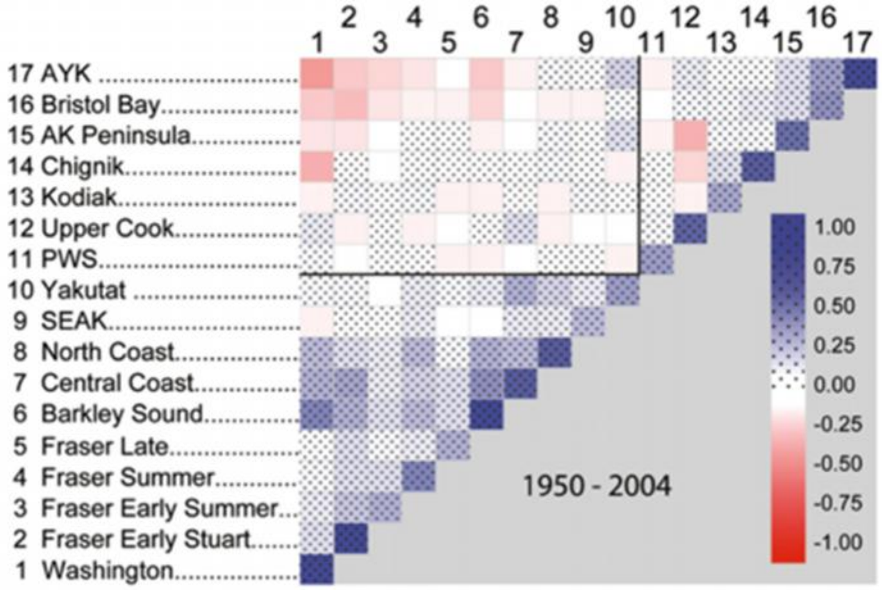


Figure 20: Summaries of correlations in productivity between groups of Sockeye salmon populations, based on annual residuals from the best stock specific stationary stock-recruitment model. To illustrate and emphasize geographical patterns, stocks were grouped by geographical location of their ocean entry points, or, in the case of the Fraser River stocks, by adult run-timing group. For example, the Central Coast cell is comprised of the Atnarko, Long Lake and Owikeno Lake populations. This plot illustrates that populations from geographical locations that are closest to each other exhibit more correlated survival (darker blue) than those are distant from each other (darker red). From Peterman and Dorner (2012).

In light of the evidence that broad-scale marine processes are likely contributing to depressed Atnarko Sockeye abundance, the feasibility of recovery appears to depend, at least in part, on improvements in marine conditions. With this as the backdrop, recovery appears to be both biologically and technically feasible if other potential threats to Atnarko Sockeye viability can be identified and addressed until marine conditions improve. However, broad scale changes in marine productivity coupled with projected northward changes in the distribution of pelagic fish species associated with increases in temperature under climate change (Cheung *et al*. 2015) suggest that marine conditions may become less favorable for Atnarko Sockeye in the future. If this is the case then risk-averse approaches to managing other threats such as harvest (both directed and non-target) may become increasingly important to support the recovery of Atnarko Sockeye. Specific threats potentially affecting the recovery of Atnarko Sockeye are summarized in the section that follows.

4.2 Limiting factors, threats and risk to population

Limiting factors are the biological and physical conditions that limit a species' or population's viability (e.g., high water temperature). Threats are the human activities or natural processes that cause the limiting factors (e.g., reductions in flow due to a dam leading to high water temperatures). While it is common to think about threats in isolation, in reality it is likely that multiple factors are, or can, act in combination. The result of multiple interacting factors may be synergistic where their combined influence on survival is greater than their individual effects (e.g., possible competition and aquaculture effects on Fraser Sockeye; Ruggerone and Connors 2015) or antagonistic where one factor offsets the influence of another (e.g., due to compensatory effects on survival). Disentangling the influence of multiple potentially interacting factors operating at multiple spatial and temporal scales, all with severe knowledge and information gaps as is the case with Atnarko Sockeye, is a difficult, if not impossible task.

In this section we review potentially limiting factors and threats to Atnarko Sockeye survival and productivity by life stage. This is not an exhaustive review of all literature on factors limiting life stage specific survival of Sockeye. Instead, the limiting factors discussed below are based upon the review and identification of plausible limiting factors during the recovery planning workshop in the fall of 2015. In the following sections we follow an approach used in other BC Sockeye recovery plans (Cleveland *et al*. 2006; Lakelse Watershed Society *et a*l. 2005) where, for each life stage, we identify plausible threats and then qualitatively assign a level to the threat (possible, presumed, known) and risk posed by it (unknown, low, moderate, high). For example, a "known" threat is one where there is clear evidence the process can be a limiting factor to Sockeye while "high" risk occurs when there is a high level of exposure to the threat and the adverse population level consequences of exposure to the threat are also high.

