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Wild Salmon Policy Status, Limit Reference Point, and Candidate Escapement Goals for Okanagan Sockeye Salmon

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Canada

Foreword

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

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ABSTRACT

Canadian Okanagan Sockeye salmon (*Oncorhynchus nerka)* are geographically and genetically distinct from all other Sockeye salmon in British Columbia, as they spawn in the Canadian portion of the Columbia River Watershed, the Okanagan Basin. This migratory route through the United States (U.S.) also causes them to have a unique history, primarily driven by the construction of nine mainstem Columbia River hydroelectric dam structures along their migratory route. Although Okanagan Sockeye salmon have provided an abundant source of food and trade for the Syilx people since time immemorial, as early as the late 19th century the health of the stock has been constrained by fish fences, dams, habitat degradation, and water flow regulation issues, among other threats. Despite this history, the stock showed signs of recovery in the early 2000's, driven in part by improvements in freshwater flow management and dam passage, as well as habitat restoration projects, and hatchery supplementation aimed at re-establishing populations in previously inaccessible habitats. Therefore, harvesting was allowed to resume in some areas both in the U.S. and Canada.

Okanagan Sockeye salmon are lake-rearing, and until 2009 they had access only to Osoyoos Lake (the southernmost lake in the Canadian portion of the Okanagan River Basin). In the last 15 years, restoration of passage at Okanagan River mainstem dams, and targeted hatchery programs, have facilitated the establishment of a population in Skaha Lake, while efforts are ongoing to also establish a population in Okanagan Lake, which is the largest lake in the Okanagan River basin.

These changes in accessible range and population structure require the revision of reference points (both for management and conservation) and stock status. In this document, we consider three alternative methods for establishing reference points:

1. estimating total spawner capacity based on habitat attributes for all three lake populations,
2. estimating total rearing capacity based on the results of bioenergetic models of lake food webs, which was possible only for Skaha and Osoyoos lakes, and
3. population dynamics (spawner-recruit and spawner-smolt) modelling for the Osoyoos Lake population.

Habitat-based estimates of spawning capacity were found to be the most useful approach for determining biological benchmarks in order to assess status under the *Wild Salmon Policy* and therefore to determine status relative to the Limit Reference Point, and to identify candidate management targets.

Wild Salmon Policy status was assessed based on data combining Osoyoos and Skaha lakes. Lower and upper benchmarks for the relative abundance status metrics were identified at 20% and 40% of estimated median spawner capacity, respectively (20% of habitat-based S_{max}: 28,603; 40% of habitat-based S_{max}: 57,207). The final status of the Osoyoos-Skaha-Okanagan Sockeye salmon Conservation Unit (CU) for 2023 was assessed as Amber with high confidence. However, the CU faces serious threats from climate change and is at high risk of declining into Red status in the near future.

The Okanagan Sockeye salmon Stock Management Unit (SMU) contains a single CU which is currently not of *Red* status. Therefore, the SMU is above the status-based Limit Reference Point (LRP) under the Fish Stock Provisions of the modernized *Fisheries Act*.

Habitat-based estimates of the number of spawners that maximize juvenile recruitment (i.e., S_{max}, corresponding to full use of the available spawning habitat) were summed for all three lakes and were used to identify candidate management targets for the Okanagan Sockeye salmon SMU. A candidate target range of 96,000-135,000 spawners would approximate an

escapement goal based on S_{MSY} (as 50-70% S_{max}). A candidate target range of 192,000-231,000 spawners could be used to represent a goal of maximizing total production (100-120% S_{max}). Escapement goals specific to each lake population are also estimated and provided.

1. INTRODUCTION

Canadian Okanagan Sockeye salmon (*Oncorhynchus nerka*) are the last remaining Sockeye salmon spawning within the Canadian portion of the Columbia River Watershed (DFO, 2023a). Okanagan Sockeye salmon (as well as Chinook salmon, Coho salmon, Steelhead Trout, and other fish species) were managed by the Syilx-Okanagan people since time immemorial. These fish provided an abundant source for food and trade, prior to colonization, and continue to play an important role in the culture of the Syilx-Okanagan people. As early as the late 1800s, salmon passage on the Columbia River has been intermittently blocked, earlier by fish fences (Department of Fisheries 1888), and later by the development of large-scale hydroelectric dams. The building of Grand Coulee Dam (completed in 1942) blocked all salmon passage on the Columbia mainstem upstream of the Okanagan River Basin, functionally eliminating the upstream salmon runs. The rebuilding of Okanagan Sockeye salmon has been hampered by mounting anthropogenic pressures that include irrigation diversions, hydroelectric dam operations, flood reduction measures, overfishing, and introduction of invasive species, as well as urban and industrial development (Hyatt and Rankin, 1999; Murauskas et al., 2021; Nehlsen et al., 1991; Quinn, T.P., 2018; Slaney et al., 1996). Nevertheless, since the early 2000s, Okanagan Sockeye salmon underwent perhaps the greatest recovery of any salmonid population in the Pacific Northwest (Murauskas et al., 2021). Over the past two decades, Okanagan Sockeye salmon have, on average, accounted for more than 80% of all Sockeye salmon returning to the Columbia Basin (Hyatt et al., 2018c). Increases in escapement are believed to be mainly a result of synergies between several basin-level management actions taken within the Canadian Okanagan River basin, Columbia River hydrosystem improvements and favorable marine conditions (Alexander et al. In Press). Some of the major basin-level factors that have been linked to the recovery include: 1) the reintroduction of Sockeye salmon into Skaha (beginning in 2004) and Okanagan (beginning in 2016) lakes through a conservation hatchery program; 2) the design and implementation of the Fish Water Management Tools (FWMT), starting in 2004, to promote fish-friendly flows in the Okanagan River (Alexander and Hyatt, 2013; Hyatt et al., 2015); and 3) the execution of several habitat remediation projects (Alex and Lukey, 2023), and fish passage improvements across the Columbia and Okanagan basin (NOAA, 2022; Okanagan Nation Alliance, 2023).

Okanagan Sockeye salmon exhibit lake-type ecology and include three populations named for their respective nursery lake (Osoyoos, Skaha, and Okanagan lakes; refer to Figures 3 through 5). In addition to fish passage being impeded on the U.S. part of the Columbia mainstem, Sockeye salmon populations in Skaha and Okanagan lakes were extirpated when passage to nursery lakes and spawning streams was blocked in 1921 and 1915, respectively, limiting Sockeye salmon rearing to Osoyoos Lake only. As a result, a single Conservation Unit (CU) for the Okanagan Sockeye salmon was defined under the Wild Salmon Policy (WSP); (DFO, 2005), consisting only of the Osoyoos Lake population (DFO, 2005; Holtby and Ciruna, 2007).

Over the past twenty years, Sockeye salmon were reintroduced to Skaha and Okanagan lakes through the release of hatchery-origin fry, initially from wild brood stock from the Osoyoos Lake population, and later from salmon migrating past Osoyoos Lake, and returning to Oliver. Although hatchery-origin Sockeye salmon were reintroduced into Skaha Lake in 2004, returning spawners were unable to access the lake until 2009, when modifications to the McIntyre and Skaha Lake Outlet Dams provided returning spawners passage to the lake. The first naturally-returning spawners in the Skaha Lake spawning areas were observed in 2011 (Karilyn Alex, Fisheries Biologist and Fluvial Geomorphologist, Okanagan Nation Alliance, Westbank, BC, pers. comm.). Since then, the Skaha population has become well established (Hyatt et al., 2021a; Hyatt et al., 2021b). Reintroduction of hatchery-origin Sockeye salmon to Okanagan

Lake commenced in 2016 (Hyatt et al., 2018c). Access to the lake through Penticton Dam[1] was made possible in 2019, following the rehabilitation of an existing fish-way, with a limited number of spawners being granted entry each year. Since 2022, both Sockeye salmon and Chinook salmon have had open passage to Okanagan Lake.

The WSP defines a CU as “a group of wild salmon sufficiently isolated from other groups that, if lost, is very unlikely to recolonize naturally within an acceptable timeframe (e.g., a human lifetime or a specified number of salmon generations)”. Despite expanding into two new nursery lakes, the three populations are considered as a single CU, given their genetic similarity. Moreover, it was determined that the three populations were sufficiently likely to recolonize each other’s nursery lakes (in the event of one lake population’s extirpation) that they should be considered as one CU (DFO, 2005). As a result, the CU was recently changed to not only include Osoyoos Lake fish, but also those rearing in Skaha and Okanagan lakes. The CU is now called the Osoyoos-Skaha-Okanagan (OSO) CU.

Throughout this report, we refer to these three combined Sockeye salmon populations in the basin as the Okanagan Sockeye salmon Stock Management Unit (SMU). The CU corresponding to it is the OSO CU, which is the only CU in the Okanagan Sockeye salmon SMU. We use the terms OSO CU, Okanagan Sockeye salmon SMU, and Okanagan Sockeye salmon stock throughout this report, depending on the context, but all three terms refer to the combination of Sockeye salmon rearing in the three lakes. We use the term “population” only when referring to all Sockeye salmon rearing in one of the individual lakes. Figure 1 summarizes the structure of the Okanagan Sockeye salmon.

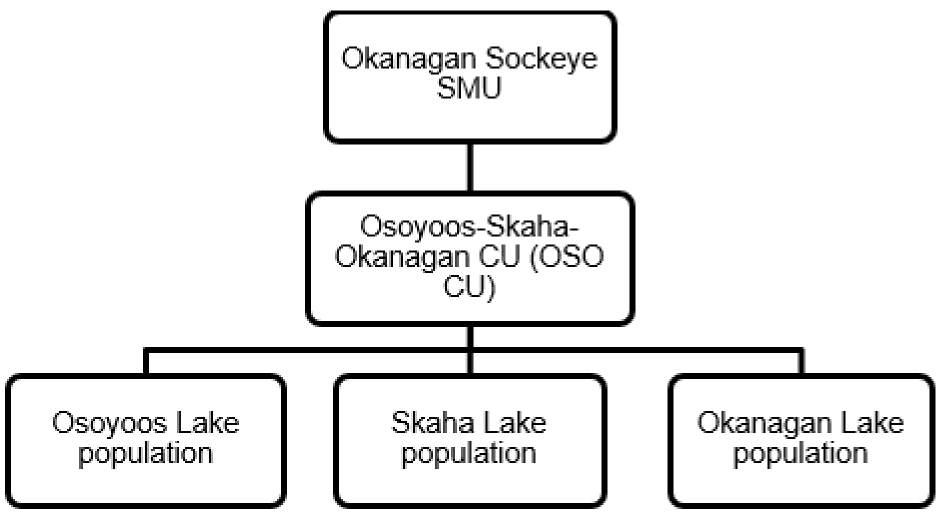

Figure 1. Stock structure of the Okanagan Sockeye salmon SMU, showing revised conservation unit (CU) delineation and the three component populations defined by rearing lake.

Until the late 1990s, insufficient data on adult age composition and juvenile production limited the establishment of specific escapement objectives for the basin. Instead, an escapement objective, aimed to co-manage the mixed stock of Okanagan and Wenatchee-bound Sockeye salmon, was adopted. It set a combined escapement goal of 65,000 fish past Priest Rapids Dam in the mid-Columbia River (Hyatt and Stockwell, 2019). Any surplus was considered harvestable by treaty-tribal and commercial fisheries. Subsequent to that study, stock-specific

[1] Officially known as the Okanagan Lake Outlet Dam

escapement goals were set for Okanagan Sockeye salmon; DFO fisheries managers defined a spawning objective of 35,500 adults returning to the Okanagan River or 61,200 adults enumerated at Wells Dam (DFO, 2023a). These escapement goals were based on the study that was conducted by Hyatt and Rankin (1999), who recommended a provisional escapement objective of 29,365 adults on the “index” section of the spawning grounds or 58,730 adults counted at Wells Dam. Hyatt and Rankin’s (1999) recommendations were based on their conservative estimate of the rearing capacity of Osoyoos Lake along with the declining state of the Okanagan River Sockeye salmon in the 1990s. Nevertheless, their study estimated that the spawning habitat capacity of Osoyoos Lake could support up to 135,000 spawners.

Given the recent range expansion and increased abundance of Okanagan Sockeye salmon (escapement has exceeded the 35,500 target in 12 of the past 20 years; 2004-2023), there is strong support to revisit the existing escapement goals, which were developed for the Osoyoos Lake population only. Thus, DFO Fisheries Management has committed to revising the Okanagan Sockeye salmon SMU spawning escapement objectives to better reflect the status of the combined stock and individual lake populations. Revised escapement goals are intended to support fisheries management within Canada and to inform the bilateral discussions regarding the setting of a new harvest sharing agreement for Sockeye salmon in the Columbia River basin. Whereas the final escapement goals need to consider socioeconomic objectives, cultural values, and future risk assessments (all of which are beyond the scope of this process), they must be guided by science-based estimates of the biological capacity of the current Okanagan Sockeye salmon range. This paper reports on the status of the OSO CU (and therefore the status of the Okanagan Sockeye salmon SMU relative to its LRP) and provides scientific recommendations for potential management reference points that can be used as a basis for generating revised escapement goals for the whole SMU, or for the individual lake populations.

We explored three alternative approaches for developing biologically-based candidate management reference points:

1. biological carrying capacity of the system based on quantifying the spawning habitat capacities of the three nursery lakes (Osoyoos, Skaha, and Okanagan lakes),
2. updated estimates of freshwater productivity in two of the rearing lakes (Osoyoos and Skaha), and
3. a spawner-recruitment (SR) model for the Osoyoos Lake population.

Additionally, the biological status of the OSO CU is assessed based on established metrics, benchmarks and considerations for implementing Strategy 1 of the WSP strategy, while accounting for the range expansion of Sockeye salmon in the CU. Finally, uncertainties in the data and methods, as well as a discussion of the potential impacts of climate change on Okanagan Sockeye salmon, and future work are presented.

2. CULTURAL CONTEXT

This assessment occurs on the unconquered, unceded territory of the Syilx-Okanagan people of this land, their mother (S. Lawrence, pers. comm.). The Okanagan Nation has accepted the responsibility to serve for all time as protectors of the lands and waters including *nk̓mip* (Osoyoos Lake), *t̓uʔcin* (Skaha Lake) and *kłusxənitkʷ* (Okanagan Lake) in Syilx territories, so that all living things return regenerated (Syilx water declaration).

Prior to colonization, the Syilx-Okanagan Nation (comprised of seven member communities in the Southern Interior of BC: Okanagan Indian Band, Osoyoos Indian Band, Penticton Indian Band, Upper Nicola Band, Upper and Lower Similkameen Indian Bands, the Westbank First

Nation, and the Colville Confederated Tribes in Northern Washington State) managed Sockeye (*sćwin*), Chinook (*ntitiyx and sk̓lwist*), and Coho (*kísuʔ*) salmon, as well as Kokanee (*kəkni*) salmon, Steelhead trout (*qwəyqwəyʕaćaʔ*) and other species of the Okanagan River system for countless generations (Armstrong, 2020). Indigenous resource management focuses on considering multiple components of an ecosystem as opposed to managing based on optimizing the harvest of a targeted stock alone (Atlas et al., 2021; Berkes et al., 2000; Turner et al., 2000). For the Syilx-Okanagan Nation in Canada, salmon has a vital nutritional, cultural and spiritual significance (Blanchet et al., 2021). *captík̓ʷł*, traditional Syilx teachings, tell us that *snk'lip* (coyote) brought salmon up the Columbia River and its tributaries, including the Okanagan basin. He did this to prepare the land for the arrival of the *sqilxʷ* (Indigenous people), ensuring that the Syilx people would always have sustenance from the rivers and streams that flow over their lands. The people enjoyed the beauty and the bounty of their lands and waters for a long time, respecting their relationships and responsibilities to all living beings, through ceremony and by caring for the land and water in accordance with their laws and cultural protocols.

The Syilx-Okanagan concept of land encompasses more than the physical geography of place; it includes the spiritual connections of everything living on and within it (Okanagan Nation Alliance, 2018).The Syilx people believe that *k̓ʷuləncútn*, the Creator, gave them the gift of salmon, and in return they have a responsibility to honour the kinship they have with salmon, through ceremonies that aim to thank the salmon for giving their lives to provide the Syilx people with nourishment. They also understand that it is their duty to protect and care for the water and land so that the salmon will continue to come back year after year (ONA, 2023).

European settlement of the Columbia River and Okanagan River watersheds brought about dams, agriculture, water engineering, and overfishing. These changes were also accompanied by European-centric fish management, which altered fish assemblages and added a long list of exotic fish species (Clemens, 1939; Ferguson, 1949; Northcote et al., 1972; Okanagan Nation Alliance, 2003, 2002, 2001; Rae, 2005; Webster, 2007). With colonization, water management changed from reciprocity with nature to a system of possession and control over resources (Phare, 2009). Ernst (1999) researched the relationship between the Okanagan River dams and the loss and destruction of fish habitat (specifically for Sockeye salmon). This work revealed a relentless drive and pressure within the basin to have the water resources of the area rigorously controlled. These actions ignored the requirements of salmon habitat and ultimately led to salmon population reduction and subsequent resource and cultural loss for the Syilx-Okanagan people. The loss of salmon habitat severely impacted Syilx food security and their sovereignty over their Indigenous food systems and economies, and contributed to the disruption of their physical and social well-being (Blanchet et al., 2021). Some of the negative consequences included disconnection from Indigenous cultural and economic practices, poor nutrition, and a disproportionally high level of food insecurity, obesity, nutrition-related chronic diseases, and illbeing (Batal and Decelles, 2019; Blanchet et al., 2021; Vernon, 2015).

In response to the Supreme Court of Canada ruling in *Regina v. Sparrow* (1990), Fisheries and Oceans Canada (DFO) launched the Aboriginal Fisheries Strategy (AFS) in 1992. The AFS provided support for the ONA to create its Fisheries Department (1996), which in turn went about re-establishing Indigenous-based processes in Okanagan salmon fisheries research (ONA 2023). The Syilx elders and leaders have provided a clear vision and guidance to the Okanagan Nation Alliance Fisheries Department. Their vision is to rebuild Okanagan Sockeye salmon and restore them to their former historic migratory range (ONA, 2023).

The Okanagan Nation Alliance found partners at Fisheries and Oceans Canada and the Provincial Ministry of the Environment that together developed funding and collaborative arrangements with American public utilities, Washington State Fisheries, and other government agencies (Correia et al., 2024). All of these efforts culminated in a complex series of restoration projects such as the Okanagan Basin Salmon Reintroduction project that returned the salmon to parts of their historic range and began to repair damaged ecosystems through initiatives such as the Okanagan River Restoration Initiative (ORRI) and the FWMT. These projects were initiated by means of Syilx knowledge and understanding, and all of them began on or around 2004. Thus, 2004 begins a period of "*tmix^{w}*-centred" management of Okanagan Sockeye salmon. In *Nsyilxcen*, the Syilx peoples' language, the concept of *tmix^{w}* is complex and nuanced, centred around the concepts of "all life forms, all animals, the spirit of all living things," and can be understood as "a system of relationships being reconstructed limitlessly, and which is actually the life-force of the place" (Armstrong 2010). The *tmix^{w}*-centred period is therefore defined in this document as beginning when a multi-faceted rebuilding program was implemented to address the multi-faceted needs of the Okanagan basin for the benefit of anadromous salmon. There were also substantial changes to stock assessment monitoring programs beginning with this more recent period, meaning that data from before and after this point are not always comparable (Table 1; see more discussion in Sections 4.3 and 7.1.1).

The increases in returning salmon have provided for traditional ceremonies throughout the basin such as the Salmon Feast and First Salmon Ceremony.

3. STUDY AREA

3.1. OKANAGAN RIVER BASIN

The Okanagan River (Canada) drains a series of Canadian lakes (Wood, Kalamalka, Okanagan, Skaha, Vaseux) into Osoyoos Lake, which straddles the Canada-USA border. Osoyoos Lake empties into the Okanogan[2] River (USA) that flows south into the Columbia River (Figure 2). In the past 100 years, the Okanagan River in British Columbia (BC) experienced drastic and widespread anthropogenic hydrological changes that affected its connectivity to its floodplain, wetlands and hyporheic flows. Currently, only 16% (4.9 km) of the river remains in a natural (2.8 km) or semi-natural (2.1 km) state. Approximately 84% (30.4 km) of the river has been channelized, straightened, narrowed, and/or diked (Bull, 1999; NPCC, 2004). As result, the river length was reduced by 50% (Bull, 2000) and its habitat simplified.

Returning Okanagan Sockeye salmon enter the Columbia River during May–July and negotiate fishways at a minimum of 10 dams before arriving to their natal nursery lakes (Figure 2) during late June through early September (reviewed in Hyatt and Rankin, 1999). Peak spawning occurs in October, primarily in natural or semi-natural reaches of the Okanagan River above Osoyoos and Skaha lakes (Hyatt et al., 2003; Stockwell and Hyatt, 2003), or more recently, in tributaries of Okanagan Lake. Historically, Okanagan Sockeye salmon were able to migrate upstream through Osoyoos Lake into Skaha Lake, Okanagan Lake, and beyond, and were widespread and abundant (Ernst, 2000; Fryer, 1995; Hewes, 1998; Kennedy and Bouchard, 1998; Long, 2005).

[2] The American spelling will be used for the American sections of the river.

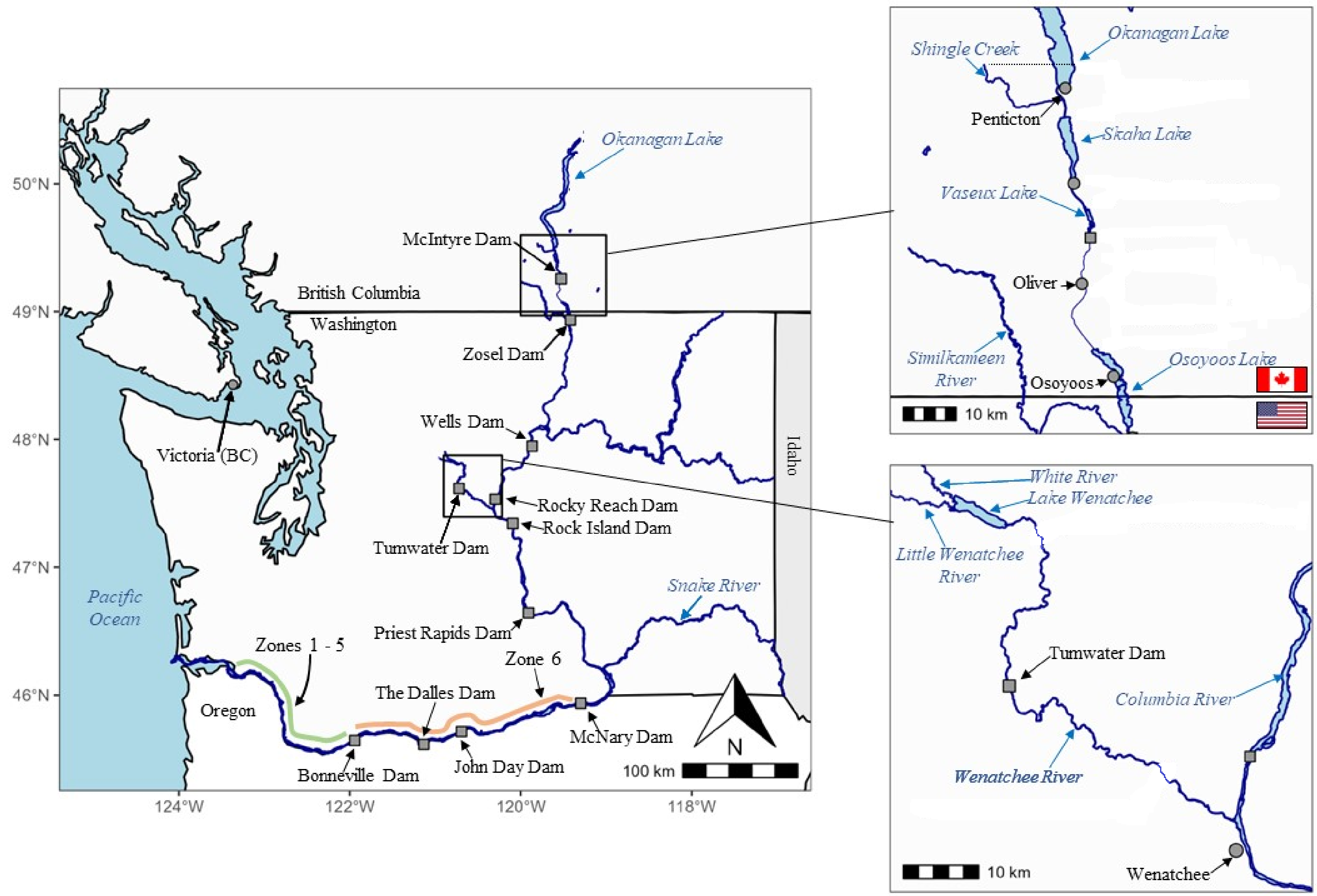

Figure 2. Columbia River basin and the Okanagan and Wenatchee rivers. Shown on the map are some of the dams along Columbia River Sockeye salmon migratory routes, as well as the commercial and treaty fishing zones on the Columbia River. Zone 6 stretches between Bonneville and McNary dams. Zones 1-5 extend between the mouth of the river and Bonneville Dam. Adapted from Judson et al. (2023).

3.2. THE REARING LAKES

3.2.1. Osoyoos Lake

Osoyoos Lake is the southernmost lake in a series of connected lakes that drain the Okanagan basin. It has a surface area of 23 km^2, a maximum depth of 63 m, and a mean depth of 14 m. It is a glacial lake that extends over 16 km and is divided into three sub-basins, namely the northern, central, and southern basins. The southern basin straddles the Canada/U.S. border (Jensen et al., 2012). Only the northern basin is suitable for Sockeye salmon rearing; it is the deepest of the three (mean depth = 21 m) and has a brief water residency time (i.e., weeks to months). It offers approximately 933 hectares of year-round, limnetic fish habitat suitable for the rearing of juvenile salmonids (Hyatt et al., 2017b). The central and southern basins are shallower and more susceptible to high water temperatures and low oxygen conditions in the summer, making them inhospitable to juvenile salmonids (Hyatt and Stockwell, 2013). Flows into Osoyoos Lake are largely controlled by upstream dam releases, particularly flows from Penticton Dam[3], at the outflow of Okanagan Lake. Outflows from Osoyoos Lake occur through Zosel Dam, WA (Figure 3). Releases are regulated in accordance with the mandates of the Canada-US International Joint Commission (Stockwell et al., 2020).

Osoyoos Lake is moderately productive (i.e., mesotrophic); its zooplankton assemblage diversity is relatively low and was negatively affected by the introduction of the invasive pelagic shrimp (*Mysis diluviana),* which competes for resources with Sockeye salmon parr and presmolts; but becomes prey for age-1+ Sockeye salmon and sufficiently large presmolts (Hyatt et al., 2018a). Approximately 28 invasive species have now been documented in Osoyoos Lake, with numerous invasive taxa such as bass (*Micropterus sp.*) and carp (*Cyprinus sp.*) as well as numerous native fishes such as sculpins (*Cottus spp.*), whitefish (*Prosopium williamsoni*), and Kokanee salmon *(Oncorhynchus nerka*), significantly changing the fish assemblage present in the lake. Osoyoos Lake has a small population of Kokanee salmon (non-anadromous *O. nerka*) that is estimated not to exceed 2% of the total abundance of Sockeye salmon (Hyatt et al., 2017b). Anadromous Chinook salmon (*O. tshawytscha*) and Steelhead trout (*O. mykiss*) both utilize Osoyoos Lake, although their numbers are small in comparison to Sockeye salmon (Hyatt et al., 2015). Osoyoos Lake has been described as one of the most productive Sockeye salmon nursery lakes in North America (Chapman et al., 1995). Nevertheless, the lake's epilimnion suffers from elevated summer temperatures, which can exceed 17 ºC, while its hypolimnetic oxygen concentrations often fall below 4 mg L^{-3}. These conditions represent the physiological extremes that juvenile Sockeye salmon can tolerate (Levy, 1990) and produce a "temperature-oxygen squeeze" which can limit Sockeye salmon parr and returning adults to a narrow belt of stratified water (Hyatt and Stockwell, 2010).

Prior to the implementation of the FWMT program in 2004, incubating Sockeye salmon eggs and alevins in spawning creeks and river sections upstream of Osoyoos Lake suffered from non-"fish-friendly" flows, causing habitat scouring and/or desiccation, which were identified as a critical bottleneck for the productivity of Okanagan Sockeye salmon (Hyatt et al., 2015). With the adoption of the FWMT, high priority has been given to ensuring that "fish-friendly flows" are released from Okanagan Lake, particularly during the Sockeye salmon egg–alevin incubation phase (Alexander and Hyatt, 2013; Hyatt et al., 2015). Concomitantly, the Okanagan Nation Alliance (ONA) implemented several habitat restoration projects to improve the spawning grounds and revitalize the Syilx salmon ceremonies. The rebound of Okanagan Sockeye

[3] Officially named Okanagan Lake Outlet Dam

salmon is believed to be due at least in part to these basin-level changes in the mid-2000s (Alexander et al. In Press).

More recently, the Osoyoos Lake Sockeye salmon population was impacted when the Testalinden Dam (in the headwaters of Testalinden Creek; refer to Figure 3) failed on June 13, 2010. The failure resulted in the release of silt and agricultural contaminants upstream of Osoyoos Lake (Kuo et al., 2012; Tannant and Skermer, 2013). The event had multi-year impacts on the structure of the pelagic zooplankton community and negatively affected the abundance of juvenile Sockeye salmon for one to two years post-failure (Hyatt et al., 2018b; Hyatt and Ogden, in prep.[4]).

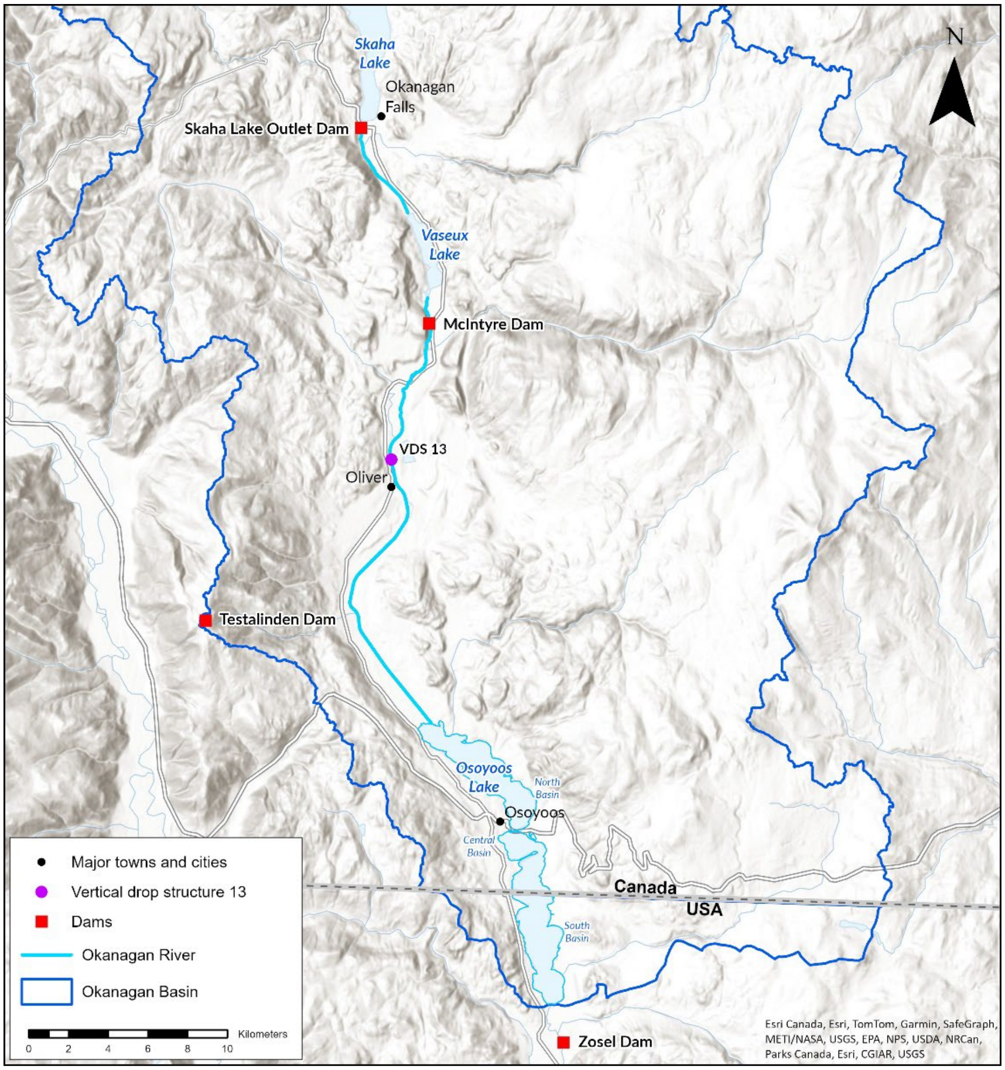

Figure 3. *Map of Osoyoos Lake.*

[4] Hyatt, K.D. and Ogden. A.D. In preparation. An Assessment of Impacts of the 2010 Testalinden Dam Breach on Aquatic Food webs and Planktivores (*Oncorhynchus nerka* and *Mysis diluviana*) at Osoyoos Lake, British Columbia, Canada.

3.2.2. Skaha Lake

Skaha Lake (Figure 4) is situated upstream of Osoyoos and Vaseux lakes. It is 12 km long, has a surface area of 1946 ha, a volume of 0.56 km^3, a maximum depth of 57 m, and a mean depth of 26 m (Northcote et al., 1972; Pinsent and Stockner, 1974; Stockner and Northcote, 1974). Water residency time is typically several months, although this varies considerably with precipitation. In this lake, during summer, waters deeper than 15 m provide suitable thermal habitat for juvenile and adult Sockeye salmon holding there because the hypolimnion does not go hypoxic at any time during the year (Hyatt et al., 2021a).

As mentioned previously, hatchery-origin juvenile Sockeye salmon from Osoyoos Lake brood stock were experimentally reintroduced into Skaha Lake (180 fish/ha) beginning in 2004 (Wright and Smith, 2004). The introduced fish were monitored for their in-lake interactions with other fish. Observations were made over four brood cycles before there was enough evidence to proceed with establishing fish passage via restoration and reengineering of the McIntyre and Skaha Lake Outlet dams (Figure 3 and Figure 4). The McIntyre dam was initially refitted in 2009, allowing spawners to swim up to the Skaha Outlet Dam. Yet, natural spawners were detected in Skaha Lake after high-water events in 2011 and 2012. The Skaha Outlet Dam was re-engineered in 2014 to provide reliable, fulltime passage, allowing adult Sockeye salmon to move upriver and spawn naturally in Penticton Channel (Figure 4). Skaha lake spawners also utilize Shingle Creek, which is a tributary of the Okanagan River located in Penticton, BC (Figure 4). In more recent years, Skaha Lake spawners, on average, have accounted for around 50% of Okanagan Sockeye salmon spawners (refer to section 4.1 for more details).

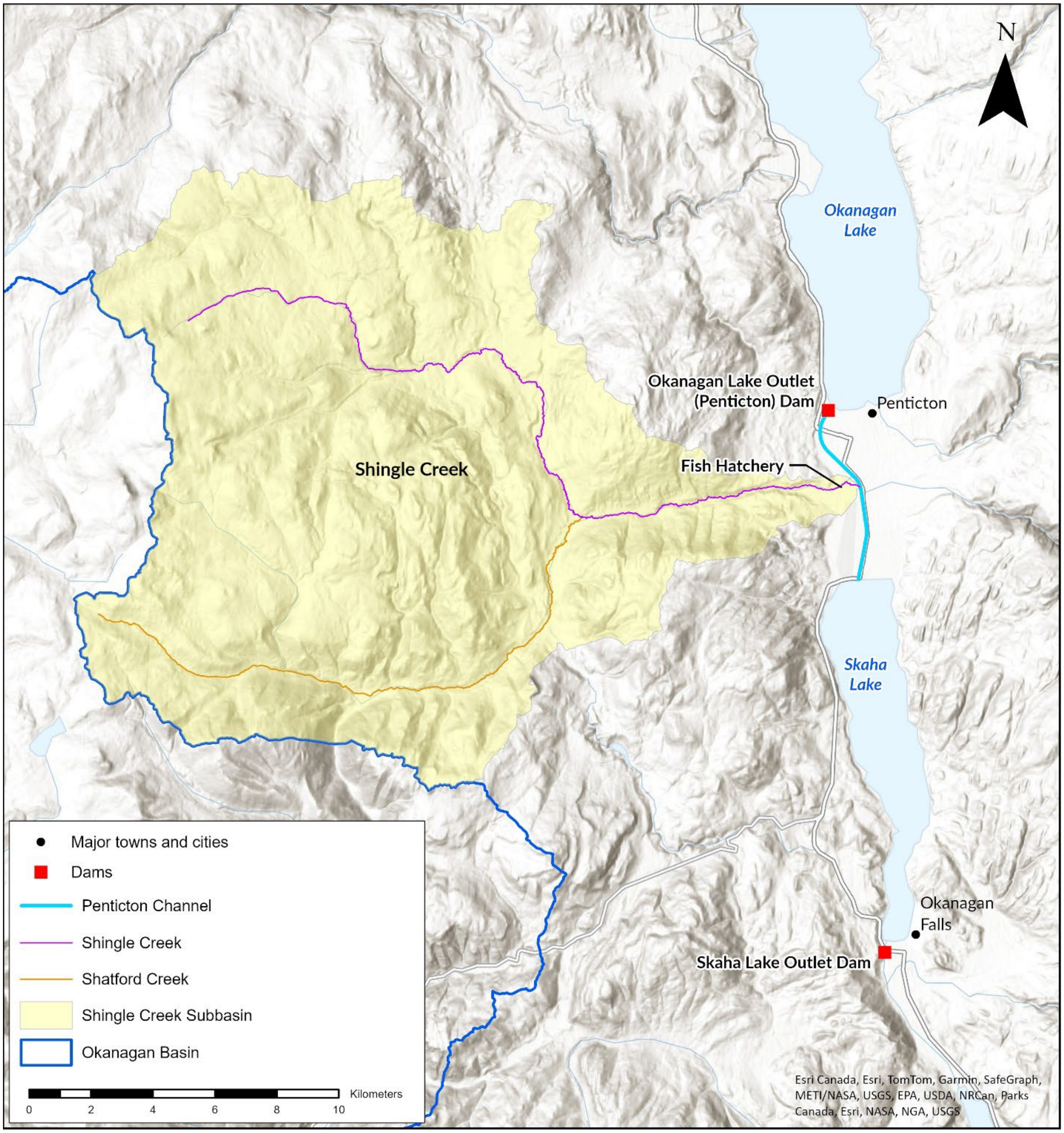

Figure 4. Map of Skaha Lake.

3.2.3. Okanagan Lake

The Okanagan Lake watershed exceeds 8,000 km^2 (Rae and Andrusak, 2006), and the lake itself is a large, low-productivity lake that is fed by more than 18 tributaries draining from small montane lakes that offer potential fish habitat (Figure 5). It is approximately 110 km long, with a surface area of approximately 350 km^2. Its water residence time exceeds 60 years (Rae, 2005). Most of the lake is oligotrophic, with relatively low levels of organic nutrients (total phosphorous: 2 -12 μg·L^{-1}) and phytoplankton (average epilimnetic chlorophyll-*a* concentration = 2.5 μg·L^{-1} (Andrusak et al., 2008).

In an effort to reverse the declining trend in the Kokanee salmon population in Okanagan Lake, the invasive opossum shrimp (*Mysis relicta*) was introduced in 1966 with the intent of providing a food source for juvenile Kokanee salmon. Instead, mysids directly compete with juvenile Kokanee salmon for prey and have since been identified as a driver of their decline (Andrusak et al., 2008; Rae and Andrusak, 2006). Some of the Kokanee salmon in Okanagan Lake exhibit a shore-spawning life history strategy, wherein individuals spawn in the gravelly littoral zone of the lake under a half meter of water. These shore-spawning fish have been observed to utilize more than 90 km of the lake's shoreline. The average proportion of shore-spawning as compared to stream-spawning Kokanee salmon over ten recent years (2013-2022) was 0.212 (SD=0.085; data provided by the BC Ministry of Water Land, and Resource Stewardship). Unfortunately, much of the lake's edge has been degraded and altered by development (65% of the recreational docks in BC are on Okanagan Lake; Rae, 2005). Together, introduced species, habitat alterations, climate change and anthropogenic disturbances have substantially altered the ecology of Okanagan Lake. Recreational fisheries have gradually shifted from focussing primarily on Kokanee salmon to one that also harvests other salmonids (e.g., rainbow trout, whitefish, and lake trout); there is also a commercial harvest of the invasive mysid shrimp (Andrusak et al., 2008; Rae and Andrusak, 2006; Shepherd, 1999).

Sockeye salmon access to Okanagan Lake has been blocked by Penticton Dam[5] since 1915. In 2016, a small ceremonial release of <10,000 hatchery-origin fry (also from the Osoyoos Lake population brood stock) were first reintroduced to tributaries of Okanagan Lake by the ONA (Hyatt et al., 2018c). In 2017, the ONA submitted an application with DFO's Introductions and Transfers Committee to release up to 750,000 Sockeye salmon fry into Okanagan Lake, with plans to reintroduce a maximum of 3.5 million fry per year (Hyatt et al., 2018c). Since 2015, a cumulative total of 12.9 million fry have been released into the lake. In 2019, the first of the hatchery-origin adults (from releases to Okanagan Lake) returned and aggregated below Penticton Dam, which remained a fish barrier at that time. In each of 2020 and 2021, 60+ adult Sockeye salmon were allowed past the dam at Okanagan Lake, but in 2022 and 2023, adult Sockeye salmon were able to pass into the lake freely via a fishway. Building an improved fish passage facility is planned for the future at the Penticton Dam and is supported by the BC Ministry of Water Land, and Resource Stewardship.

Due to urbanization, recolonizing Sockeye salmon may be limited by the availability of suitable spawning habitat in Okanagan Lake tributaries (Alex et al., 2020). It should be noted that historically, according to Traditional Ecological Knowledge, some of the tributaries, such as Mission Creek (Figure 1), supported large runs of Sockeye salmon (Long, 2005). Currently, some of the Okanagan Lake tributaries are utilized by stream-spawning Kokanee salmon, especially in Mission Creek and the Mission Creek Kokanee salmon spawning channel. There are plans to remediate and restore much of the available stream spawning habitat in the Okanagan Lake tributaries (Alex and Lukey, 2023).