Life stage: eggs and alevins

- Random loss of genetic variation due to low spawning abundance (presumed threat, moderate risk). Populations lose genetic variation faster when fewer adults contribute to the next generation. Presumed threat because the population structure of Atnarko Sockeye (i.e., relative contribution of the three life history types to overall population) is not well known. Moderate risk because current spawner abundances of ~ 2,500 fish in recent years are at or above what is typically assumed to be a minimum population size from a genetic perspective in Pacific salmon (Allandorf *et al.* 1997; Cultus Sockeye Recovery Team 2005).

- Sediment inputs into spawning and incubation habitat and scouring of redds during extreme hydrologic events (known threat, unknown risk). Known threat because sediment impacts on Pacific salmon fertilization and incubation success are well documented (e.g., Birtwell 1999; Galbraith *et al.* 2006) and wildfire and beetle kill has destroyed a large percentage of hillside and riparian vegetation around some Atnarko nursery lakes, with severe flooding in recent years potentially exacerbating sediment inputs. Unknown risk because magnitude and persistence of sediment inputs is unknown.
- Impacts of freshwater acidification on developing embryos as a consequence of CO_{2-} emissions (possible threat, unknown risk). Possible threat because freshwater CO_{2-} acidification impacts have been documented in Pacific salmon under experimental conditions (Ou *et al*. 2015). Unknown risk because degree of CO_{2-} acidification in the Atnarko watershed is unknown.

Life stage: fry and parr

- Sediment inputs into nursery lakes leading to reduced primary productivity with consequences for secondary productivity and energy flow to higher trophic levels (presumed threat, low risk). Presumed threat because reductions in hillside and riparian vegetation around some nursery lakes due to wildfire and beetle kill over the past decade has presumably led to increases in sediment inputs into nursery lakes which can affect lake primary production (Birtwell 1999). The risk posed by this threat is considered low because, while the degree to which sedimentation has led to altered nursery lake productivity and trophic structure in Atnarko nursery lakes is unknown, by virtue of their size and reduced flow, lakes are likely to moderate sediment impacts.
- Displacement of fry and parr out of rearing habitat in the Atnarko and Bella Coola rivers during extreme hydrologic events (possible threat, moderate risk). This is considered a possible threat because high discharge has been shown to be correlated with reduced Chinook survival and population productivity, likely as a result of displacement from rearing and feeding habitat and reduced foraging opportunities (Neuswanger *et al*. 2015). Increases in discharge and displacement are most likely to affect river type Sockeye life histories that rear in the river for extended periods of time. The risk of increased frequency and magnitude of high discharge events is considered moderate because, while the extent to which climate change is predicted to alter patterns of discharge specifically within the Atnarko and Bella Coola Rivers is not known, in general snow dominated systems like the

Atnarko are predicted to experience higher spring and early summer discharges relative to those experienced in the past (Schnorbus *et al*. 2011).

Life stage: smolts

- Competition with enhanced salmon (possible threat, unknown risk). High abundances of hatchery-reared salmon that interact with wild juveniles as they migrate to sea and during early marine life have the potential to reduce prey availability, change wild salmon foraging behaviour, and drive shifts to lower quality foods, if food resources are limiting and hatchery fish directly or indirectly compete with wild ones (e.g., Kostow 2012). For the past 30 years approximately 2 million enhanced Chinook have been released annually into the Atnarko River around the same time wild sockeye are migrating to sea (or possibly slightly after) and at approximately the same size. Over the same time period approximately 7 million Chum have been released each year but in tributaries to the lower Bella Coola River at an earlier date than sockeye are likely to migrate to sea and at a much smaller size. It is possible that these large numbers of enhanced fish might compete for food with Atanrko sockeye but very little is known about interactions between these species during early marine life and so this threat is consider possible and of unknown risk.
- Mismatch between the seasonality of prey productivity and critical feeding period during early marine life (known threat, moderate risk). This is a known threat because mismatch between the timing of the spring bloom, which can be variable in the Central Coast (Tommasi et al. 2013), or the seasonality of prey production, and critical early marine feeding periods in Sockeye can lead to reduced survival and population productivity (e.g., Tanasichuk and Routledge 2011; Malick *et al.* 2015). In addition, increases in SST in the winter months preceding marine entry (a proxy for biological and physical oceanographic conditions) are correlated with reduced Sockeye productivity in general (Mueter *et a*l. 2002a, 2002b, 2005; Pyper *et a*l. 2005) and Atnarko Sockeye in particular (Section 3.2). This threat is considered a moderate risk because SST is predicted to increase, on average, by ~1^{o}C over the next half century under current climate change projections (Abdul-Aziz *et al*. 2011) and because extreme oceanographic events like the “blob” of 2015 (Kintisch 2015) may become more common.