[5] Officially named Okanagan Lake Outlet Dam

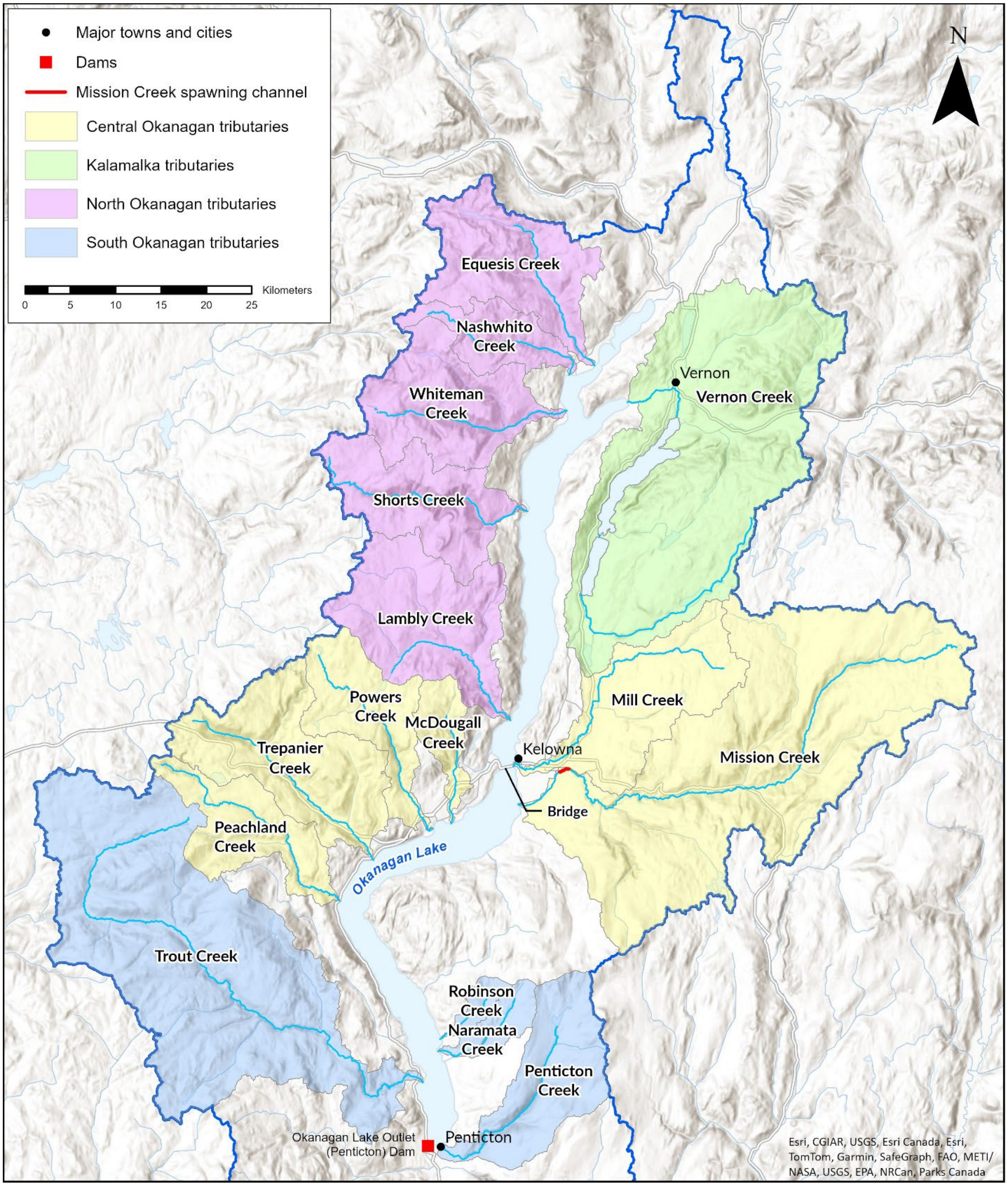

Figure 5. Map of Okanagan Lake and tributaries with potential spawning habitat.

4. DATA AND METHODS OVERVIEW

The approaches we used in determining CU Status, SMU status compared to the LRP, and developing advice for setting management reference points, were highly dependent on data availability and data quality[6]. Due to the unique histories of each of the three lake-rearing populations, and their gradient from well-established and self-sustaining (Osoyoos Lake population) to newly re-introduced (Okanagan Lake), the data available, and therefore the methods applicable to each, were variable.

In terms of direct population sampling, estimates of spawners were available for all three lake populations. Stock-recruitment (SR) modelling is generally the default method for determining reference points, but unfortunately a suitable time series currently exists only for the Osoyoos Lake population. Therefore, two other methods were explored in order to estimate habitat-based capacity. The benefit of these methods is that they provide candidate reference points that are based on the potential each habitat has, rather than on the current population abundance, which for Skaha and Okanagan lakes is still being supported by hatchery supplementation, and perhaps still has not fully recolonized all of the available habitat and reached a naturally self-sustaining equilibrium (as the Osoyoos lake population likely has).

The first of these habitat-based methods involves using fish length, redd area, spawning habitat area, and bed particle (gravel) size to estimate spawning capacity. The data required for this method was recently updated for all three lake populations. This is the only method that could be applied (at this time) to all three populations.

The second habitat-based method aims to estimate lake-rearing capacity. This method is much more data-intensive, and requires estimates of juvenile abundance/density, as well as broad biological sampling of the entire pelagic food webs. The data were available to apply this method to both Osoyoos and Skaha Lakes over a short time period, but not to Okanagan Lake.

Table 1 gives an overview of available data and an indication of which methods they were used for. APPENDIX A provides additional information of funding sources and data availability. Further detail on these data are provided below.

[6] Note that ONA and DFO are conducting an ongoing review of the abundance estimates of spawners, returns, and in-lake juveniles. The data shown here were the best available when this document was being finalized.

Table 1. Available data for the Okanagan Sockeye salmon across their three rearing lakes. Data limitations and the methods the data were used in are also stated. Note that data for production models are required by brood year, so 2023 adult returns provide the age-5 component for the recruits from the 2018 brood year, and 2023 smolt estimates provide the age-2 component of smolt production from the 2021 brood year. Osoyoos Lake spawner-recruit data were available for the 2004-2018 brood years, and spawner-smolt data were available for the 2004-2021 brood years, with gaps. Skaha Lake spawner data were available only for the 2012 to 2018 brood years (later escapements were also available, but not used), and spawner-smolt data were available only for the 2012-2018 brood years, with gaps. Years shown are brood years except where noted.

Data	***Time Period***	***Consideration***	***Osoyoos population***	***Skaha population***	***Okanagan population***
Spawner abundance	2002 to present	Consistent application of area-under-the-curve (AUC) methods.	2004-2023 for SR modelling. Brood years 2009 and 2010 excluded due to the Testalinden Dam failure	2012-2023 (non-zero) time series too short for SR modelling (data available for 2012-2018 brood years)	2022 (non-zero) time series too short for SR model

Data	*Time Period*	*Consideration*	*Osoyoos population*	*Skaha population*	*Okanagan population*
			2006-2008, 2011-2014, 2016, and 2018-2021 data used for rearing bioenergetics capacity model	2012-2014, 2016, 2018 for rearing capacity model	
	1961 to 2001	AUC equivalents were obtained for Osoyoos Lake via cross-calibrations; data were of unknown accuracy.	Unreliable data. not used in models.	Not applicable	Not applicable
Adult returns	1980 to present	Refer to section 4.1 for details	2004-2023. Brood years 2009 and 2010 excluded due to the Testalinden Dam failure	2012-2023 (non-zero) too short for SR modelling (data available for 2012-2018 brood years)	Only for 2022 (non-zero) too short for SR model

Data	*Time Period*	*Consideration*	*Osoyoos population*	*Skaha population*	*Okanagan population*
Adult age composition	2002 to present	Consistent sampling of biological data from dead spawners started (age, sex, length).	2004-2023. Brood years 2009 and 2010 excluded due to the Testalinden Dam failure	2012-2023 (non-zero) too short for SR modelling (data available for 2011-2018 brood years)	Only for 2022 (non-zero) too short for SR model
	1980 to 2002	Inconsistent methods, biased sampling, and partial resorption of scales	Unreliable data. not used in models.	Not applicable	Not applicable

Data	***Time Period***	***Consideration***	***Osoyoos population***	***Skaha population***	***Okanagan population***
Smolt abundance	1996 to present	Survey estimates from acoustic and trawl surveys (ATS), which also record, length, weight, condition, age from scales, and hatchery origin from otolith samples.	2006-2008, 2011-2015, and 2018-2020 data used for SR modelling. Brood years 2009 and 2010 excluded due to the Testalinden Dam failure.	2012-2014, 2016, 2018-2020 too short for SR modelling	Not applicable
			2006-2008, 2011-2014, 2016, and 2018-2021 data used for rearing bioenergetics model.	BY 2012-2014, 2016, and 2018 escapements for rearing capacity model	

Data	*Time Period*	*Consideration*	*Osoyoos population*	*Skaha population*	*Okanagan population*
	1983 to 1995	Developed using a linear regression between presmolts estimated after 1996 and McNary Dam counts of returning adults.	Unreliable data. not used in models.	Not applicable	Not applicable
Smolt age composition	1996 to 2023	Unpublished analyses suggest that age-2 proportion may be underestimated (Scott Akenhead, pers. comm.)	2006-2008, 2011-2013, 2015, and 2017-2023 data used for SR modelling. Brood years 2009 and 2010 excluded due to the Testalinden Dam failure.	2012-2023 too short for SR modelling	Not applicable

Data	*Time Period*	*Consideration*	*Osoyoos population*	*Skaha population*	*Okanagan population*
		Assessments of fish species composition were based on combined data from midwater trawls and echosounding.	2006-2008, 2011-2013, 2015, and 2017 data used for rearing capacity model	2012-2014, 2016, 2018 for rearing capacity model	Not applicable
Spawning area and habitat metrics	2001, 2009-2023	Sediment characteristics of each polygon were quantified using a modified Wolman pebble count sampling method (Wolman, 1954).	Original survey conducted in 2001, updated in 2009 and 2021 to account for river restoration. Used for spawning capacity model.	Data collected between 2013-2018; data for the Okanagan River mainstem upstream of Skaha Lake. Shingle Creek assessed in 2023. Used for spawning capacity model.	2023 estimates for the 15 Okanagan Lake tributaries. Used for spawning capacity model.

Data	*Time Period*	*Consideration*	*Osoyoos population*	*Skaha population*	*Okanagan population*
Food Web Data	2006-2012, 2014, 2016	*Mysis*, zooplankton, and fish predator densities and composition.	2007-2013, 2015 in-lake years for rearing bioenergetics model	2005*-2013, 2015, and 2017 in-lake years for bioenergetics model	Not applicable
	2013	Insufficient field sampling for Osoyoos Lake only.	Insufficient data to use in bioenergetics model	Sufficient data to use in bioenergetics model	Not applicable
	2015	Insufficient field sampling	Insufficient data to use in bioenergetics model	Insufficient data to use in bioenergetics model	Not applicable
	2006-2014 and 2016	Fish stomach contents available.	2007-2013, 2015 in-lake for rearing bioenergetics model	2005-2013, 2015, and 2017 in-lake years for rearing bioenergetics model	Not applicable

*Note that in Skaha Lake, we were able to use limnological and nerkid in-lake data for bioenergetics modeling in years before there were spawners able to return to the Skaha Lake spawning area.

4.1. ADULT RETURNS

Returning adult Sockeye salmon arrive at the mouth of the Columbia River from mid-May through July of each year. Daily fish passage data are recorded at several dams along the Columbia River. Bonneville Dam, located at river kilometer (RKm) 235, is the first dam on the Columbia River at which salmon passage is monitored (Figure 2), and, on average over the last 25 years (1999-2023), 50% of the Sockeye salmon run passed Bonneville between June 24th – 27th (CBR-DART). Total annual Sockeye salmon harvest in the Columbia River downstream of Bonneville Dam[7] is added to the expanded (24-hr) total annual Sockeye salmon counts at Bonneville to derive an estimate of the total annual Sockeye salmon returns to the Columbia River. Estimated Snake River Sockeye salmon returns (JCRMS 2022)[8] are then deducted from this total to obtain an estimate of the combined annual abundance of Sockeye salmon returning to the Wenatchee and Okanagan River basins. While both Wenatchee and Okanagan-bound salmon stocks pass by Rock Island Dam at RKm 729, the Wenatchee population turns off into the Wenatchee River approximately 20 km upstream of this dam, and Okanagan-bound Sockeye salmon continue up the Columbia River mainstem to the Rocky Reach Dam (RKm 761). Thus, the ratio of Sockeye salmon passage at Rocky Reach Dam relative to the total number passing Rock Island Dam can be used to estimate the annual stock proportions of Wenatchee- and Okanagan-bound Sockeye salmon (Judson et al., 2023; Bailey et al., in prep.)[9].

On the spawning grounds in the Okanagan River, BC, Okanagan Sockeye salmon spawners are enumerated and apportioned into the Osoyoos and Skaha populations based on the relative abundance of adults spawning on the spawning grounds of each of these lakes. The enumerated spawners are further apportioned into hatchery-origin and natural-origin components based on the presence/absence of unique thermal-marks on the otoliths of sampled “deadpitch” carcasses. Hatchery-origin juveniles that were released into the Okanagan Lake tributaries since 2016 had not, until recently, been able to access those tributaries to spawn as adults; therefore, the hatchery-origin fish in Penticton Channel were by default included as Skaha Lake population spawners. Okanagan-basin bound Sockeye salmon returning to the mouth of the Columbia River that were bound for Osoyoos Lake were estimated by using the relative proportion of spawners on the Osoyoos Lake spawning grounds as compared to the Skaha Lake spawning grounds, adjusted for observed straying rate, and the proportion of natural-origin spawners in the Osoyoos Lake spawning areas were estimated by assessing the deadpitch otoliths for hatchery thermal marks. Age-specific returns for Osoyoos Lake are estimated by otolith-based ageing of the deadpitch to determine the proportions of the returns that recruited from individual brood years. Figure 6 shows adult returns at the mouth of

[7] Fisheries downstream of Bonneville Dam occur in Statistical Zones 1-5 from the mouth of the Columbia River to 8 km below Bonneville Dam and are designated as the non-treaty or all-citizen’s commercial fishery. Treaty Indian commercial, ceremonial & subsistence fisheries occur in statistical Zone 6, a 225 km reach of mainstem river between Bonneville and McNary Dams and includes only members of the four Columbia River Treaty tribes. Ocean harvest of Columbia River Sockeye salmon is negligible (Bailey et al. 2024).

[8] See Table 15, p. 78 in (JCRMS 2022).

[9] Bailey, C.J., Stiff, H., Judson, B., Thompson, P. and Ogden, A.D. In preparation. Osoyoos Lake Sockeye salmon (*Oncorhynchus nerka*) return abundance (1977-2023), adult age composition (1985-2023), and marine survival (1998-2021). 2024. Can. Manuscr. Rep. Fish. Aquat. Sci.

the Columbia River for Okanagan (split into Skaha and Osoyoos because Okanagan Lake returns are assumed to be negligible for these years) and Wenatchee populations.

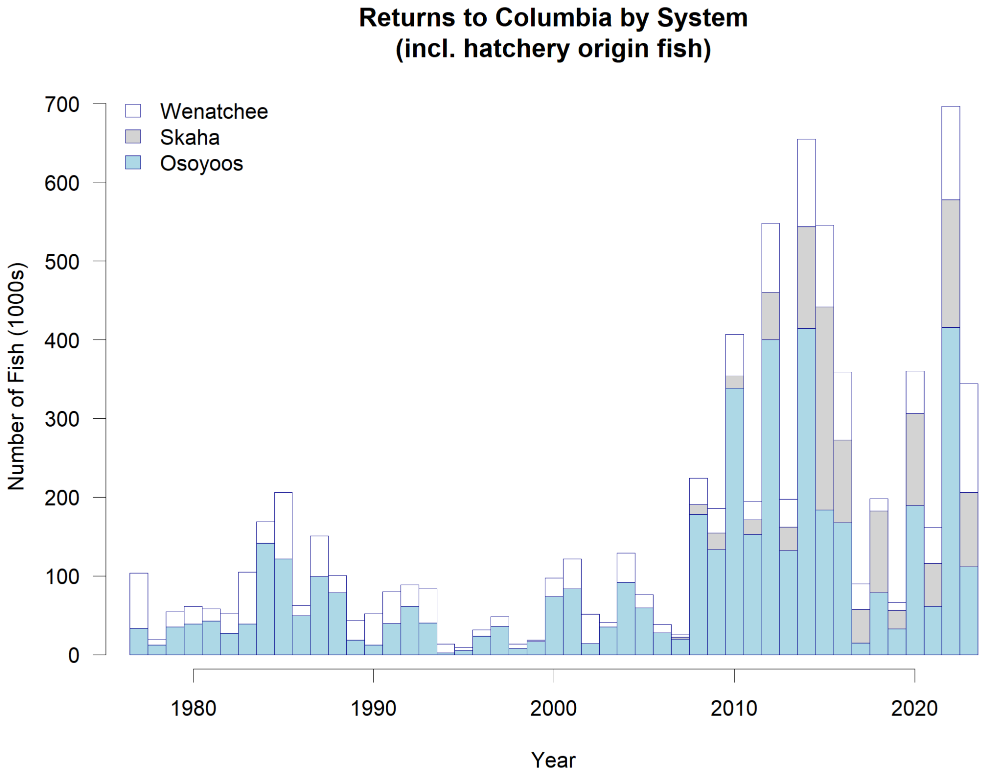

Figure 6. Adult returns at the mouth of the Columbia River.

4.2. HARVEST

There is very little marine bycatch of Columbia River-bound Sockeye salmon (estimated 0.5%). Harvest starts when the fish enter the Columbia River estuary. US harvests include recreational, commercial and U.S. treaty-tribal fisheries that operate in the estuary and the mainstem of the river (refer to Bailey et al., in prep.)9 for details on how harvests are estimated). During years in which a temperature barrier to upstream migration occurs in the Okanogan River above Wells Dam, there is substantial opportunistic harvest in the Wells Dam impoundment ("Wells pool"). A thermal barrier affecting harvest also forms at the confluence of the Okanogan and Columbia rivers, where water temperatures from the two rivers may differ by 10 to 15 °C (Murauskas et al., 2021; Jeff Fryer, Senior Fishery Scientist, Columbia River Inter-Tribal Fish Commission, pers. comm.), and at other sites in the Columbia River. Okanagan Sockeye salmon do not enter the Okanogan River if its temperatures exceed 21 °C. This can delay their migration by several weeks or more (Major and Mighell, 1967; Murauskas et al., 2021). In years when the fish do not encounter a thermal barrier above Wells Dam, they continue upstream to hold in Osoyoos Lake where they are targeted by Canadian recreational, Osoyoos Lake demonstration[10] (when abundance permits, as governed by the decision guidelines in DFO, 2023a), and Food Social and Ceremonial (FSC) fisheries. Harvest data from all these sources are summarized in Table 2.

[10] A demonstration fishery is a commercial fishery conducted by First Nations. Reference: [Fs144-48-2011-eng.pdf]

Table 2. Total annual harvest of Okanagan Sockeye salmon (including US and Canadian extraction).

Year	Spawners	Harvest
1985	31,946	48,531
1986	15,472	6,818
1987	21,090	45,023
1988	20,653	37,950
1989	17,947	937
1990	6,261	714
1991	19,738	1,663
1992	33,184	1,538
1993	17,151	2,460
1994	1,977	217
1995	4,581	329
1996	17,035	1,125
1997	11,996	1,544
1998	3,708	263
1999	5,648	642
2000	21,838	2,502
2001	39,024	6,333
2002	3,560	728
2003	17,753	989
2004	41,791	3,698
2005	31,260	2,405
2006	20,819	1,166
2007	13,490	1,313
2008	126,972	9,729
2009	64,024	25,399
2010	182,122	68,857
2011	45,326	21,544
2012	103,098	153,471
2013	42,930	24,026
2014	194,937	119,878
2015	20,415	74,407
2016	87,371	101,981
2017	35,257	12,079
2018	56,175	51,613
2019	29,251	4,185
2020	79,399	87,201
2021	19,231	28,086
2022	109,644	175,864
2023	32,144	53,022

4.3. SPAWNER ABUNDANCE

During the fall of each year, Okanagan Sockeye salmon spawners are routinely enumerated via visual surveys in the Okanagan River basin (Mathieu et al., 2023). On the spawning grounds, abundance increases with arrivals and decreases with post-spawn mortality; thus the distribution of spawners approximates a trapezoid that can be used to estimate the total abundance of fish (area under the curve; AUC), given an estimated stream-residency time on the spawning grounds (Hilborn et al., 1999). The stream residency time for the Okanagan River basin was estimated as 11 days, which was used by Perrin and Irvine (1990) to estimate Early Stuart Sockeye salmon. Since 2002, the area-under-the-curve (AUC) method has been consistently used to estimate the total number of spawners from the survey data. Prior to 2002, "AUC equivalents" were obtained via cross-calibrations between different methods; therefore, the pre-2002 data were of varying accuracy.

Age estimates for Okanagan Sockeye salmon spawners are available starting in 1980, but they are most reliable beginning with return year 2002, when consistent biological sampling (age, sex, length) of dead spawners on the spawning grounds started. Beginning in 2004, biometric samples from spawner carcasses have been collected and used to estimate age-at-return and to apportion the spawners to natural-origin Sockeye salmon, hatchery-origin Sockeye salmon, and Kokanee salmon (Bailey et al., 2025.). Kokanee salmon are scarce in Osoyoos Lake; however, Okanagan Lake is home to a sizable Kokanee salmon population. In Skaha Lake, both ecotypes are now common, which necessitates the separation of spawning Kokanee and Sockeye salmon data in the Skaha Lake spawning areas (i.e., Penticton Channel and Shingle Creek). This was done primarily by separation on the basis of size in the carcass biosampling and applying these proportions to the nerkid spawner numbers estimated using AUC. Regressions between the fork length and the post-orbital hypural length (which is more reliable for badly decayed carcasses) were used to estimate fork length of the carcasses. A 35 cm cut-off was used to apportion fish into Kokanee (<35 cm) and Sockeye (>35 cm) salmon. Ageing on the basis of otoliths was also used to identify precocious ("jack") Sockeye salmon that were below the 35 cm threshold (Hyatt et al., 2021a, Bailey et al., 2025.).

As can be seen from Figure 7, Skaha Lake spawners were first observed in 2011 (although the spawner estimates that year were uncertain, so we did not use that year in the analyses), whereas Okanagan Lake spawners were observed only in 2022, and only one Sockeye salmon jack was observed there in 2023.