Life stage: Marine phase

- Increases in salmon competitors (known threat, moderate risk). Broad scale changes in oceanographic conditions across the North Pacific Ocean have led to the increased survival and abundance of Pink, Chum and Sockeye salmon in the northern part of their range (i.e., Alaska and Russia) and the highest abundance of Pacific salmon observed across the entire North Pacific in at least 50 years (Ruggerone *et al*. 2010). Increasing production of hatchery raised Pink and Chum salmon, particularly from central Alaska and Asia has also contributed to the record high abundances. This is a known threat because these increases in abundance have led to increased competition for a limited pool of resources and evidence of declines in size, increases in age-at-maturity, and reduction in survival of Sockeye in the southern part of their range (Ruggerone and Connors 2015) including in the Atnarko (Section 3.2). This risk of continued competition-related impacts on Atnarko Sockeye is considered moderate because with projected increases in hatchery production and continued favorable marine conditions for salmon in the northern part of the range, the abundance of salmon competitors is likely to remain high for the foreseeable future.

- Predation by invertebrates, birds, fishes and marine mammals (possible threat, unknown risk). Numerous species are known to consume Sockeye at sea and some including salmon sharks and daggertooth fish may prefer Sockeye salmon over other salmon species. However, no studies have demonstrated that any of these predators, or harbor seals which have increased drastically in abundance, consume sufficient numbers to pose a population threat to Sockeye salmon and so this threat is only considered possible (Christensen and Trites 2011). Because the risk posed by these predators is poorly understood it is considered unknown.

Life stage: Adult migration and spawning

- Directed and indirect harvest in commercial and FSC fisheries (known threat, unknown risk). The overexploitation of salmon stocks is a known threat to population persistence and viability. Atnarko Sockeye are no longer targeted in commercial fisheries and the total number of fish taken in the lower Bella Coola River FSC fishery has averaged less than 100 fish per year over the past decade. Current estimates of incidental FSC harvest of Atnarko Sockeye in Area 8 (Fisher Fitz-Hugh Sound) are low but highly uncertain since they are based on only one year of stock ID work. Incidental harvest of Atnarko Sockeye in Central Coast Sockeye, Pink and Chum fisheries is also unknown. As a result of these uncertainties the risk posed by overexploitation is currently unknown, however, harvest (both directed and incidental) may need to be managed even more conservatively in the face of climate change.
- Increases in river temperature (known threat, low risk). Upriver migration survival of adults is reduced at water temperatures greater than 18° C as result of increased energy use (Rand *et al*. 2006), increased rate of development of pathogens and their effects on host physiology (Bradford *et al*. 2010, Wagner *et al*. 2005) and reductions in aerobic scope (Eliason *et al*. 2011). These effects can lead to elevated freshwater migration and pre-spawn mortality (Martin *et al.* 2011, 2012). Given the well-established threat that increased river temperatures can pose to Sockeye salmon this is considered a known threat. However, predicted increases in temperature on the Central Coast of BC are moderate relative to other parts of the province and though predictions for the Atnarko and Bella Coola Rivers are not available, coarse scale predictions suggest maximum average summer temperatures will not routinely

exceed 18^{o}C (Nelitz 2012) and so the risk of increased temperatures to Atnarko Sockeye is considered low.

- Degradation of spawning habitat as a result of extreme hydrologic events (possible threat, unknown risk). This is considered a possible threat because high discharge events like those in the late 2000s could result in displacement of spawning substrate and scour which, due to the fact that much of the Atnarko spawning habitat is downstream of lakes, may be slow to be replaced. However, because there have been no assessments of spawning habitat in recent decades the risk posed by alteration to spawning habitat is unknown.

4.3 Goals and objectives

The biological goals, objectives, and approaches for recovery of Atnarko Sockeye need to be both realistic and feasible. As the Atnarko Sockeye population appears to be fry-recruitment limited (not enough spawners) and producing Sockeye well below capacity, the most immediate biological need is to reverse this trend by improving natural production (i.e., getting more spawners on the spawning grounds). The overarching goal of Atnarko Sockeye recovery process is therefore to

> **…reverse the decline of Atnarko Sockeye salmon and re-establish self-sustaining, natural spawning populations for the benefit of future generations and the surrounding ecosystem while ensuring the preservation of the unique biological characteristics of Sockeye from the Atnarko watershed.**

Recovery objectives to meet this goal need to take into consideration the various threats potentially affecting Atnarko Sockeye including the evidence that processes outside of the Atnarko watershed, and so largely beyond recovery plan control, are contributing to the population's currently depressed status. Additionally, the plan needs to consider the time frame over which objectives can realistically be expected to be met. As a result, the immediate and long-term objectives of Atnarko Sockeye recovery are to:

Immediate term:

- Reduce biological risk to Atnarko Sockeye.
- Maintain spawning and rearing habitat.
- Identify, and where feasible, begin to restore lost critical habitats.
- Improve the information base upon which status of Atnarko Sockeye is assessed.

Long term:

- Protect, and where necessary and feasible, rehabilitate habitats critical to recovery.
- Monitor and, where feasible, reduce potential threats to critical rearing and spawning habitat.
- Ensure population productivity remains, on average, above replacement and that the population experiences sustained growth until the population approaches the carrying capacity of system.

Recovery targets

A provisional recovery goal of ~15,000 spawners, and a limit reference point of ~4,000 spawners, are proposed corresponding to the upper (S_{MSY}) and lower (S_{gen1}) biological benchmarks derived from the shape of the Atnarko Sockeye stock recruitment relationship (Section 2.5; Table 3). The limit reference point is meant to indicate the population size at which the need for management intervention is high and as proposed is slightly higher than what is typically assumed to be a minimum population size from a genetic perspective in Pacific salmon (Allandorf *et al.* 1997; Cultus Sockeye Recovery Team 2005). Both the recovery goal and limit reference point are provisional and must be revaluated, and modified as necessary, as the recovery planning process continues (i.e., within 2 years).

4.4 Recovery activities

The recovery plan committee identified, discussed and then prioritized a suite of activities that could be undertaken in support of the immediate and long-term goals of the Atnarko recovery plan (Table 7). These activities fall into one of three categories: (i) assessment related activities focused on improving the foundation of information upon which recovery and management activities are based, (ii) habitat related activities focused on improving habitat believed to the critical to Atnarko Sockeye, and (iii) enhancement related activities focused on hatchery related actions to promote recovery and long-term resilience of Atnarko Sockeye.

The highest-priority activity over the immediate term is the compilation and synthesis of existing data on Atnarko Sockeye ecology, life histories, growth, enhancement activities and survival to improve an understanding of population structure (i.e., composition of life-history types) and maximize learning from the conservation enhancement efforts that have occurred over the past decade (e.g., life history specific survival rates). This effort would inform the two other high-priority activities which include developing a conservation enhancement strategy based on guidelines from other jurisdictions and then implementing it in support of ongoing conservation enhancement efforts.

Medium-priority activities include improved estimates of incidental and FSC harvest of Atnarko sockeye, particularly in Area 8 FSC fisheries, to ensure that harvest of Atnarko Sockeye does occur at a level that could jeopardize their recovery. In addition, it is recommended that freshwater habitat and juvenile population assessments are periodically carried out to identify any freshwater factors that could be addressed to support recovery.

Though rated as lower priorities, the development of revised and standardized adult enumeration and biological sampling programs are activities that will improve the ability to monitor the biological status of Atnarko Sockeye and provide the necessary information against which to measure recovery success. As the planning and implementation of recovery activities proceeds, the duration and scope of each activity will need to remain flexible to changing priorities as project results, funding opportunities and new information becomes available.

Table 7: Prioritized list of assessment, habitat and enhancement activities to support recovery plan.