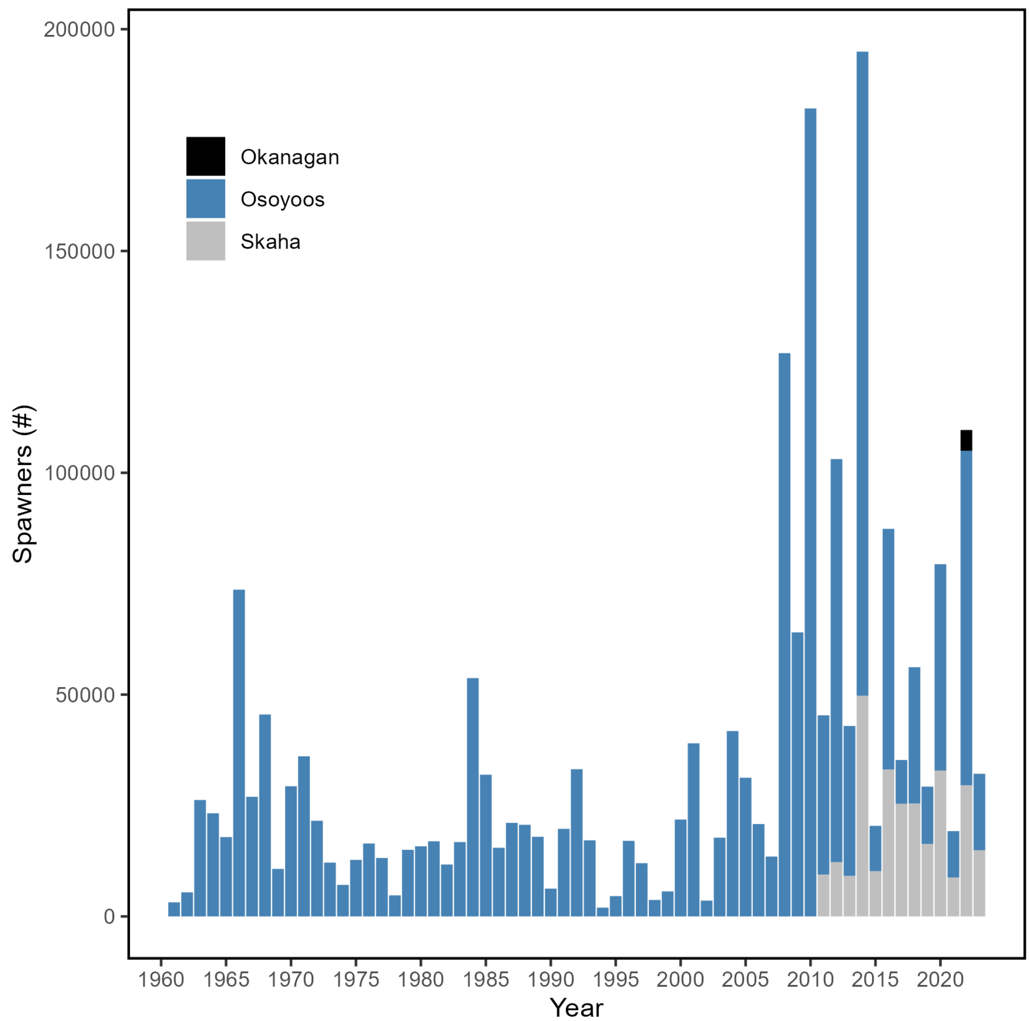

Figure 7. Spawner abundance over time for the Osoyoos Lake, Skaha Lake, and Okanagan Lake Sockeye salmon populations.

4.4. HATCHERY CONTRIBUTIONS

All three lakes in the system have had hatchery supplementation, which is ongoing for Skaha and Okanagan lakes, but has not occurred since 2013 for the Osoyoos Lake population (Table 3). To estimate the influence of hatchery releases on the Sockeye salmon populations in the three lakes, we calculated the proportionate natural influence (PNI) for each (Equation 1). The PNI was developed and applied by the American Hatchery Scientific Reform Group process (Hatchery Scientific Review Group (HSRG), 2014, HSRG, 2009) and is currently the most widely applied metric to assess the genetic risks of hatchery production on natural fish populations. The PNI was calculated as:

$$PNI \approx \frac{pNOB}{pNOB + pHOS} \quad \text{(Equation 1),}$$

where *pNOB* is the proportion of natural-origin parents in the brood stock, and *pHOS* is the proportion of hatchery-origin fish spawning naturally (Withler et al., 2018). The definition of *pHOS* being used here is the census variant as shown in Equation 2.

$$pHOS_{census} = \frac{N_H}{N_H + N_N} \quad \text{(Equation 2)},$$

where N_H and N_N are the estimates of hatchery-origin and natural-origin spawners observed on the spawning grounds, respectively (Withler et al., 2018).

We used otolith thermal mark data to estimate the proportion of hatchery-origin spawners in the Osoyoos, Skaha and Okanagan lake spawning areas in order to estimate pHOS for each population. Brood stock are typically collected over two to three weeks starting in mid-October near Oliver (refer to Figure 3) and are assumed here to represent the proportions of hatchery-origin and natural-origin spawners in the basin. Thermal mark data were available for brood stock captured near Oliver in 2007-2022 (except 2009), and those data were used to estimate pNOB. In 2009, there was an insufficient sample size, and otoliths from the 2023 return year have not yet been read. For 2009, we used the proportions of natural-origin fish in the basin as a whole to estimate pNOB, based on the proportions of otolith thermal marks in the deadpitch of all adults in the spawning areas of the three nursery lakes. In these calculations, we assumed that the brood stock is selected randomly and representatively from among the adult escapement returning to the Okanagan River basin. In the Okanagan Lake tributaries, there were 187 Sockeye salmon carcasses recovered in 2022, all of which were hatchery-origin, which is consistent with no natural-origin fish straying from the other two populations (Elinor McGrath, ONA Biologist, pers. comm.). In 2023, only a single Sockeye salmon carcass was found, and it was of natural origin.

The PNI for the Osoyoos Lake population has been consistently ≥ 0.87 except for 2013, when a higher proportion of hatchery-origin fish was observed because of the juvenile releases there in 2011 (Table 3). With the exception of 2012-2014 and 2019, the Skaha Lake population has had PNI > 0.80 (Table 4). For the Okanagan Lake population, the first year that Sockeye salmon appeared in the tributaries there, the PNI was zero. Based on K.R. Holt et al. (2023), populations above a PNI threshold of 0.51 can be included in the WSP status assessment. This means that two out of three of the populations that make up the OSO CU currently meet that criterion (i.e., Osoyoos and Skaha lakes), while the Okanagan Lake population is still in the very early stages of reintroduction.

Table 3. Number of hatchery-released fry by rearing lake. Fry are released into the creeks and river segments above each lake in the spring following brood stock collection from the previous fall.

Brood Year	Osoyoos Lake	Skaha Lake	Okanagan Lake
2003	0	352,500	0
2004	0	1,205,500	0
2005	0	1,384,000	0
2006	0	1,479,000	0
2007	0	885,500	0
2008	0	1,614,300	0
2009	432,400	448,300	0
2010	0	900,000	0
2011	837,800	0	0
2012	869,300	0	0
2013	0	0	0
2014	0	1,764,223	0
2015	0	357,578	9,994
2016	0	4,493,577	683,856
2017	0	1,222,602	10,110
2018	0	0	4,106,296
2019	0	643,174	643,174
2020	0	2,029,615	2,070,088
2021	0	333,171	10,000
2022	0	752,653	3,812,941
2023	0	177,560	1,334,184

Table 4. Proportionate natural influence (PNI) for the three populations in the OSO CU. The first hatchery releases were from brood year 2004. Thermal marks have not yet been read for 2023.

Year	Osoyoos Lake PNI	Skaha Lake PNI	Okanagan Lake PNI
2004	1.0	-	-
2005	1.0	-	-
2006	1.0	-	-
2007	0.87	-	-
2008	0.94	-	-
2009	0.87	-	-
2010	0.96	-	-
2011	0.92	N/A	-
2012	0.97	0.57	-
2013	0.79	0.54	-
2014	0.97	0.70	-
2015	0.98	N/A	-
2016	0.99	0.99	-
2017	1.00	1.00	-
2018	0.99	0.90	-
2019	N/A	0.68	-
2020	0.97	0.83	-
2021	0.92	0.81	-
2022	0.99	0.94	0

4.5. JUVENILE ABUNDANCE

The Okanagan Sockeye salmon are lake-type Sockeye salmon, meaning that the juveniles rear for their first year or longer in a nursery lake. Acoustic and trawl surveys (ATS) in Osoyoos and Skaha lakes are conducted multiple times throughout the summer and fall to winter of each year in order to estimate the abundance of Sockeye salmon parr and presmolts (Hyatt et al., 2017b). ATS methods are detailed thoroughly elsewhere (Hyatt et al., 2017b, MacLennan and Simmonds, 1992), although they generally consist of two steps:

- Using an acoustic sounder to estimate the total density of limnetic fishes, and
- Using biometric data obtained from nocturnal trawls, in combination with the target strengths of the acoustic data, to apportion the fish into bins that correspond to different species, ages, and origins (e.g., hatchery- or natural-origin).

In the Skaha Lake ATS surveys, the categories of fish are further broken down by means of thermal otolith marks in the trawl bio-samples, to estimate the proportion of hatchery-origin Sockeye salmon, and by genetics, to separate the proportions of natural-origin age-0 Sockeye salmon, age-0 Kokanee salmon, and age-0 Sockeye-Kokanee salmon hybrids. These proportions are then applied to the densities of fish, which are estimated by echosounding, to generate the compositions of hatchery-origin and ecotype. Scales are used for ageing the trawl bio-samples in both Osoyoos and Skaha lakes.

Surveys are conducted along standard and consistent transects each year and are designed to estimate the average abundance of parr (April to September) and presmolts, which are sampled from October until mid-March, before they begin to undergo smoltification and emigrate from the system (usually March-April). These surveys have been conducted annually in Osoyoos Lake since 1996. In earlier years, DFO personnel (Kim Hyatt, Paul Rankin, Barry Hanslit and Rick Ferguson) and Don McQueen led the surveys, and ONA fisheries personnel apprenticed with them; in later years, the ONA continued the surveys using the same methods initiated in 2005.

In this document, we refer to juveniles in their first in-lake year before smolting as age-0. They become age-1s when they leave the lake after their first freshwater year (the majority). Those that remain in the lake for an additional year are then defined as age-1 until they smolt after their second in-lake year, upon which time they become age-2. Presmolts are estimated as the average density of juveniles from October through mid-March for each category, age-0 and age-1. The abundances of age-0 and age-1 presmolts for Osoyoos and Skaha lakes are summarized in Table 5. The proportions of each shown here were based on back-calculation from adults aged in the carcass recovery.

In Osoyoos Lake, the survival of juvenile Sockeye salmon was adversely affected by the Testalinden Dam breach for brood year 2009, and likely for 2010 as well (see Section 3.2.1); therefore, presmolts from those brood years are left out of most analyses. Moreover, insufficient numbers of samples were collected in Osoyoos Lake in 2016 and 2018 to accurately estimate presmolt numbers (these are in-lake years, i.e., brood years + 1 for those juveniles that remain in the lake for only one year). For Skaha Lake, age-0 natural-origin Sockeye salmon densities were available for 2013-2015, 2017, and 2019 (in-lake years). Estimates of age-1 Sockeye salmon are unavailable because there were no biometric data to apportion them among natural-origin Sockeye salmon, Kokanee salmon, or hybrids.

Table 5. Abundance of age-0 and age-1 natural-origin presmolts in Osoyoos and Skaha lakes by brood year.

a) Osoyoos Lake

Brood year	Age-0 presmolts[1]	Age-1 presmolts[2]
2006	1,362,802	681,090
2007	575,194	309,756
2008	4,924,063	2,074,059
2009	638,213	146,043
2010	4,310,465	61,487
2011	2,463,889	123,914
2012	3,633,040	1,098,008
2013	2,034,873	582,814
2014	5,491,638	1,563,397
2015	N/A	N/A
2016	3,262,889	791,109
2017	N/A	N/A
2018	2,397,810	56,913
2019	1,282,253	118,491
2020	3,402,917	217,036
2021	1,132,038	58,979

b) Skaha Lake

Brood year	Age-0 presmolts[1]	Age-1 presmolts[2]
2012	114,814	N/A
2013	355,145	N/A
2014	1,043,056	N/A
2015	N/A	N/A
2016	600,017	N/A
2017	N/A	N/A
2018	375,520	N/A
2019	N/A	N/A
2020	N/A	N/A
2021	N/A	N/A

[1]: Age-0 become age-1 when they smolt and leave the lake
[2]: Age-1 become age-2 when they smolt and leave the lake

4.6. SPAWNING HABITAT: GRAVEL SIZES

The available spawning areas across the Okanagan River mainstem, Shingle Creek (an Okanagan River tributary), and the Okanagan Lake spawning tributaries were estimated by the ONA between 2001 and 2023. Table 6 summarizes the locations where the spawning habitat was estimated for each of the three populations of the Okanagan Sockeye salmon and the periods when the analyses were conducted. Field measurements on the mainstem of the river were conducted when flows were around 11 m^3 s^{-1}, the FWMT-recommended flow for the spawning period (O'Sullivan and Alex, 2024). Field assessments on the tributaries occurred when discharge levels were within 0.06 m^3s^{-1} of average flows during the spawning period (Alex et al., 2024).

During the field work, the entirety of each studied reach was visited and assessed. Spawning areas were mapped as polygons, and their respective areas determined in m^2. The sediment characteristics of each polygon were quantified using a modified Wolman pebble count sampling method (Wolman, 1954). Wolman counts are a standard method for the determination of gravel sizes (Kondolf, 1997; Wolman, 1954). Mainstem polygons were composed of a 1 m x 1 m grid, with 0.1 m spacing. One hundred gravel pieces were selected from each of these grids. For tributary polygons, the field crews adopted a modified Wolman (1954) approach. The crews randomly selected pieces of gravel while they traversed the cross-section of each defined polygon. This process was repeated until 50 pieces of gravel were sampled per polygon (Alex et al., 2024). For each of the collected gravel pieces, the b-axis was measured (neither the longest nor shortest diameter) in mm (O'Sullivan and Alex, 2024). Upon completing sediment data collection and particle size measurement, both the D_{50} and D_{84} were determined for each polygon.

Table 6. Location of Okanagan Sockeye salmon spawning habitats by rearing lake.

Okanagan Sockeye salmon	Location of spawning habitat	Years surveyed
Osoyoos Lake population	Mainstem Okanagan River from Osoyoos Lake to Skaha Lake (Figure 3).	2001; updated 2009, 2021 to account for river restoration

Okanagan Sockeye salmon	Location of spawning habitat	Years surveyed
Skaha Lake population	Mainstem channel between Skaha Lake and Okanagan Lake (Figure 4)	2013-2018
	Shingle Creek	2023
Okanagan Lake population	15 tributaries flowing into Okanagan Lake (Figure 5)	2023

4.7. LAKE FOODWEB

Details of the methods used to collect the biological data are available in Hyatt et al. (2018a, 2017b; 2021b) and McQueen et al., in prep.)[11]. Below is a brief description of the methods used to collect the data used in the bioenergetics analysis conducted for Osoyoos and Skaha lakes.

Phytoplankton, zooplankton, and *Mysis diluviana* were sampled (1, 5, 10 m integrated samples) during May-October at two locations in the northern basin of Osoyoos Lake and at two stations in Skaha Lake. During 2005-13 and 2015, samples were taken at least once per month in Osoyoos Lake. During 2014, 2016 and 2017, samples were taken once every two months. In Skaha Lake, samples were taken between 2005 and 2013 and in 2017. All phytoplankton samples were processed using the Utermöhl technique, and taxa were identified to genus and many to species. Densities, cell sizes, cell shapes, and bio-volumes were recorded.

Zooplankton were sampled every 2-3 weeks along the long axis of the north basin of Osoyoos Lake and the long axis of Skaha Lake, using a vertical haul net (0-30 m night-time hauls, 100 µm mesh, 0.5 m net diameter, net length 3 m, Rigosha flow-metered). All samples were Rigosha flow-metered (McQueen and Yan, 1993) to account for spatial and seasonal variability of water volume moving through the net. At the laboratory, the samples were used to produce one volume-weighted (based on Rigosha data), combined sample for each sampling date. All zooplankton were identified to species, measured, and their eggs counted. *Mysis diluviana* were sampled every 3 to 6 weeks using a vertical haul net (0-30 m night-time hauls, 300 µm mesh, 1.0 m net diameter, net length 3 m, Rigosha metered). Samples in Osoyoos Lake were collected at ten stations along the long axis of the northern basin. Samples were also collected at ten stations in Skaha Lake. Mysid diets were assessed by direct inspection of gut contents of juveniles (2-10 mm length) and adults (11-22 mm) from each sample.

Assessments of fish species composition, densities, ages, biomasses and diets were based on combined data from midwater trawls (Enzenhofer and Hume, 1989) and echosounding (Hyatt et al., 2017b; MacLennan and Simmonds, 1992). Trawl-caught fish were sampled at night, five to seven times per year in each lake between June and March. Fish stomachs were removed from individual fish, and identifiable zooplankton in the stomachs were counted by species or genus. Fish abundance in Osoyoos and Skaha lakes was determined on 5 to 7 dates each year through the use of ATS. Density estimates from echo-integration analysis were used to determine total numbers of fish. These data were further partitioned into species and size or age

[11] McQueen, D.J., Ogden, A.D. and Pham, S. In preparation. Bioenergetics-based estimation of lake-carrying capacity for juvenile Sockeye salmon (*Oncorhynchus nerka*) in Osoyoos Lake, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 3283.

classes within species based on trawl-sample composition combined with acoustics target strength analysis (Hyatt et al., 2017b).

5. SPAWNING CAPACITY ESTIMATES FOR OSOYOOS, SKAHA, AND OKANAGAN LAKE SOCKEYE SALMON POPULATIONS

5.1. METHODS

The spawning capacity of Okanagan Sockeye salmon was determined using the method proposed by Riebe et al. (2014). The method was developed from a mechanistic model of redd building by female salmon. It combines empirical relationships between fish length, redd area, and the sizes of bed particles (gravel and cobbles) moved by fish during spawning to estimate spawning habitat capacity. Model inputs include grain-size indices, namely D_{50} (the median substrate size of all the measured particles in a unit) and D_{84} (the size of substrate that is larger than 84% of all pebbles in a unit), and an estimate of the length of female spawners. The latter is used to predict the size of the redds and to determine the size of the largest particle a female can move on the spawning grounds. A model assumption is that larger fish can move larger river sediments; thus, they are able to use more riverbed area for spawning. The Riebe model assumes that the fractional coverage of the bed by moveable particles equals the fractional area that facilitates spawning. Model outputs include predictions of the fraction of the bed that a fish can use for redd building, which in turn gets translated into the number of redds that can be built within the useable habitat area.

Using the gravel size measurements conducted in the Okanagan River mainstem, upstream of Osoyoos and downstream of Okanagan Lake, O'Sullivan & Alex, (2024) implemented the Riebe et al. (2014) method and estimated the spawning capacity along the Okanagan River mainstem. Their work was then built upon by Alex et al. (2024) to determine the spawning capacities of the Okanagan Lake spawning tributaries and the Okanagan River tributary (Shingle Creek) to add to the existing mainstem estimates. Both O'Sullivan & Alex (2024) and Alex et al. (2024) used the mean Osoyoos Lake Sockeye salmon fish fork length (483 mm) in their calculations. Note that the mean length corresponds to the mean size of Okanagan Sockeye salmon spawners as determined from the dead-pitch (carcass count) data collected in the Osoyoos spawning areas between 2000 and 2016.

Using the collected gravel data and the mean fish length, the two studies estimated the number of redds per m^2 that can be constructed in each of the spawning segments. Multiplying that number by the field-determined spawning area for each of the segments provides an estimate of the total number of females that can spawn per segment. Using site-specific average sex ratios for Osoyoos and Skaha spawning sites, the total number of spawners per segment was then determined. For the Okanagan Sockeye salmon, the yearly sex ratios were based on dead-pitch data (carcass counts) collected between 2000 and 2016 (Hyatt et al., 2017a).

Monte Carlo simulations were conducted to estimate the uncertainties in the mean predicted spawning habitat capacity for each of the three lakes as a function of female spawner fork length. The simulations were intended to account for the natural variability in the female spawner length when estimating spawning areas. Using reported fish lengths from the dead-pitch (carcass count) data collected between 2000 and 2016 in the Osoyoos spawning areas, a fish fork length distribution was defined for the Okanagan Sockeye salmon spawners. The distribution was found to be normally distributed with a mean of 483 mm and a standard deviation of 40 mm. For the simulations, we assumed that fish fork length among the three lakes were the same. For each identified segment/tributary, 10,000 fish lengths were randomly drawn and propagated into the Riebe et al. (2014) model to generate a distribution of the spawning habitat area. The resulting 10,000 model estimates for each segment/tributary were then plotted to determine the shape of their distribution. The data were found to be well described by a lognormal distribution. This was ascertained graphically by generating quantile-to-quantile plots (QQplots). The segment/tributary-based Monte Carlo simulations were then aggregated (summed) to generate lake-wide distributions of spawning habitat that accounted for fish length variability. The QQplots indicated that the lake-wide distributions were also well represented by a lognormal distribution (Figure 8). Note that although the sum of independent uncorrelated log-normal distributions does not have a closed form solution, it can still be reasonably approximated by another log-normal distribution (Fenton, 1960; Lo, 2013). Summary statistics for each of the three lakes as well as the combination of lakes were then generated from the Monte Carlo simulations (Table 8).

These model-estimated spawning capacities did not account for potential competition over spawning sites by the resident Kokanee salmon population in the lakes. Given the relatively small Kokanee salmon population in Osoyoos (< 2% total *O. nerka* abundance), neglecting Kokanee salmon is not expected to impact the estimated Sockeye salmon spawning capacity estimate there. However, Skaha and Okanagan lakes are home to substantial populations of Kokanee salmon, which may compete for some of the same spawning sites as Sockeye salmon. For Skaha Lake, all spawning beds were constructed through the ONA rehabilitation projects, which selected different gravel sizes for each ecotype. Overall, the rehabilitation work provides spawning beds with fine gravel sizes to accommodate up to 8,118 Skaha Lake Kokanee salmon (Karilyn Alex, Fisheries Biologist and Fluvial Geomorphologist, Okanagan Nation Alliance, Westbank, BC, pers. comm.). The total Sockeye salmon spawning capacity estimates reported in Table 7 represent the total available spawning habitat for Skaha Sockeye and Kokanee. Note that Sockeye salmon spawners have been seen to use Kokanee salmon beds during strong return years (Karilyn Alex, pers. comm.). It should be noted that the salmon beds in Penticton channel are expanding marginally each year, due to gravel deposits from Shingle Creek.

For Okanagan Lake, two genetically distinct populations of Kokanee salmon, lake spawners and stream spawners, are found (Rae, 2005). Competition for spawning grounds with Sockeye salmon is likely to impact the latter. For example, Mission Creek supports the largest stream-spawning Kokanee salmon population of any tributary of Okanagan Lake; it also has the largest potential spawning capacity for Sockeye salmon. To quantify potential competition over spawning habitat capacity between the two ecotypes, Alex et al. (2024) used the Reibe et al. (2014) method to estimate the mean spawning area requirements for stream-spawning Okanagan Lake Kokanee salmon. To do that, they used the river-spawning Kokanee salmon's 10-year averaged peak abundance multiplied by 1.5 (Webster, 2007) and a mean female length (267 mm). Their model-based predictions showed that the spawning requirements of the 10-year mean population of river-spawning Kokanee salmon was 8,645 m^2 of the total available spawning habitat across the 15 Okanagan Lake tributaries.

5.2. RESULTS

Osoyoos Lake provides the largest spawning capacity of the three lakes, with a mean total estimated at 108,977 m^2 (Table 7). The Okanagan Lake tributaries had the second largest capacity, estimated at 49,569 m^2. Yet, looking closer at the spatial distribution of the Okanagan Lake spawning tributaries shows that Mission Creek alone accounted for almost three quarters of the total available habitat (Table 7). The mean total spawning capacity of the Skaha Lake Sockeye salmon population was estimated at 35,998, with only a modest contribution to the total capacity from Shingle Creek (2,020 m^2; Table 7). However, in the future, gravel recruitment from Shingle and Ellis creeks may further increase the spawning capacity of the Skaha Lake population, given that over the past 25 years, both creeks contributed gravel, which had the ideal size for Sockeye salmon spawning, to Penticton Channel.

Table 7. Model estimated mean spawning habitat capacity for the Osoyoos, Skaha, and Okanagan lake populations.

a) Osoyoos Lake

Reach	Available spawning area (m^2)	Total Sockeye salmon spawning capacity
Okanagan River; Osoyoos to Vaseux lakes	104,818	107,575
Okanagan River; Vaseux to Skaha lakes	1,368	1,402
Osoyoos Lake population total:	***139,663***	***108,977***

b) Skaha Lake

Reach	Available spawning area (m^2)	Total Sockeye salmon spawning capacity
Okanagan River (Penticton channel): Skaha to Okanagan lakes	33,477	33,954
Shingle Creek	2,020	2,044
Skaha Lake population total:	***35,497***	***35,998***

c) Okanagan Lake

Reach	Available spawning area (m^2)	Total Sockeye salmon spawning capacity
Bear (Lamby)	32	31
Naramata	181	182
Trepanier	229	222
McDougall	239	228
Whitemans	317	314
Nashwito	415	391
Powers	447	439
Mill	500	498
Trout	1,055	921
Deep	1,318	1,293
Equesis	1,597	1,537
Shorts	1,599	1,586
Penticton	2,167	2,024
Lower Vernon	2,775	2,866
Mission	37,374	37,037
Okanagan Lake population total:	***50,243***	***49,569***

Accounting for the mean Kokanee salmon spawning habitat requirements reduced the available area for the Skaha and Okanagan lakes Sockeye salmon by 22% and 17%, respectively (Alex et al., 2024). It is worth noting that the population of stream-spawning Kokanee salmon in Okanagan Lake has historically shown large inter-annual variability (between 90,000 in 2013 and 310,000 in 2022). Therefore, there is a need to continue collecting data on their abundance to better estimate the range of their spawning habitat requirements. Additionally, more information is needed to assess whether the Sockeye salmon, once well-established in Okanagan Lake, will attempt to spawn along the shoreline, thus potentially competing with the shore-spawning ecotype of Kokanee salmon, and representing additional spawning area in the Okanagan Lake population that was not accounted for in our models.

5.3. DISCUSSION

The number of spawners utilizing the Osoyoos and Skaha lakes spawning grounds have exceeded the model-estimated spawner capacity in several years (brood years 2008, 2010, and 2014 for Osoyoos Lake Sockeye salmon; 2014 for Skaha Sockeye salmon), indicating that the model estimates might be conservative or that the population may have exceeded the available spawning habitat capacity in those years, causing potential redd superimposition.

There are ongoing efforts that are part of the Okanagan River Restoration Initiative and other programs to further increase the spawning habitat capacity within the Okanagan River basin, but the potential for adding new habitat varies by rearing lake. For Skaha Lake, spawning bed restoration projects between 2013 and 2018 were able to restore 72% of the estimated area that was available in 1909 (Rivard-Sirois, 2021). Future restoration work aims to add more spawning habitat for the Skaha Lake population spawners. Meanwhile, restoration of spawning beds and salmonid habitat diversity in the 15 tributaries of Okanagan Lake is an ongoing priority for the ONA. Currently, spawning areas have been improved in Trout, Penticton, Mill, and Powers creeks. Further work is planned in the coming years to increase the spawning areas in Mission, Equesis, Lower Vernon, and Trepanier creeks (Figure 5).

Estimates of spawning habitat capacity may be sensitive to model assumptions, such as the assumption that all fish are of mean length, and that fish across the three lakes are well represented by those observed at Osoyoos Lake. Table 8 and Figure 8 show the results of Monte-Carlo simulations, from random sampling of fish lengths. The results indicate that capacity estimates can vary substantially when fish lengths are randomly sampled. This sensitivity analysis tests for only one assumption of the model and shows considerable uncertainty. Thus, the model-estimated spawning capacities for the three lakes should be interpreted with caution, given that they represent habitat that is currently available for Sockeye salmon spawning, and include several assumptions, most of which have not been accounted for in our estimates of uncertainty.

An additional source of uncertainty for the Okanagan Lake Sockeye salmon spawning habitat estimates is that the Reibe model used here accounts only for the gravel available in the tributaries. If, in the future, the Sockeye salmon spawn in the lake along the shoreline, those spawning sites would have to be added to the estimated spawning habitat area. Because of the low number of years in which Sockeye salmon have had access to Okanagan Lake and its tributaries, it is presently unknown whether this population will exhibit the shore-spawning phenotype.

Table 8. Estimated spawning habitat capacity estimates across Osoyoos, Skaha, and Okanagan lakes based on the Monte Carlo simulations that vary fish length.

	Quantiles					
Lakes	**10%**	**25%**	**50%**	**75%**	**90%**	**Mean**
Osoyoos	90,130	97,548	107,080	118,240	130,127	108,977
Skaha	28,305	31,248	35,090	39,747	44,675	35,996
Okanagan	41,126	44,237	48,330	53,183	58,351	49,257
Osoyoos+Skaha	124,436	132,820	143,017	155,293	167,465	144,973
Osoyoos+Skaha+Okanagan	171,607	180,754	192,453	205,588	218,637	194,230

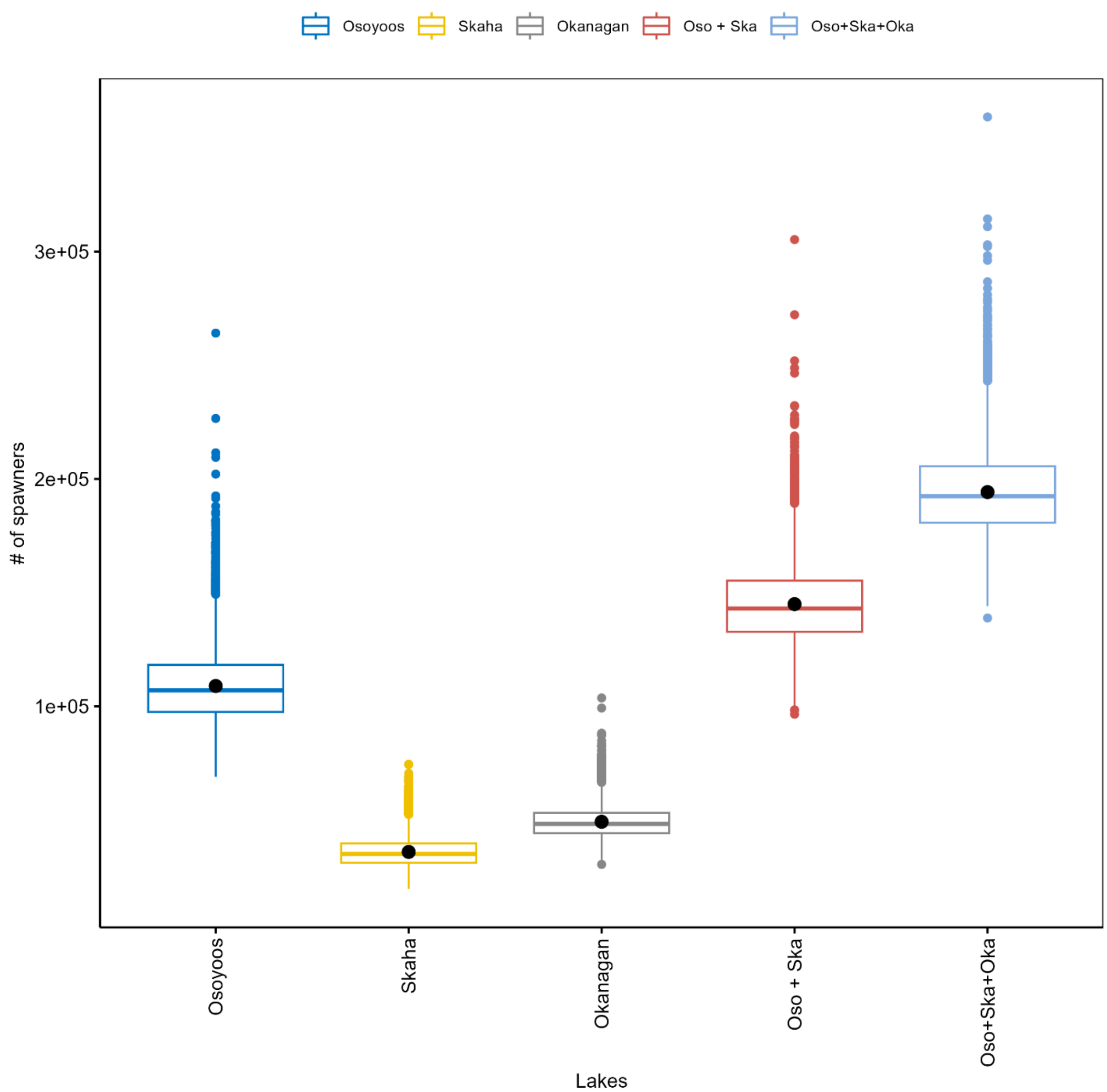

Figure 8. Monte Carlo-based estimates of spawning capacity as a function of nursery lake. Oso + Ska represents the total spawning capacity across Osoyoos and Skaha lakes. Oso + Ska + Oka represents the total spawning capacity across Osoyoos, Skaha, and Okanagan lakes.

6. REARING HABITAT ESTIMATES FOR OSOYOOS AND SKAHA SOCKEYE SALMON POPLUATIONS

6.1. METHODS

A bioenergetics-based (Beauchamp et al., 1989; Hanson et al., 1997) consumption and production analysis (Beauchamp et al., 1989; Hanson et al., 1997) was conducted to estimate lake carrying capacity for age-0 Sockeye salmon rearing in Osoyoos and Skaha lakes. The bioenergetics analysis was based on the Wisconsin Fish Bioenergetics 4.0 shiny application in R (Deslauriers et al., 2017). The Osoyoos Lake bioenergetics analysis presented in this report is based on the study conducted by McQueen et al. (in prep.)[11]. The bioenergetics analysis detailed here for Skaha Lake was based on Hyatt et al. (2021a). For both lakes, the consumption-production method focused directly on the pelagic zone, where age-0 Sockeye salmon live their first year of life. Both the Osoyoos and Skaha lake food webs are complex, comprised of five groups of pelagic predators (age-0 nerkids[12], age-1+ nerkids (Sockeye and Kokanee salmon), age-2+ nerkids (Kokanee salmon), Lake Whitefish, and *Mysis diluviana*) and seven species of zooplankton prey (three copepod species: *Diacyclops thomasi, Leptodiaptomus ashlandi* and *Epischura nevadensis*, and four common cladocerans *Daphnia thorata, Bosmina longirostris, Leptodora kindtii,* and *Diaphanosoma leuchtenbergianum).* Furthermore, there is a trophic triangle in these two lakes, with *Mysis* acting both as predator and prey (Holt and Polis, 1997; Hyatt et al., 2018a).

The data used in both studies were based on annual surveys of lake-specific limnological and ichthyological data (summarized briefly in section 4.7) which were collected between 2005 and 2017 (Hyatt et al., 2017b; Hyatt et al., 2021b) and revised by McQueen et al. (in prep)[11]. Both Osoyoos and Skaha lakes were annually surveyed (3-7 surveys/year). More recent data (post-2017) could not be included in the model due to the unavailability of fish stomach diet data. The bioenergetics-based carrying capacity estimates for Osoyoos and Skaha lakes were calculated for in-lake years 2007-2013, 2015, as well as 2005, 2006 and 2017 for Skaha Lake. The numbers of samples were deemed insufficient for 2014 and 2016 and thus were excluded.

The densities, biomasses, age-specific growth, production, and survival of mysids and all pelagic fish were recorded and used to quantify changes in the populations of the limnetic predators. The stomach contents of the pelagic predators were examined to estimate average zooplankton species-specific diets. Model inputs also included mysid density, diet, mean weight at age, the fish densities across all size classes, fish diet, and the daily water temperatures at depths occupied by the highest percentage of fish. Energy density for mysids was fixed at 3,400 joules/g wet weight, energy densities for zooplankton as prey were set at 2,500 and 3,000 joules/g wet weight for cladocerans and copepods respectively. Mean annual (May or June to October, when most of the production occurs) rates of species-specific zooplankton production were principally calculated using the egg-ratio method (Borgmann et al., 1984; Cooley et al., 1986; Paloheimo, 1974) from quantitative taxonomic counts of zooplankton species and their eggs (loose and attached). Given that *Epischura nevadensis* broadcast their eggs, their production was estimated using both the increment summation method, which sums the growth increments in biomass during a cohort's lifespan (Cusson et al., 2006), and the size-frequency method, which sums the loss of biomass between successive size classes and weights them by

[12] In this document, the term "nerkid" is used to refer to Kokanee salmon, Sockeye salmon, or both together.

the number of days between surveys. The results of those two methods were averaged to generate estimates.

When zooplankton consumption by fish and mysids exceeds zooplankton production, density-dependent suppression of juvenile nerkid production can be assumed. Moreover, observing nerkids changing their feeding habits may also indicate that the lake is reaching its carrying capacity (Don McQueen, Professor Emeritus, York University, pers. comm.). Changes in feeding habits occur when production from the preferred prey fall below nerkid consumption even though the ratio of predator consumption to prey production remains at or below 50% McQueen et al. (in prep)[11]. Detailed methods and results for the bioenergetics components are provided in Hyatt et al. (2018a, 2017b; 2021b) and McQueen et al. (in prep)[11].

6.2. RESULTS

6.2.1. Osoyoos Lake: bioenergetics results

From 2006-2017, McQueen et al. (in prep)[11] compared the average rates of consumption of–by fish and *Mysis*–each species of zooplankton prey (including *Mysis*), to the average rates of production by each of the prey species. During this period, notable changes in the rates of discharge from the Okanagan River into Osoyoos Lake were observed. These changes affected the mean annual patterns of several limnological parameters, including total chlorophyll (linear regression model between chlorophyll and flow had an R^2=0.33, p=0.04, n=13), and the biomasses of both phytoplankton (linear regression model between phytoplankton biomass and flow had an R^2=0.41, p<0.02, n=13) and zooplankton (linear regression model had an R^2=0.54, p<0.01, n=13) (McQueen et al., in prep)[11]. During that period, there was also a significant bottom-up relationship between phytoplankton and zooplankton biomass (R^2=0.71, p<0.01, n=13). Yearly average (mid-June to end-October) rates of consumption by all pelagic fish were strongly correlated with total fish density (R^2=0.79, p<0.001, n=10) and less correlated with age-0 nerkid density (R^2=0.74, p=0.006, n=10). This reflects the importance of considering age-1 and age-2+ nerkids when analyzing the bioenergetics of Osoyoos Lake. Given the average densities of each age group during the study years (age-0 = 3,763 ha^{-1}, age-1 = 864 ha^{-1}, and age-2+ = 176 ha^{-1}), it was estimated that each age-1 nerkid consumed about three times as much food as each age-0 nerkid, and each age-2+ nerkid consumed twelve times as much food as each age-0 nerkid. Age-0 Sockeye salmon on average were found to consume only 18% (range 6% to 38%) of the prey biomass, and their growth success depended on rates of consumption by more powerful competitors, and also upon the availability of their preferred prey, especially *Daphnia* (average biomass 9 µg L^{-1} range 3-23 µg L^{-1}) and *Epischura* (average biomass 4 µg L^{-1} range 1-8 µg L^{-1}). Both of these species have decreased in abundance since river flow rates increased after 2010.

The bioenergetics-based consumption and production analyses showed that in Osoyoos Lake, consumption never exceeded 50% of total prey production over the study period. One may be tempted therefore to conclude that the lake never reached its rearing capacity. Yet in 2015 (brood year 2014), consumption reached 50% of production, and that resulted in lower-than-average age-0 Sockeye salmon survival (2.6% versus the long-term average of 2.8%) and growth (2.7 g by mid-November versus the long-term average of 3.8 g). A closer look at the data from that year showed that age-0 Sockeye salmon's consumption exceeded the production of their usual prey (i.e., *Diacyclops*, *Daphnia*, *Mysis*, and *Epischura*). Furthermore, age-0 Sockeye salmon had to expand their diet that year and consume prey not usually consumed by them, such as *Leptodiaptomus*. The decrease in survival was not substantial, but taken together, these latter considerations suggested that the lake reached or approached its rearing capacity that year. That capacity was determined to be ~5,900 age-0 nerkids/ha (5.5 million in total).

That translates to around 131,619[13] (95% confidence interval 111,386 – 151,852) adult spawners based on the long-term relationship between spawners and the densities of age-0 Sockeye salmon in Osoyoos Lake (Figure 9). Nevertheless, the bioenergetics model results showed that in certain years, the lake was able to support densities of Sockeye salmon presmolts higher than the estimate for 2015, without negative impacts on growth and survival. For example, the density of age-0 Sockeye salmon in 2009 was estimated at 8,040/hectare, without any signs of reduced growth or survival. That year, the zooplankton biomass was high and the percent of consumption to production reached only 38% (McQueen et al. , in prep)[11]. This indicates that the lake capacity is expected to vary inter-annually and will depend on zooplankton production, which in turn appears to be affected by changes to lake inflows.

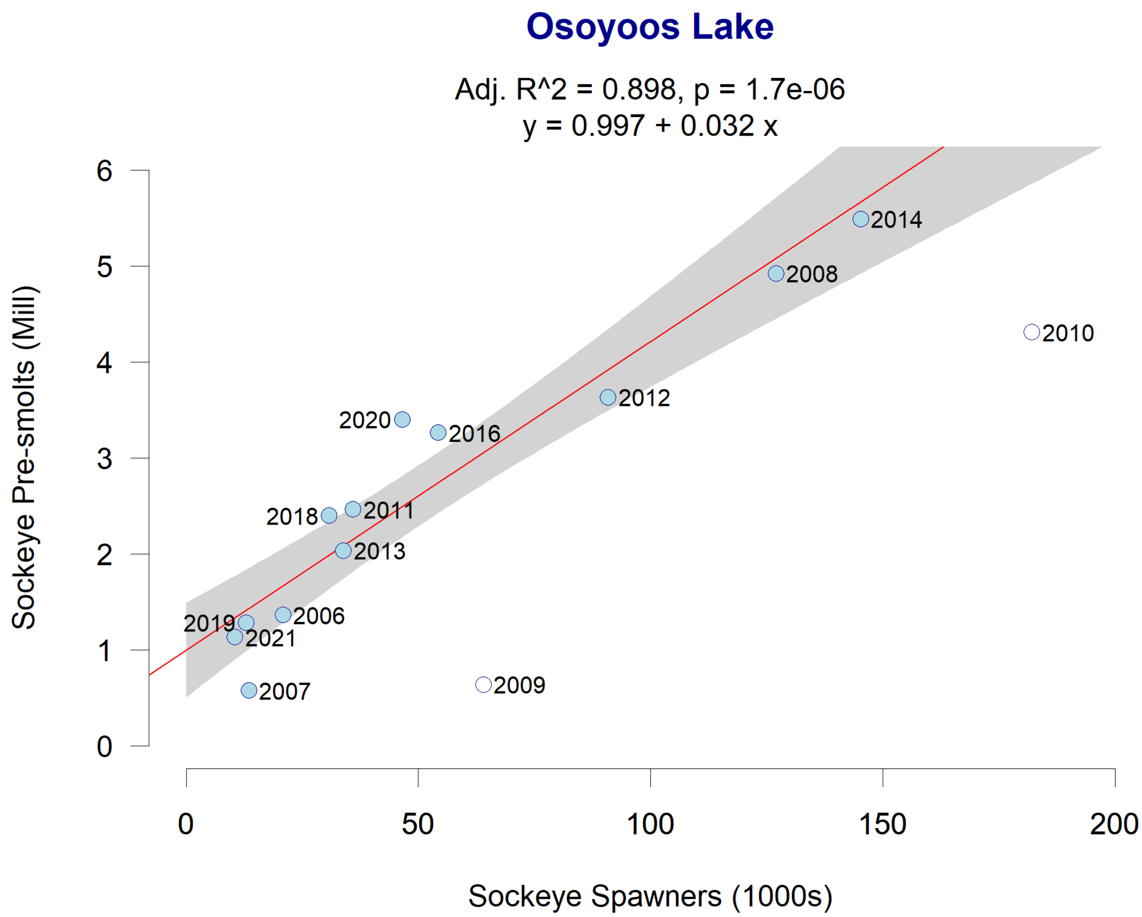

Figure 9. Relationship between Osoyoos Sockeye salmon presmolts and spawner abundance (estimated by AUC). Years 2009 and 2010 (open circles) were excluded from the regression model because data from both years were affected by the failure of the Testalinden dam (refer to Section 3.2.1). Labels show brood years.