Activity	Priority (# of Votes[1])	Type	Cost[2]	Timeline	Description of activity	Potential sources of funding
1. Compile and synthesize existing data on Atnarko Sockeye ecology, life histories, growth, enhancement activities and survival.	High (7)	Assessment	\$-\$\$	Short - term	Compilation and synthesis of existing data on Atnarko Sockeye ecology and life histories to quantify: life stage specific growth rates from archived scales and otoliths (e.g., Duffy and Beauchamp 2011; Volk *et. al*. 2010); variation in life history (i.e., lake, river and ocean) among years and location of sample collection to improve understating of population structure; and interannual variation in the timing of marine entry and growth rates in relation to environmental covariates (e.g., SST). Compilation and synthesis of existing data from conservation enhancement program to: estimate and compare fry-to-adult survival by broodstock location, release timing and year; and relate fry-to-adult survival to interannual variation in growth increments in freshwater and the marine environment (e.g., Cross *et al.* 2009) as well as the life history exhibited by the fish recovered. Fry-to-adult survival and growth could also be related to the timing, magnitude and location of enhanced Chinook and Chum releases to evaluate interactions with enhanced fish. Lastly, historic samples of each life history type could be used to inform molecular analyses of population structure and extent of unique adaptation at a finer scale than is currently considered.	Partnerships with academic and non-profit organizations and graduate student support (e.g., MITACS scholarships)
2. Develop a conservation enhancement strategy and best practice guidelines	High (5)	Conservation enhancement	\$	Short - term	Develop and document an enhancement strategy and best-practice guidelines (e.g., broodstock sourcing, genetic considerations, spawning and rearing methodologies, marking strategy, enhancement decision rules, and release timing and location) to optimize future enhancement of Atnarko Sockeye based on learning from Activity 1 and best practices in conservation enhancement from other jurisdictions (e.g., Flagg *et al*. 1999; Brown *et al.* 2002).	Salmonid Enhancement Program; Habitat Stewardship Program for Species at Risk; Aboriginal Species at Risk Fund
3. Continue conservation enhancement program	High (5)	Conservation enhancement	\$\$-\$\$\$	Medium - term	Continue conservation enhancement activities to help protect Atnarko Sockeye from genetic and ecological risks of small population size while also maximizing opportunities to learn about Atnarko Sockeye ecology and life history and gain insights into potential limiting factors (e.g., differential survival rates between lake and river type fish would suggest that differences in the habitats that they inhabit contribute to variation in survival). Revise conservation enhancement activities based on outcome of Activity 2.	Salmonid Enhancement Program; Habitat Stewardship Program for Species at Risk; Aboriginal Species at Risk Fund
4. Improve estimates of stock composition in Area 8 FSC fisheries	Medium (4)	Assessment	\$\$	Medium - term	Conduct genetic stock ID of representative samples of direct and indirect sockeye harvest to improve contemporary estimates of Atnarko Sockeye exploitation rates and to update historic estimates and resulting brood tables.	Pacific Salmon Commission Northern Fund
5. Conduct pelagic fish surveys to quantify juvenile abundance in	Medium (4)	Assessment	\$\$	Medium - term	Conduct periodic pelagic fish surveys using hydroacoustics, midwater trawls and/or small-mesh gillnets to quantify the abundance of Sockeye in nursery	Habitat Stewardship Program for Species at

Activity	Priority (# of Votes[1])	Type	Cost[2]	Timeline	Description of activity	Potential sources of funding
nursery lakes					lakes and inform extent to which rearing habitat capacity is being used (Shortreed *et al*. 2001; MacLellan and Hume. 2011). When coupled with Activity 6 can inform habitat – juvenile abundance relationships in the system and extent to which habitat conditions are limiting recovery.	Risk; Aboriginal Species at Risk Fund
6. Conduct habitat, water quality and limnological assessments of freshwater habitat	Medium (4)	Habitat	$$	Medium – long term	Monitor temperature, sedimentation and pH in Atnarko river along with periodic limnological assessments (in tandem with Activity 5) to inform assessment of ongoing sedimentation, baseline pH and thermal influences on incubation and adult migration. Aerial and on-the-ground evaluation of sediment sources and terrain stability above important habitat within the five sockeye nursery lakes and relevant portions of the Atnarko River downstream and upstream. Assessment of lower Atnarko and Bella Coola rivers to identify potential limiting rearing habitat. Periodic limnological assessment of nursery lakes would inform understanding of condition of freshwater nursery habitats and extent to which they may be limiting juvenile production and survival as well as updated estimates of rearing capacity in nursery lakes (e.g., Cox-Rogers 2012).	Habitat Stewardship Program for Species at Risk; Aboriginal Species at Risk Fund
7. Monitor juvenile abundance river and during early marine residence	Low (3)	Assessment	$$$	Medium – long term	Monitor juvenile outmigration timing and duration by life history type via rotary screw trap in lower river along with net based sampling approaches such as surface (e.g. Carr-Harris et al. 2015) or midwater (e.g. Beamish *et al*. 2000) trawls, purse seines (e.g. Preikshot *et al* 2012), and beach seines (e.g. Carr-Harris *et al*. 2015) in North Bentinck Arm and Burke Channel to estimate the relative abundance (or density) and residence time of juvenile salmon. Biological samples from fish collected could inform life stage and life history specific estimates of abundance (if sampling is standardized) as well as the timing of marine entry (e.g., Stocks *et al*. 2014), growth rates (e.g., Duffy and Beauchamp 2011; Volk *et. al*. 2010) and condition (Schabetsberger *et al*. 2003). If compared to early marine growth estimates from fish sampled when they return as adults, this would quantify influence of early marine growth effects on overall marine survival (e.g., Cross *et al*. 2009) by life history type. If coupled with physical and biological oceanographic monitoring could inform extent to which early marine conditions influence growth and survival.	Habitat Stewardship Program for Species at Risk; Aboriginal Species at Risk Fund; Pacific Salmon Commission Northern Fund
8. Increased monitoring of Nuxalk food fishery	Low (2)	Assessment	$	Short term	Increase monitoring of Nuxalk food fishery in Lower Bella Coola River by hiring dedicated technicians June through August to improve estimates of FSC Atnarko Sockeye harvest and run size as well as extent to which exploitation is contributing to stock status. Biological sampling could be piggybacked on monitoring program and technicians could also do outreach with fishers on Atnarko Sockeye stock status and ongoing recovery activities.	Aboriginal Species at Risk Fund; Pacific Salmon Commission Northern Fund
9. Maintain standardized bio-	Low (1)	Assessment	$-$$	Short term	Develop a revised biological sampling protocol to ensure standardized	Aboriginal Species at Risk

Activity	Priority (# of Votes[1])	Type	Cost[2]	Timeline	Description of activity	Potential sources of funding
sampling of spawners and FSC fish					sampling of otoliths, scales and recording of marked hatchery fish occurs. These data enable estimates of annual age composition of returns to inform brood tables and brood year survival as well as life-history composition of returns. Scale or otoliths can also be used to estimate early marine growth effects on survival via comparison to growth estimates during freshwater and early marine life stages as generated by Activity 7.	Fund; Pacific Salmon Commission Northern Fund
10. Improve spawner enumeration	Low (1)	Assessment	$$-$$$	Short term	Develop a revised adult assessment protocol in collaboration with the Nuxalk and DFO consisting of a combination of helicopter overflights, foot and raft counts to improve estimates of spawner abundance each year which is a critical metric needed to asses population status. Reinstatement of a community-led enumeration event (e.g., the Atnarko bash) would help increase community involvement in, and awareness of, conservation and assessment of Atnarko Sockeye.	Aboriginal Species at Risk Fund; Pacific Salmon Commission Northern Fund

[1] Number of votes received during ranking of activities at recovery planning workshop

[2] Qualitative assessment of cost of activity ranging from approximately less than $20k per year ($), between $20k and $50k per year ($$) and greater than $50k per year ($$$)

4.5 Implementation, monitoring, evaluation and adjustment

The next step in the recovery planning process should focus on developing an implementation plan, jointly developed by the Nuxalk Nation and DFO, which takes into consideration the priority recovery actions identified in this report, potential sources of funding, and collaboration with ongoing programs. This work plan should include the periodic review of progress on, and results from, the implementation of recovery actions as well as an assessment of biological status

For immediate term recovery actions the work plan should include specific timelines, project leads, roles and responsibilities, and details of monitoring and evaluation. These elements are critical to ensuring that the implementation of recovery actions is done is a rigorous manner that monitors and evaluates their success and maximizes the opportunity to learn from the actions and adjust the recovery process as necessary.

The following considerations, adapted from the Lakelse (Lakelse Watershed Society *et al.* 2005) and Kitwanga (Cleveland *et al*. 2006) Sockeye recovery plans, should be incorporated where appropriate into the Atnarko Sockeye recovery actions that are implemented:

- *Statistical design for gathering data and identification of indicators that are sufficiently sensitive that they provide results over the time frame required*
- *Standardized sampling protocols and monitoring logistics*
- *Plans for data analysis and interpretation including description of how the results of the activity will inform subsequent recovery actions*
- *Stable and sufficient funding*
- *Inclusion of the public, to the extent possible, through stewardship initiatives that help protect critical habitats and restore impacted habitats*
- *Community awareness through information programs developed with local stakeholder and community groups*
- *Partnerships with public and industry for specific stewardship projects*

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Appendix 1. Recovery planning committee members

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