[13] Spawners were estimated based on regressing spawner abundance against presmolt abundance. The regression equation excluded brood years 2009 and 2010 that were affected by the Testalinden Dam failure. The regression equation Spawners (x1000) = -23.3 + 28.8*(Presmolts (x10^6)) had an R^2 of 0.90. The confidence interval does not include uncertainty around the AUC-estimated spawner abundance.

6.2.2. Skaha Lake: bioenergetics results

For Skaha Lake, no statistically significant density-dependent relationship was found between rates of consumption and growth rates among age-0 nerkids. The bioenergetic analysis suggested that the rates of juvenile nerkid growth and abundance were largely independent of fish or mysid density. Additionally, winter weights for age-0 nerkids were found to be statistically unrelated to May-October zooplankton biomass estimates. Overall, the results showed that the upper sustainable capacity of planktivores in Skaha Lake was rarely observed. However, observations from 2017 (brood year 2016) offered some insights on the potential role of density-dependent effects, given that 2017 had the highest recorded biomass of *Mysis*, the highest recorded consumption rates for nerkids and *Mysis*, and the lowest zooplankton production and biomass, which may have been a result of high overwinter flows. Accordingly, juvenile nerkids had the lowest recorded growth rate that year, possibly as a result of the Skaha Lake ecosystem reaching its maximum sustainable limit for zooplankton exploitation by nerkids and mysids. That year the number of age-0 nerkids in the lake was around 600,000, or approximately 300 per hectare. However, decreased survival was not detected.

However, in that year, lake capacity may have been reached. Based on the relationship between the number of spawners and the density of age-0 Sockeye salmon in Skaha Lake, we determined that the number of adult spawners that year (brood year 2016) was 30,391[14] (95% confidence interval 19,735 – 41,047) (Figure 10). Nevertheless, these conclusions must be treated with caution, given the short span of the study period. It also appears that if the lake is going to reach its rearing capacity, that condition would most likely be triggered when the zooplankton densities are anomalously low. Zooplankton abundance exhibited marked interannual variation, largely associated with lake flushing events. Also, the density of large Kokanee salmon (age 2-3) is expected to play a role in determining capacity, as they are an important predator in Skaha Lake. Therefore, the upper sustainable capacity of planktivores in Skaha Lake is likely variable and will simultaneously depend on spring flows, zooplankton abundances, and the biomasses of all planktivorous fishes and mysids (Hyatt et al., 2021b). Therefore, the carrying capacity of the lake is expected to vary and, in most years, it will be able to sustain a higher density than what was observed for in-lake year 2017.

Note that although the years of the Skaha bioenergetics study were 2005-2017, and many of the classes and ages of nerkid were available in all of those years, the only years in the time series (2005-2023) with sufficient data to estimate natural-origin age-0 Sockeye salmon presmolts for the regression shown in Figure 10 were brood years 2012-14, 2016, and 2018, because Skaha Lake adults were not able to access the spawning grounds until 2011 (although the Sockeye salmon escapement number from 2011 was not used because it was very uncertain due to insufficient sampling).

[14] Spawners were estimated based on regressing spawner abundance against presmolt abundance. The regression equation Spawners (x1000) = 4.15 + 43.73*(Presmolts ($x10^6$)) had an R^2 of 0.86.

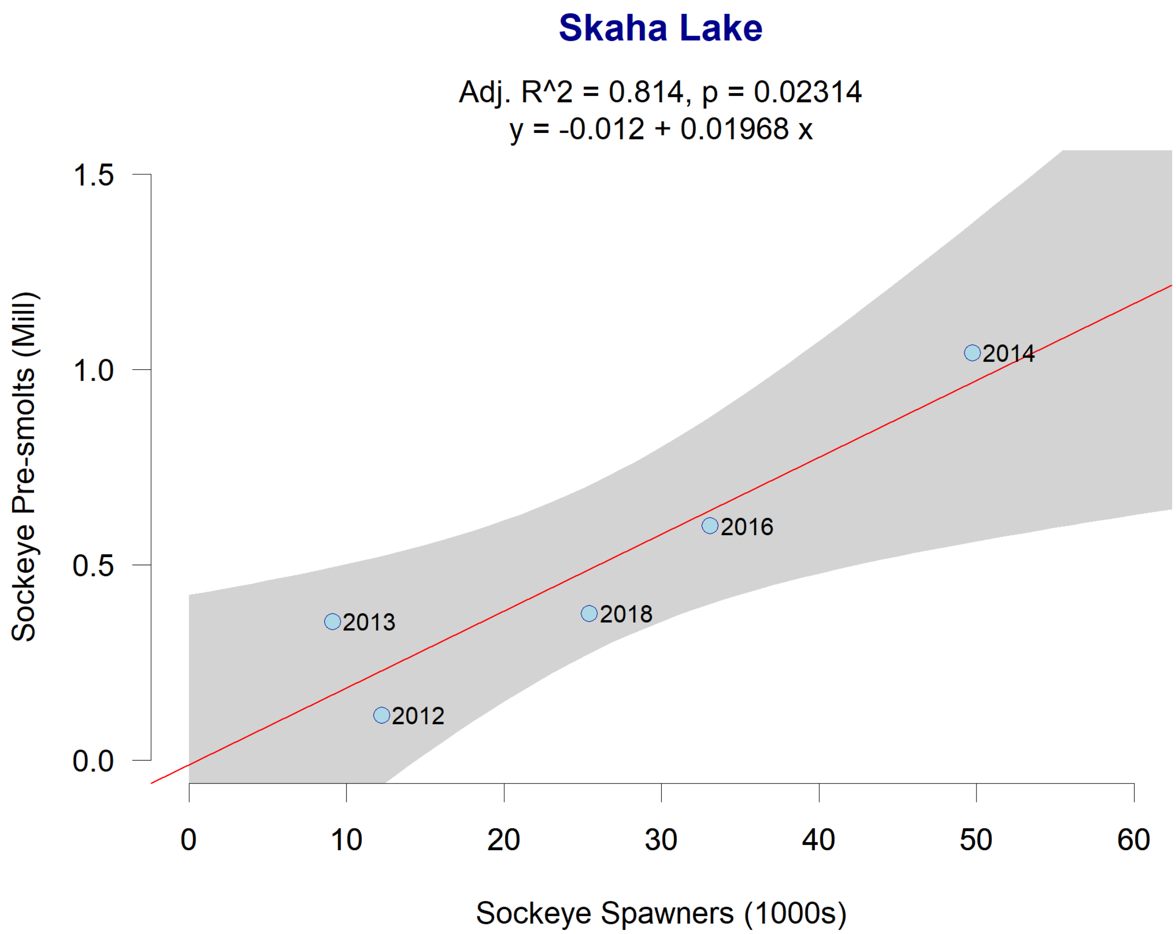

Figure 10. Skaha natural-origin presmolts (averaged over October through March) as a function of spawners abundance (estimated by AUC). Labels show brood years.

6.3. DISCUSSION

Based on the bioenergetic assessments conducted for Osoyoos and Skaha lakes, the mean total number of spawning Sockeye salmon that can be supported by both lakes was estimated at 162,010. The bioenergetics-based estimates are therefore close to those based on the spawning habitat capacity model. In Okanagan Lake, no bioenergetics studies have been conducted; nor are they planned in the near future, largely owing to the large size of the lake. Yet given its size, the lake's rearing habitat is not expected to be limiting. The initial conclusions made by Hyatt et al. (2018c) indicated that the impact of Sockeye salmon fry introductions on Okanagan Lake were unlikely to induce detectable changes to the pelagic food webs (i.e. phytoplankton and zooplankton) or to all ages and size classes of pelagic fish. They concluded that reintroductions of up to 3.5 million Sockeye salmon fry to Okanagan Lake would lead to an incremental addition of a maximum of 5% to the all-year mean of pelagic fish biomass there. With an increase of that magnitude, they concluded that it was unlikely that the proposed range of hatchery-origin Sockeye salmon fry reintroductions to Okanagan Lake would exert a detectable influence on that lake's food web or its other pelagic fish.

6.4. UNCERTAINTIES AND LIMITATIONS

A main limitation of the bioenergetics-based rearing capacity estimates was the short period (9 years) over which data were available. For each of the two lakes, rearing capacity was inferred based on unusual conditions that occurred in specific years (2015 for Osoyoos and 2017 for Skaha). Those conditions were unique and cannot be assumed to hold for all years. In fact, both lakes were able to sustain larger age-0 fry densities than those linked to the rearing capacities that were identified here. Moreover, there is a probability that future years may hold other sets of unusual conditions that have not been observed yet, but that may limit the rearing capacities of either lake. Given the complexity of the food web in both lakes and the associated number of model parameters, it is challenging to implement a meaningful local sensitivity analysis on the mechanistic bioenergetics model. Rather, a scenario-based sensitivity analysis may prove more informative (Hartman and Kitchell, 2008). However, this is beyond the scope of the current study.

7. SPAWNER-RECRUITMENT MODELS FOR OSOYOOS LAKE SOCKEYE SALMON

7.1. METHODS

7.1.1. Data

Given the short timeseries of spawners and recruits for Skaha and Okanagan Lake, spawner-recruit (SR) models could not be developed for these two populations. Thus, SR model development was restricted to the Osoyoos Lake population. For that population, both spawner to adult recruits and spawner to smolt models were developed.

7.1.1.1. Spawner abundance for the Osoyoos Lake population

For this analysis, we defined the spawner abundance of the Osoyoos Lake population as the number of fish spawning naturally between Osoyoos Lake and the Skaha Lake Outlet dam. These abundances excluded fish taken for hatchery brood stock but included hatchery-origin fish spawning in the wild, which typically contributed less than 5% to the natural spawner abundance for the Osoyoos Lake population (these were strays from Skaha or Okanagan Lake hatchery releases). This approach is consistent with other recent work on escapement goals under the Pacific Salmon Treaty (e.g., Miller et al., 2024). Note, however, that for status assessments of Sockeye salmon conservation units under the Wild Salmon Policy, hatchery-origin spawners are typically excluded from the time series (Grant et al., 2020, 2011; Grant and Pestal, 2013; Holt et al., 2009; Holt and Ogden, 2013). Since the goals of this work were to inform both biological benchmarks for WSP status determination, as well as the identification of candidate reference points, we opted to include hatchery-origin fish spawning in the wild, given that their contribution is small for the Osoyoos Lake population (refer to section 4.4).

7.1.1.2. Adult returns and recruitment for the Osoyoos Lake population

We defined adult returns as the number of Osoyoos Sockeye salmon returning to the mouth of the Columbia River in a given return year, based on the estimated proportion of Osoyoos-bound fish in the total Sockeye salmon count at Bonneville Dam on the lower Columbia River. Recruits are estimated as the number of returns from a given brood year, based on annual age proportion estimates from carcasses on the spawning grounds. The dominant age class of returning adults was four-year-olds. Age six contribution was negligible, but there was a substantial contribution of age-3 and age-5 fish, especially in some of the earlier years. Therefore, we used three age classes (age-three, age-four, and age-five+, which pools age-five and age-six returns).

7.1.1.3. Smolt abundance for the Osoyoos Lake population

We used the presmolt estimates as a proxy for smolts in the Osoyoos SR analyses. These are the estimated average number of juveniles present over winter (presmolt numbers over the October to mid-March ATS surveys as per section 4.5; Hyatt et al., 2017b). These include juveniles that migrate following their first rearing year as well as those that stay one additional year. ATS abundance estimates were available starting with the 1996 brood year.

7.1.1.4. Data used for modeling spawner-recruit dynamics of the Osoyoos Lake population

Abundance estimation methods, water management, and data quality all changed in the early 2000s (refer to Section 4). At the same time, there was a clear upward shift in spawner abundance. Hyatt and Stockwell (2019) discussed multiple potential reasons for the increase, but changes in assessment and estimation methods may also have played a role. We therefore grouped the data into three time periods for analysis: early brood years from 1961 to 2003, transition brood years from 2004 to 2007, and recent brood years starting in 2008. Refer to Table 1 for a summary of the data considerations associated with the SR analysis. Years 2004 until the present comprise the $tmix^w$-centred period of the timeseries (see Section 2).

Exploratory SR model fits using simple maximum likelihood estimation regression and a Shiny app for Bayesian SR fits (Hamazaki, 2023) showed that estimated Ricker parameters and resulting estimates of biological benchmarks for Osoyoos Lake Sockeye salmon were highly sensitive to the alternative subsets of the data used for model fitting, specifically whether to include or exclude the early period and/or the 2009 and 2010 brood years that were affected by the Testalinden Dam breach. Given the large observed effect of these data points, which we consider to be either lower quality (early brood years) or extreme events (2009, 2010), we excluded them from the model fits presented in this paper. Table 9 lists the data used for SR model fitting after applying these data quality considerations. Figures 11 to 14 show the included and excluded data.

Table 9. Data used for SR model fits. For each brood year, the number of fish spawning in the natural habitat (Spawners), total number of presmolts from that brood year, total number of adult recruits (Recruits), and the raw productivity per spawner are reported.

Brood year	Spawners	(Pre)Smolts[1]	(Pre)Smolts per spawner (SpS)	Adult recruits	Recruits per spawner (RpS)
2004	41,791	n/a	n/a	186,487	4.5
2005	31,260	n/a	n/a	150,306	4.8
2006	20,819	1,672,558	80	319,954	15.4
2007	13,490	2,649,254	196	130,678	9.7
2008	126,972	5,070,106	40	431,826	3.4
2009	64,024	n/a	n/a	n/a	n/a
2010	182,122	n/a	n/a	n/a	n/a
2011	35,900	3,561,897	99	205,175	5.7
2012	90,862	4,215,855	46	161,274	1.8
2013	33,820	3,598,270	106	13,954	0.4
2014	145,206	n/a	n/a	88,101	0.6
2015	10,255	n/a	n/a	20,776	2.0
2016	54,281	n/a	n/a	192,560	3.5

Brood year	Spawners	(Pre)Smolts[1]	(Pre)Smolts per spawner (SpS)	Adult recruits	Recruits per spawner (RpS)
2017	9,893	n/a	n/a	98,641	10.0
2018	30,755	2,516,301	82	379,391	12.3
2019	12,913	1,499,289	116	n/a	n/a
2020	46,510	3,461,896	74	n/a	n/a

[1] Presmolts include juveniles that migrate after one or two freshwater years

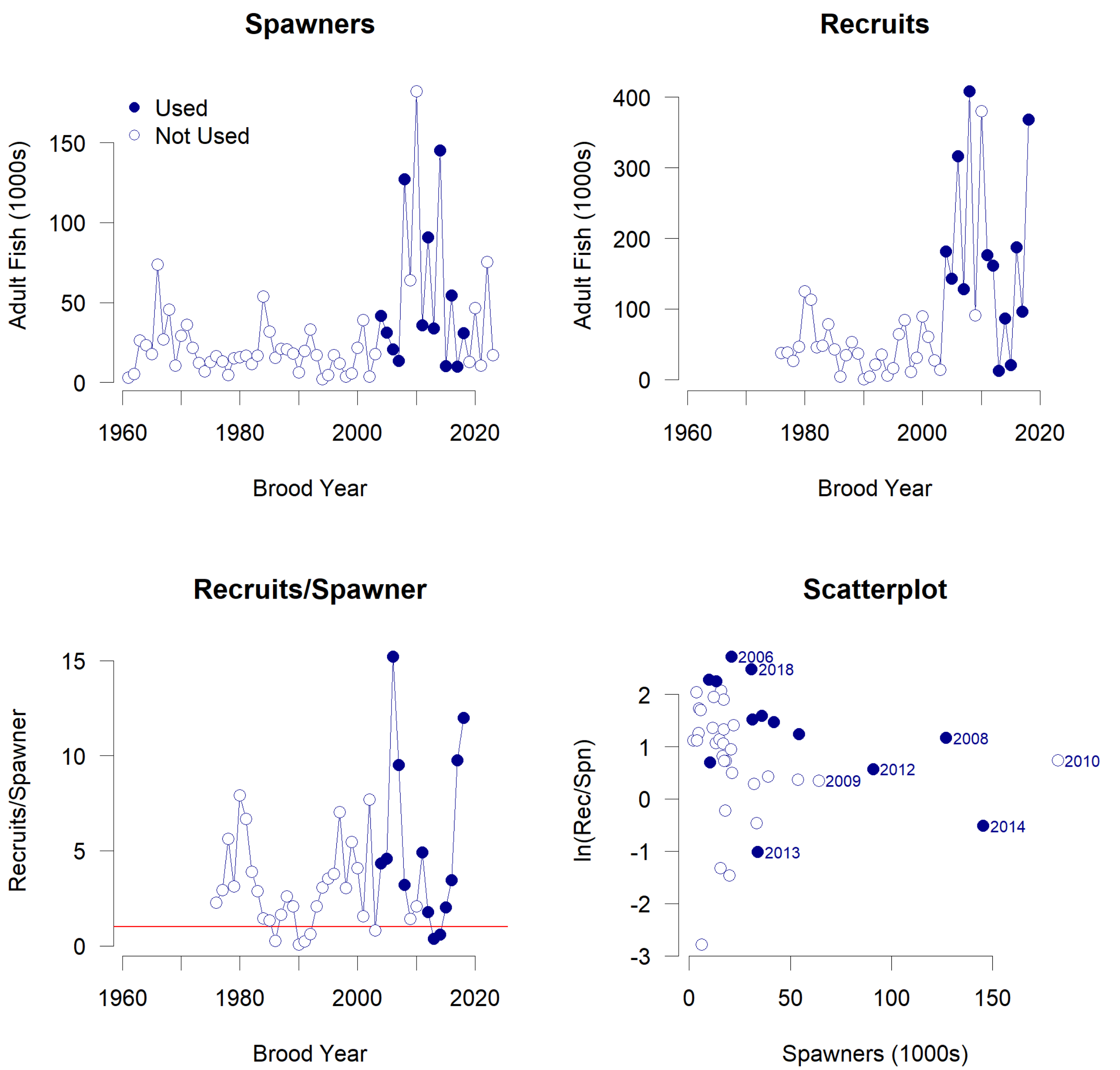

Figure 11. Available estimates of spawners, adult recruits, and recruits/spawner by brood year for Osoyoos Lake Sockeye salmon. Open circles represent data that were excluded. Solid circles represent data that were included in the SR analysis.

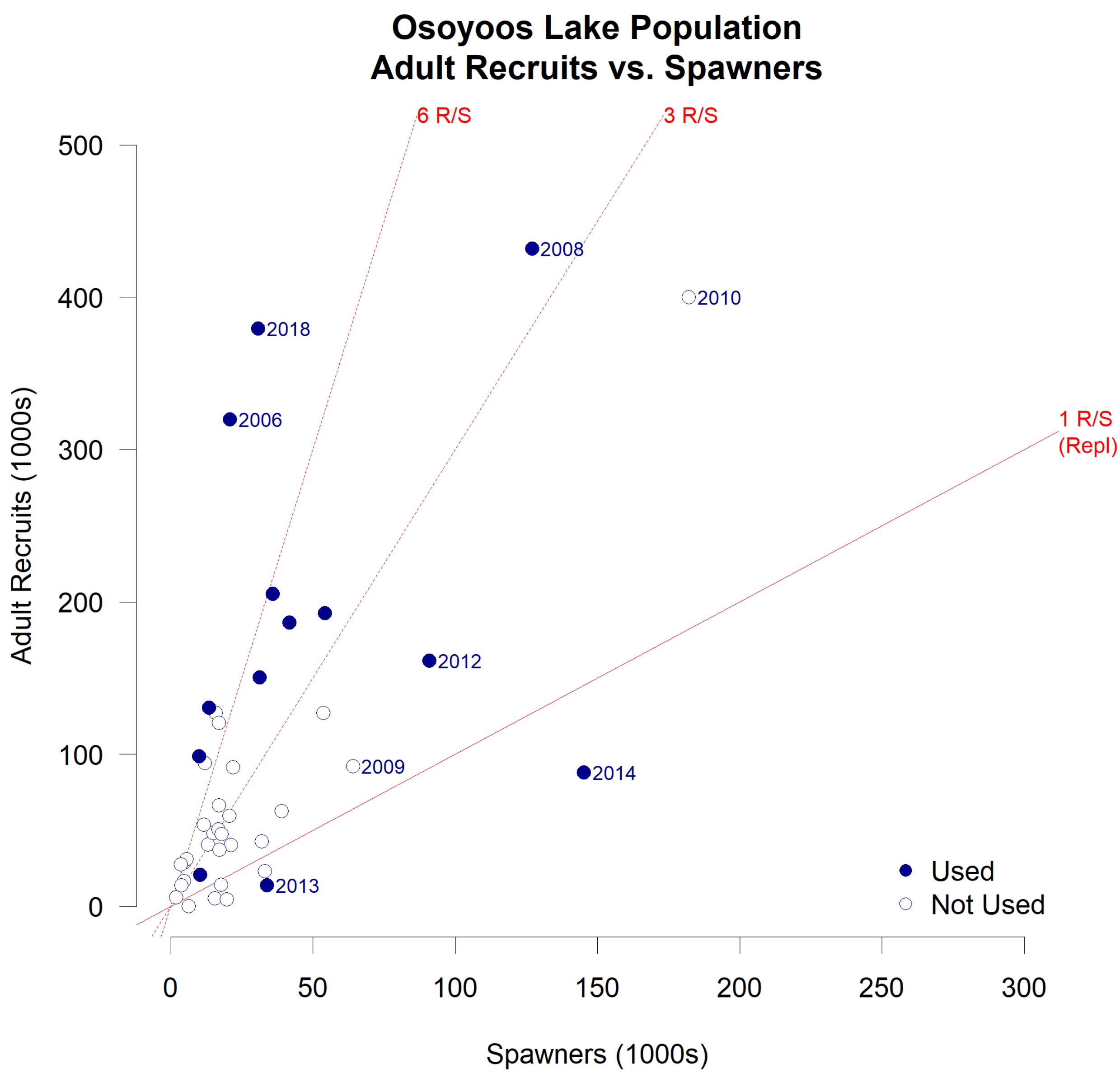

Figure 12. Scatterplot of adult recruits vs. spawners for Osoyoos Lake Sockeye salmon. Red reference lines mark one, three, and six recruits-per-spawner (R/S). At one R/S the number of recruits equals the number of spawners (i.e., the replacement line). Open circles represent data that were excluded. Solid circles represent data that were included in the SR analysis.

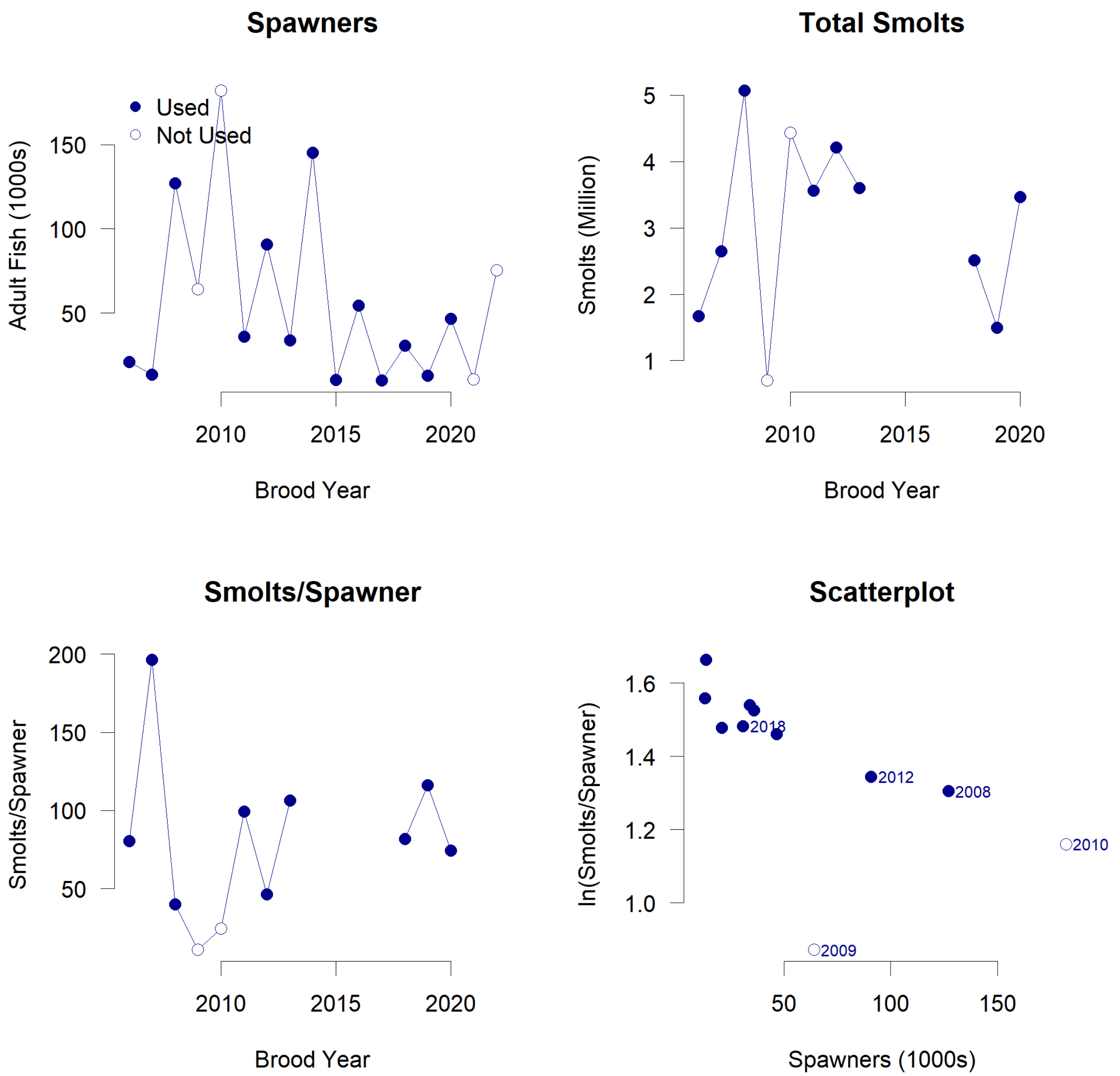

Figure 13. Available estimates of spawners, smolts, and smolts/spawner by brood year for the Osoyoos Lake population. Here presmolts were used as a proxy for smolts. Open circles represent data that were excluded. Solid circles represent data that were included in the SR analysis.

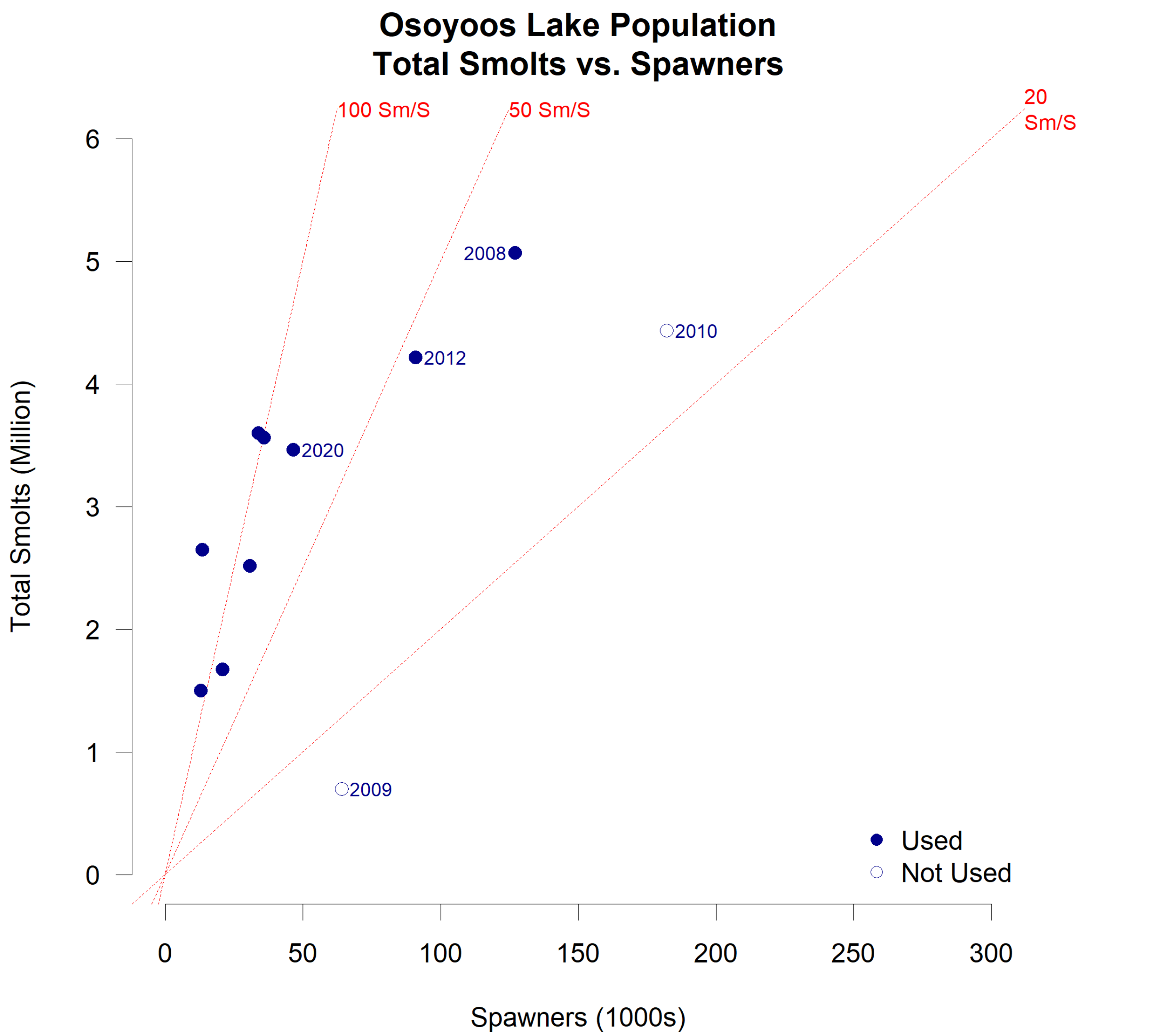

Figure 14. Scatterplot of smolts vs. spawners for Osoyoos Lake Sockeye salmon. Red reference lines mark 20, 50, and 100 smolts-per-spawner (Sm/S). Open circles represent data that were excluded. Solid circles represent data that were included in the SR analysis.

7.1.2. Bayesian Ricker SR models for the Osoyoos Lake population

The common approach for representing production dynamics of Sockeye salmon is the Ricker model. The Ricker model reflects overcompensation at larger spawner abundances due to density dependence, such that the total number of recruits is reduced when spawner abundance exceeds capacity (e.g., Myers, 2001). Mathematically, this density dependence results in a dome-shaped relationship between recruits and spawners. Productivity, expressed as log-adults-per-spawner, or log-smolts-per-spawner, decreases linearly as the abundance of spawners increases. For this population, we did not see a clear pattern of density-dependent reduction in total adult recruitment at the high end of observed spawner abundances, but rather a very noisy relationship (Figure 11).

With no obvious signal guiding us towards a specific spawner-recruitment relationship, we opted to use the Ricker model, as it has become the standard for most Sockeye salmon assessments (Atlas et al., 2021; Bocking et al., 2002; Cox-Rogers et al., 2010; Freshwater et al., 2020; Hawkshaw, 2018; Holt and Michielsens, 2020; Huang et al., 2021; Korman and English, 2013; DFO, 2023b; Peterman et al., 2003, 2000; Walters et al., 2008). Ricker model forms that explicitly account for time-varying dynamics were not applied here due to the short time series and the 2009/2010 gap in the time series. As the consistent SR time series becomes longer, this could be an area of future research.

We use a linearized version of the basic Ricker model, which assumes that residuals in log-recruits-per-spawner (or log-smolts-per-spawner) have a random normal distribution with mean 0 and variance σ^2, without any pattern in the deviations over time. For brood year *i*:

$\ln(R_i/S_i) = \ln(\alpha) - \beta * S_i + \epsilon_i$ (Equation 3)

$\epsilon_i \sim N(0, \sigma^2)$

where R_i represents adult recruits (or smolts) from brood year i, and S_i represents spawners in year i, α is the productivity parameter, β is the density-dependent parameter, and ϵ_i is the residual error (i.e., the difference between the fitted value and observed value). Standard biological benchmarks can be estimated from the Ricker model parameters (Table 10).

We implemented Bayesian estimation of the basic Ricker model using the January 2024 version of the *samEst* package (Wor et al., 2024), with some modifications to allow custom capacity priors and tracking of prior samples. Note that in *samEst*, the capacity prior is specified as a normal distribution on ln(β). To simplify interpretation, we used the corresponding values of the number of spawners that produced the maximum number of recruits $S_{max} = 1/\beta$ when discussing alternative priors. Table 11 lists the alternative prior forms.

Exploratory SR model fits using a shiny app for Bayesian SR fits (Hamazaki, 2023) showed that parameter estimates and resulting estimates of biological benchmarks were highly sensitive to prior assumptions on the capacity parameter. We therefore focused the sensitivity testing of the SR model fits on the effect of different informative normal distributions for ln(β), parameterized using the capacity parameter, S_{max}. We tested three different mean S_{max} values and three different spreads, resulting in nine alternative capacity priors (Table 12). These were tested for both the spawner-adult recruits and spawner-smolt data sets, giving a total of 18 alternative model fits. For all alternative model fits, we used the *Stan* version (Stan Development Team, 2024) of the estimation functions provided in *samEst* for Markov chain Monte Carlo sampling, with six chains with 300 warm-up and 1,000 samples, for a total posterior sample size of 6,000. Conversion was confirmed by checking the Gelman-Rubin diagnostics and effective sample sizes. The *Stan* code used is presented in APPENDIX B.

Table 10. Definition of biological benchmarks for the basic Ricker model.

Benchmark	**Definition**	**Calculation**
S_{max}	Spawner abundance that maximizes median recruits.	$S_{max} = 1/\beta$ (Hilborn and Walters, 1992)
S_{eq}	Long-term equilibrium spawner abundance in the absence of harvest.	$S_{eq} = \ln(\alpha)/\beta$ (Hilborn and Walters, 1992)
S_{MSY}	Spawner abundance that maximizes median sustainable yield (Rec-Spn), if	$S_{MSY} = \frac{1 - lambertW0\left(e^{1-\ln(\alpha)}\right)}{\beta}$

Benchmark	Definition	Calculation
	managed to a fixed escapement target under equilibrium conditions.	(Scheuerell, 2016)
U_{MSY}	Harvest mortality rate at median MSY.	$U_{MSY} = \beta * S_{MSY}$
80% S_{MSY}	Used as the upper benchmark for the relative abundance metric in WSP status assessments. If generational average spawner abundance falls above 80% S_{MSY}, the CU is designated as Green status on this metric.	Benchmark defined by Holt at al., (2009).
S_{gen}	Spawner abundance with a high probability of rebuilding to S_{MSY} in one generation in the absence of harvest. Used as the lower benchmark for the relative abundance metric in WSP status assessments. If generational average spawner abundance falls below S_{gen}, the CU is designated as Red status on this metric.	Benchmark defined by Holt at al. (2009). Calculated by optimization, using code from Connors *et al.* (2023).
40% S_{max}	Used as an approximation for 80% S_{MSY} when direct estimate is not available.	Approximation used in previous status assessments (Grant et al., 2020, p. 202, 2011; Grant and Pestal, 2013).
20% S_{max}	Used as an approximation for S_{gen} when direct estimate is not available.	Approximation used in previous status assessments (Grant et al., 2020, p. 202, 2011; Grant and Pestal, 2013).

Table 11. Prior distributions used for the Stan *implementation of the basic Ricker model in the samEst package.*

Parameter	Prior	Notes
Productivity: α	ln(α) ~ N(1.5,2.5)	Same for all model fits, very wide prior
Capacity: β	ln(β) ~ N(μlnb, σlnb)	μlnb = ln(1/Smax) σlnb = user specified Table 12 lists tested values.
SD: σ	σ ~ N(0,1); [0,+∞]	Using upper half of standard normal distribution. Same for all model fits, very wide prior.

Table 12. Alternative capacity priors used for sensitivity testing. The label column has two components, describing the value used as the mean value for S_{max} and the standard deviation adopted for the normal distribution of ln(β). For example, the values in the first row describe a prior where ln(β) is normally distributed with a mean of ln(1/107,080) and a CV of 0.2.

Label	Smax prior mean Value	CV of ln(β)	Description
HabEst_Narrow	107,080	0.20	Narrow, centred on median estimate from spawning habitat capacity model (Table 8)
HabEst_Wide	107,080	0.50	Wide, centred on median estimate from spawning habitat capacity model (Table 8)

Label	Smax prior mean Value	CV of ln(β)	Description
HabEst_VeryWide	107,080	0.85	Very wide, centred on median estimate from spawning habitat capacity model (Table 8)
MaxObs1_Narrow	182,122	0.20	Narrow, centred on largest observed spawner abundance
MaxObs1_Wide	182,122	0.50	Wide, centred on largest observed spawner abundance
MaxObs1_VeryWide	182,122	0.85	Very wide, centred on largest observed spawner abundance
MaxObs3_Narrow	546,366	0.20	Narrow, centred on 3 * largest observed spawner abundance
MaxObs3_Wide	546,366	0.50	Wide, centred on 3 * largest observed spawner abundance
MaxObs3_VeryWide	546,366	0.85	Very wide, centred on 3 * largest observed spawner abundance

7.2. RESULTS

Basic Ricker model fits converged for both the spawner to adult and spawner to smolt models for all the alternative capacity priors listed in Table 12, with the Gelman-Rubin convergence statistic (R_{hat}) falling within 0.99 and 1.01 for all tracked variables. For the same burn-in, number of chains, and retained sample size, the effective sample sizes varied depending on the capacity prior and model version, with several notable patterns:

1. wider capacity priors resulted in lower effective sample sizes,
2. spawner-smolt fits had lower effective sample sizes than spawner-adult fits,
3. the lowest effective sample size across the tracked variables dropped close to 1,000 for the very wide priors (SD for normal prior distribution of ln(β) = 0.85).

The standardized interquartile range, which captures the width of posterior distributions, increased with wider capacity priors and was generally larger for spawner to adult model fits than for spawner to smolt model fits.

Spawner-adult and spawner-smolt data both contained enough information to move the median S_{max} estimates away from the prior assumption of a large S_{max} (Figure 15). Neither type of data provided a clear signal for estimating the capacity parameter. The fitting challenge for the spawner-adult models was due to the very different number of recruits for brood years with larger spawner abundances; no single fitted curve could reconcile those different observations (Figure 16). The fitting challenge for the spawner-smolt models was very different. The Ricker fit was able to match the observed values very closely over the observed range of spawner abundances, but over that range, more spawners resulted in more smolts, and the curve bent down only because the Ricker curve imposed that shape (Figure 17).

Wider priors resulted in wider posteriors, indicating that the short data sets did not contain enough information to rule out values on the long upper tail of a wide prior distribution (Figure 18 and Figure 19). Therefore, estimates of biological benchmarks were highly sensitive to the mid-point and spread used in the capacity priors (Figure 20 and Figure 21).

Across nine alternative capacity prior specifications, the median posterior estimate of S_{max} for the Osoyoos Lake population ranged from 99,000 to 537,000 for spawner-adult Ricker fits and from 99,000 to 522,000 for spawner-smolt Ricker fits (Figure 18). In comparison, the spawning habitat capacity model for Osoyoos Lake resulted in an estimated S_{max} value of 107,000. The median posterior estimate of S_{msy} for the Osoyoos Lake population ranged from 66,000 to 300,000 for the spawner-adult Ricker fits (Figure 19). These values would result in 80% S_{MSY} values ranging from 53,000 to 240,000 (Figure 20). Where available, 80% S_{MSY} is typically used as the upper benchmark for the WSP status metric of relative abundance (Holt et al. 2009). In comparison, the upper benchmark based on 40% S_{max} estimated for Osoyoos lake based on the spawning habitat capacity, is 43,000 – lower than what is estimated based on the SR analysis (Figure 20). Estimates of S_{gen}, the number of spawners required to reach S_{msy} in one generation, in the absence of fishing, which is typically used as the lower benchmark for the relative abundance metric, ranged from 12,000 to 86,000 across prior specifications (Figure 21). In comparison, the lower benchmark, based on 20% S_{max} estimated for Osoyoos lake based on the spawning capacity, is 21,000, falling within the range of what is seen among different SR model formulations (Figure 21).

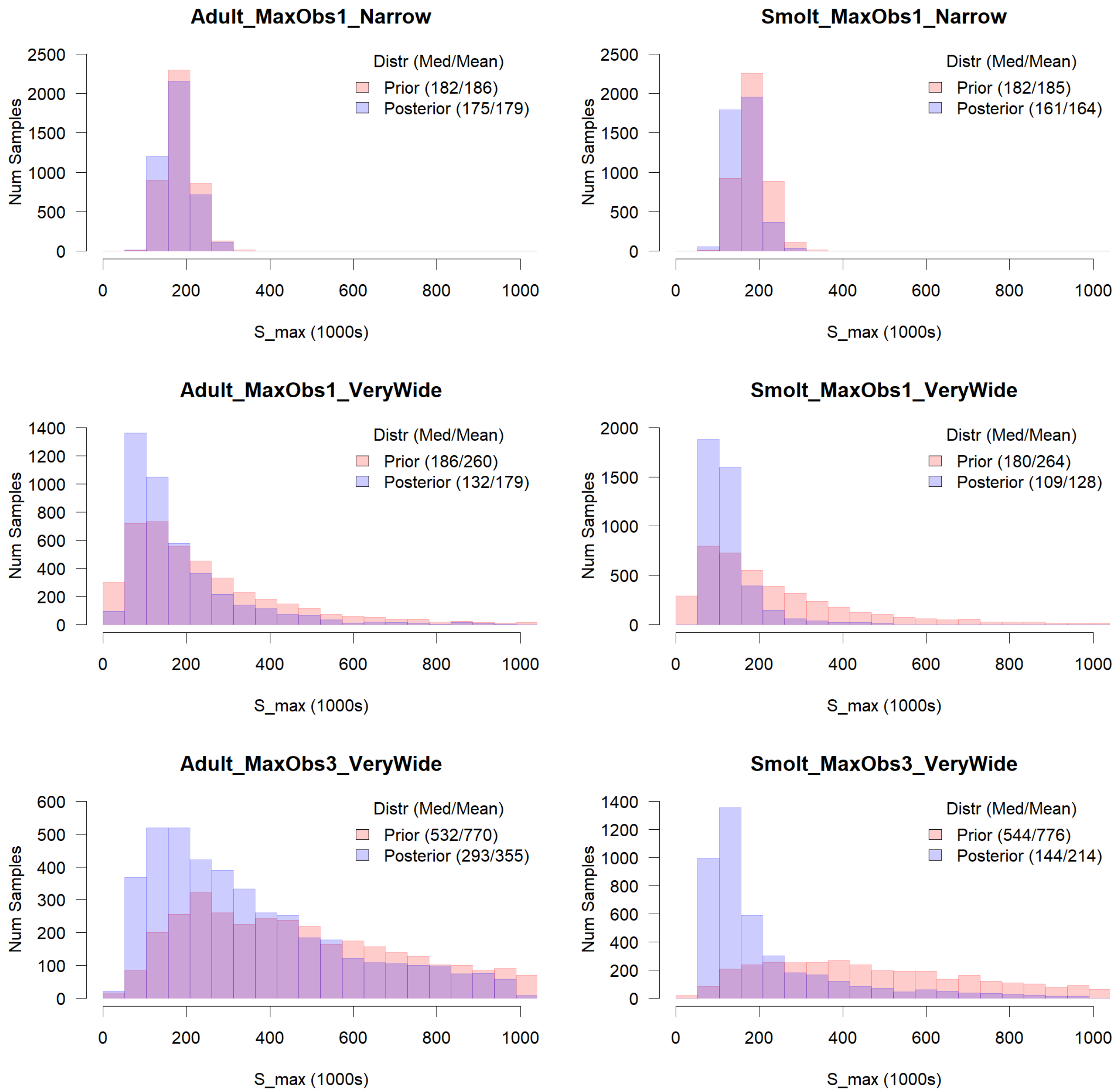

Figure 15. Comparison of prior and posterior distributions of S_{max} for six alternative prior specifications. These are examples to illustrate the observed effect, showing three of nine alternative spawner-adult fits (left column) and three of nine alternative spawner-smolt fits. Spawner-adult fits are for brood years 2004 to 2018, while spawner-smolt fits are for brood years 2004-2020. Both versions exclude 2009 and 2010 brood years. Each panel shows the prior distribution and resulting posterior distribution. Prior specifications as per Table 12. Note that distributions are plotted here in terms of S_{max}, but in the model fit, a normal distribution on $\ln(\beta)$ is used for the prior sample (Table 11). Long upper tails of the distributions are cut off in the plots.

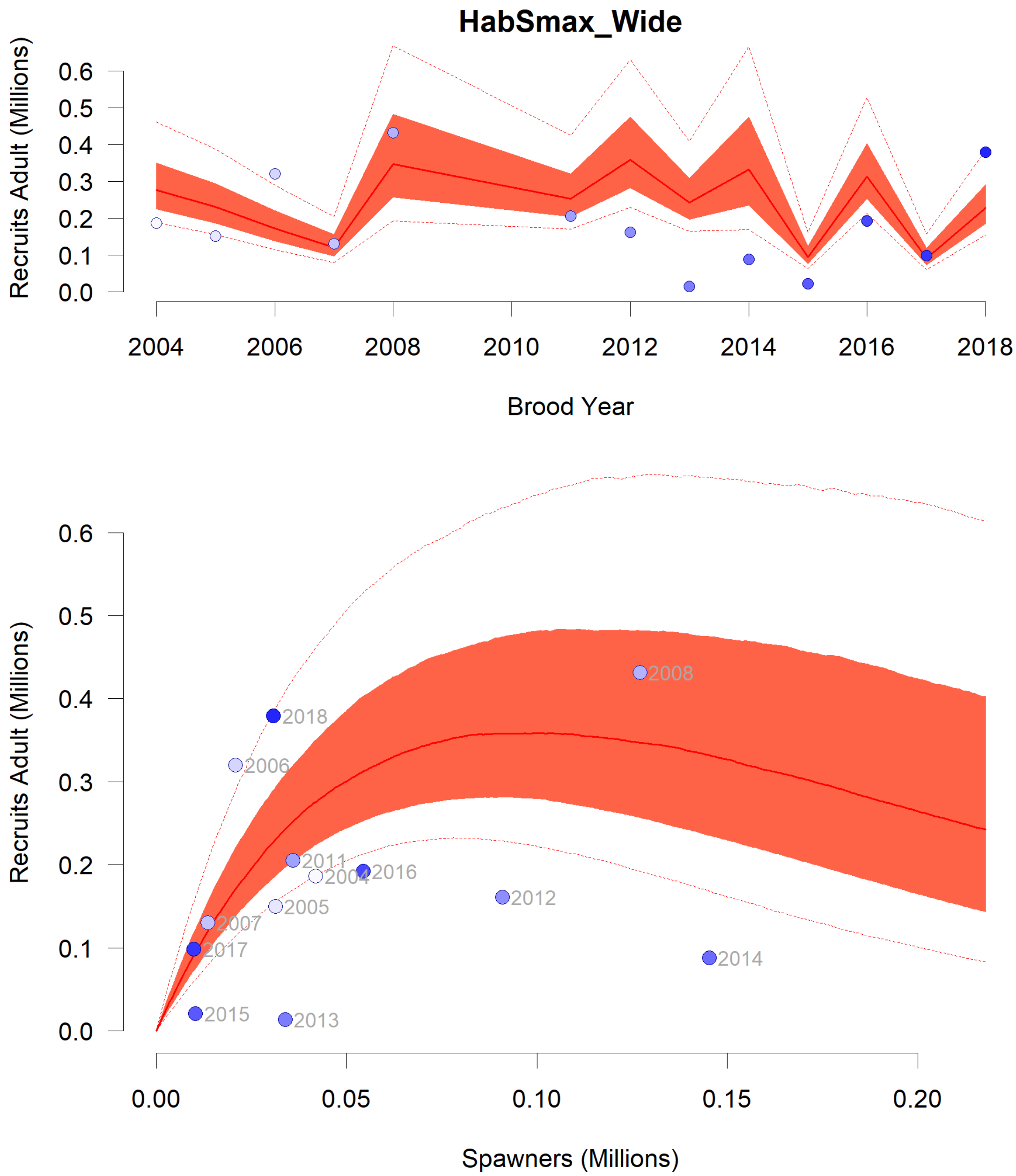

Figure 16. Predicted and observed values for a spawner-adult Ricker fit using a wide capacity prior with mid-point at median estimate of spawning habitat capacity. In both panels, darker points are for more recent observations. Ricker fit is shown as median (solid red line), 25th to 75th percentile capturing half of the distribution (orange area), and 10th to 90th percentiles capturing 80% of the distribution (dotted lines).

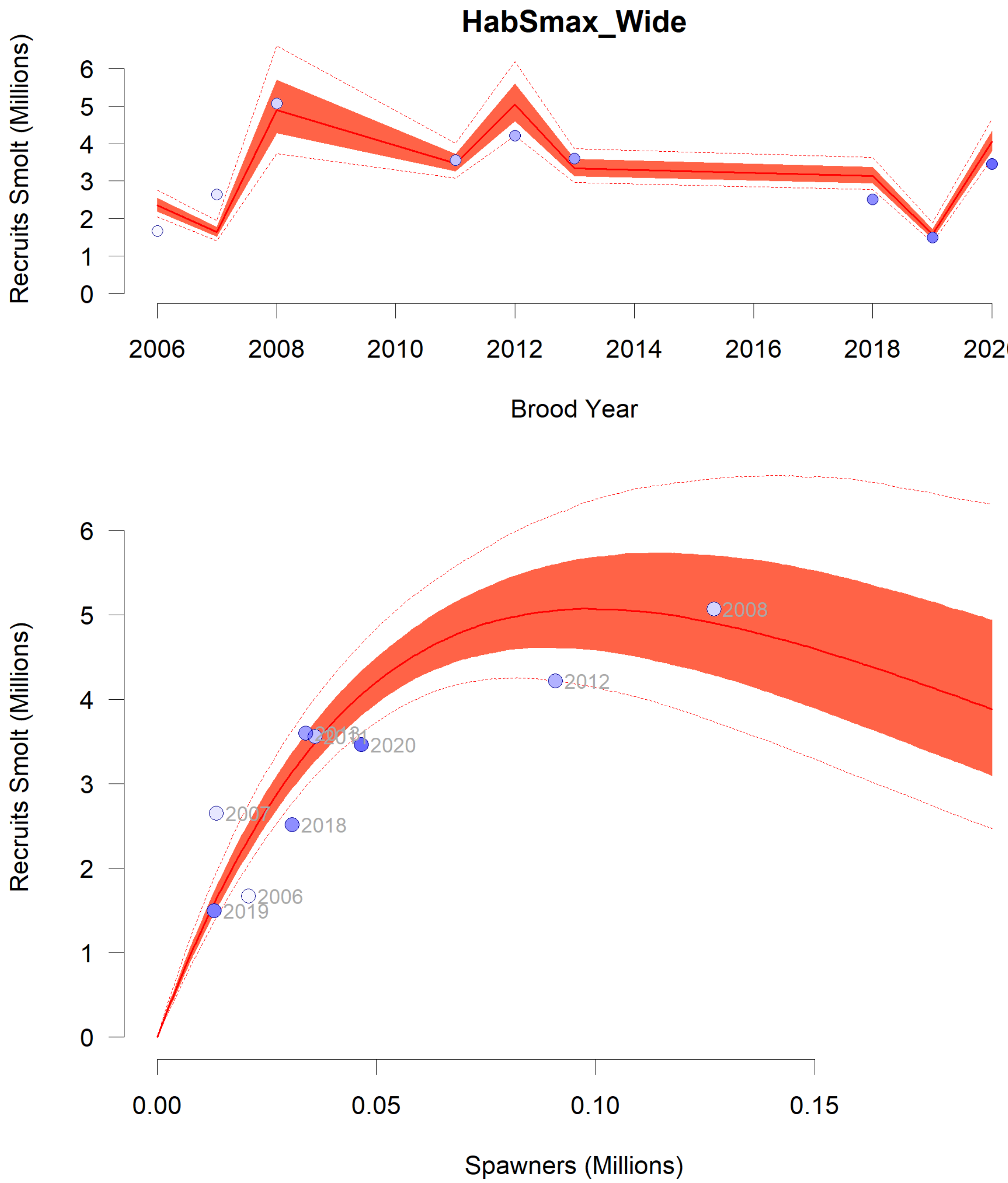

Figure 17. Predicted and observed values for a spawner-smolt Ricker fit using a wide capacity prior with the mid-point at the median estimate of spawning habitat capacity. In both panels, darker points are for more recent observations. The Ricker fit is shown as median (solid red line), 25th to 75th percentile capturing half of the distribution (orange area), and 10th to 90th percentiles capturing 80% of the distribution (dotted lines).

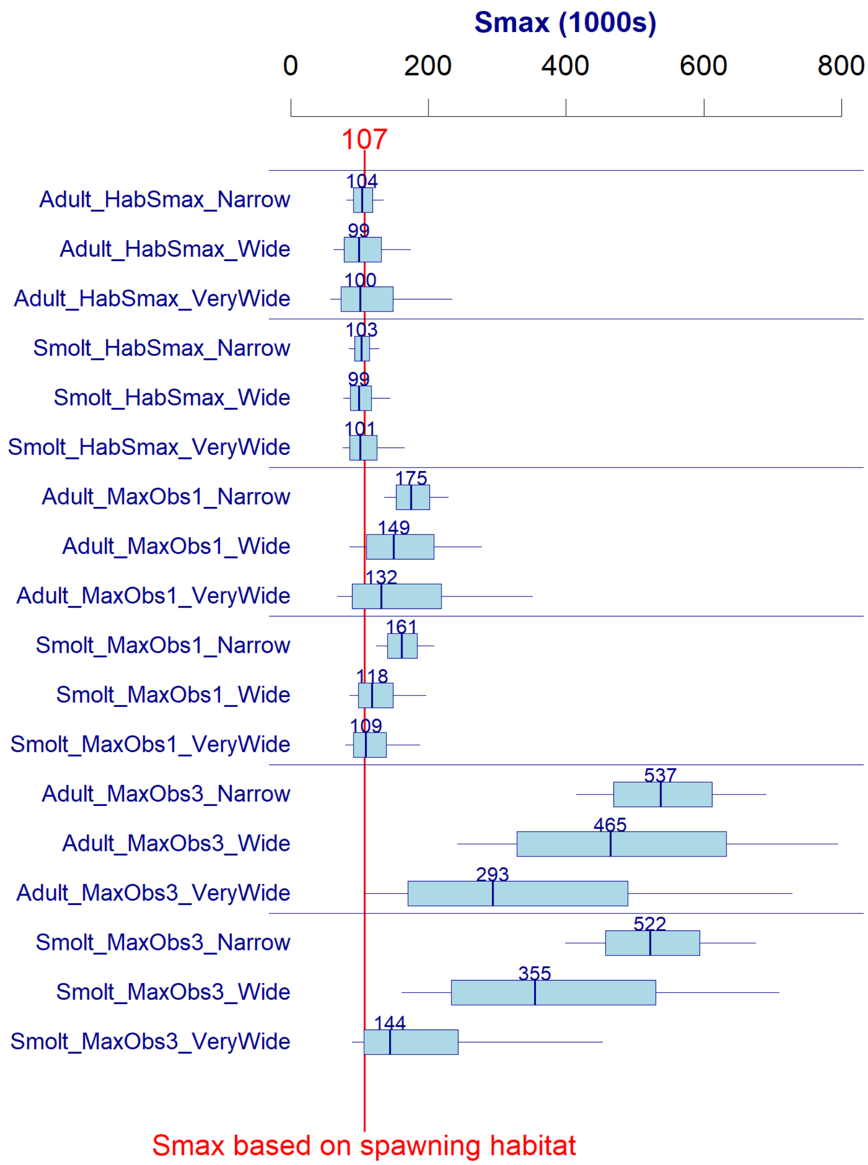

Figure 18. Comparison of S_{max} estimates for 18 Ricker Fits using alternative data sets (spawner-adult, spawner-smolt) and alternative capacity priors. Spawner-adult fits are for brood years 2004 to 2018, while spawner-smolt fits are for brood years 2004-2020. Both versions exclude 2009 and 2010 brood years. Alternative capacity priors are described in Table 12. Boxplots show median and upper/lower quarters of the distribution (25th and 75th percentiles). Whiskers show 80% of the distribution (10th and 90th percentiles).

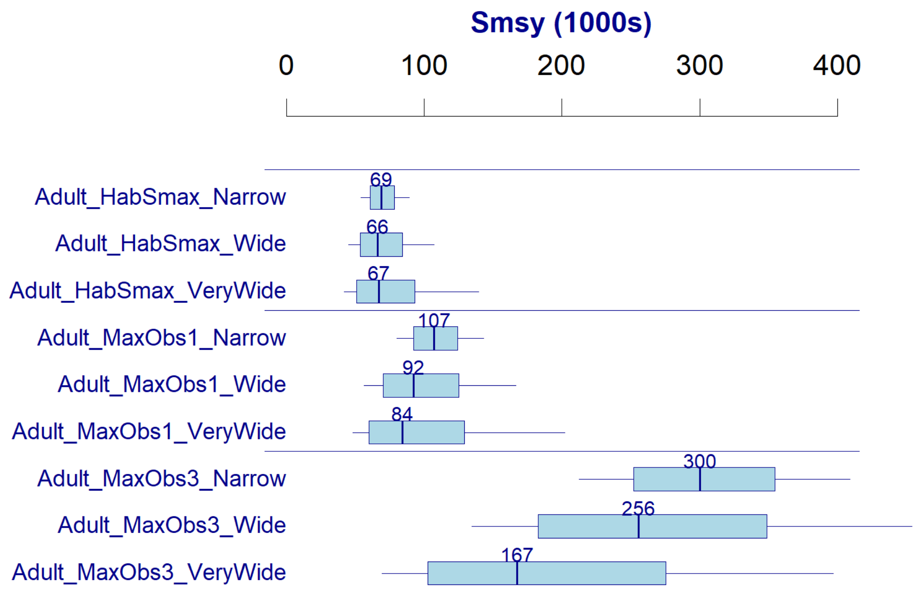

Figure 19. Comparison of SMSY estimates for 9 spawner-adult Ricker fits using alternative capacity priors. Ricker fits are for brood years 2004 to 2018, excluding 2009 and 2010 brood years. Alternative capacity priors are described in Table 12. Plot layout as per Figure 6. Spawner-smolt models are not included in this figure, because SMSY estimates are not directly applicable (unless some conversion to adult equivalents were applied first). For the spawner-adult fits, the effect of alternative capacity priors on SMSY estimates was the same as for Smax estimates (Figure 18).

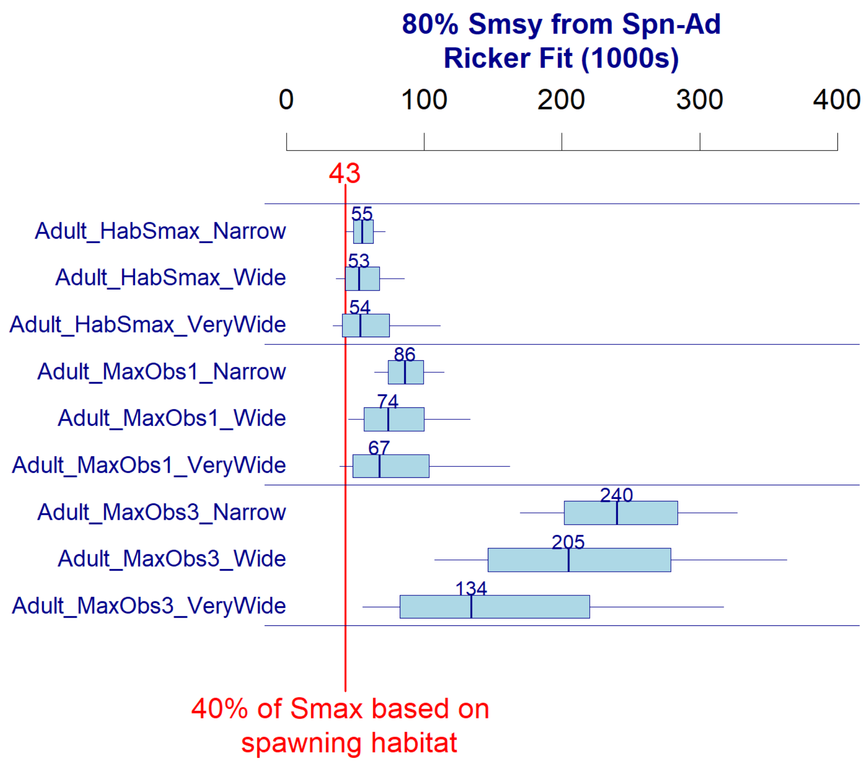

Figure 20. Comparison of upper benchmark estimates for nine spawner-adult Ricker Fits using alternative capacity priors to the approximate habitat-based benchmark estimate. Ricker fits are for brood years 2004 to 2018, excluding 2009 and 2010 brood years. Alternative capacity priors are described in Table 12. Plot layout as per Figure 19. Spawner-smolt models are not included in this figure, because S_{MSY} estimates are not directly applicable (unless some conversion to adult equivalents were applied first). 40% of S_{max} was shown to be a robust approximation for 80% S_{MSY} when S_{MSY} estimates are not possible (Grant et al., 2020, 2011). For the Osoyoos spawner-adult Ricker fits, the 40% habitat-based Smax approximation falls at the lower end of the posterior distribution for 80% S_{MSY} if the capacity prior is centred on the habitat-based estimate of S_{max}. For capacity priors anchored on larger values, the resulting estimates of 80% S_{MSY} are much larger than the 40% of the habitat-based S_{max}.

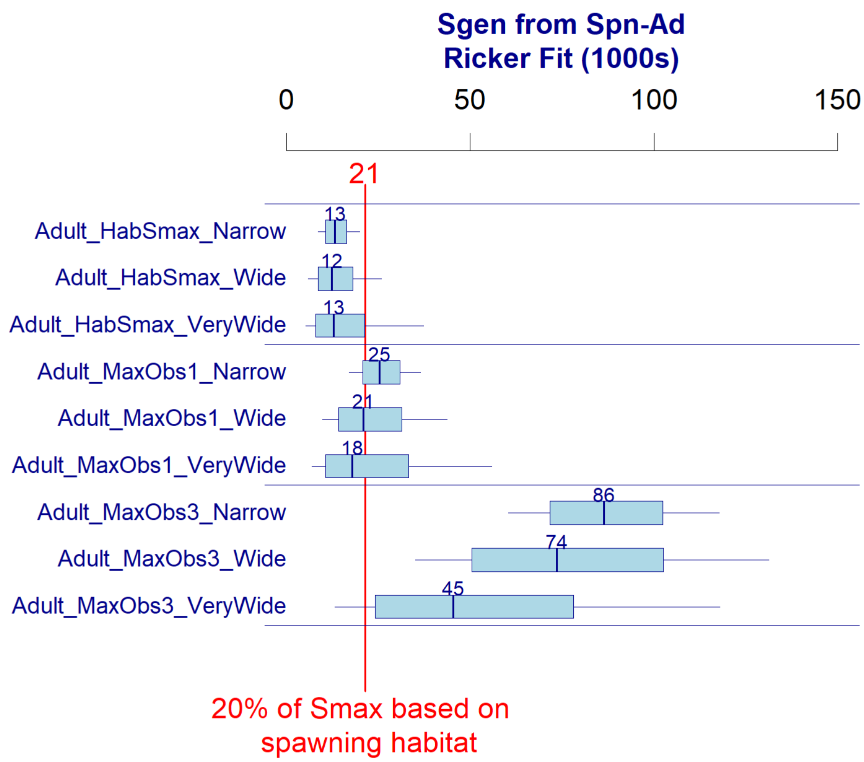

Figure 21. Comparison of lower benchmark estimates for nine spawner-adult Ricker fits using alternative capacity priors of the approximate habitat-based benchmark estimate. Ricker fits are for brood years 2004 to 2018, excluding 2009 and 2010 brood years. Alternative capacity priors are described in Table 12. Plot layout as per Figure 18.

7.3. DISCUSSION

SR models for the Osoyoos Lake population had to be fit using a relatively short time series and the resulting estimates of biological benchmarks were highly sensitive to alternative prior assumptions. Benchmark estimates were also found to differ substantially between the spawner-adult and spawner-smolt models. Contributing factors for the poor model fit include the short time series after quality filtering, uncertainty in the data, extreme environmental conditions (e.g., highly variable mortality during juvenile downstream migration), and lack of observations at larger spawner abundance than the observed range.

The following key sources of uncertainty were identified for estimates of total returns, spawners, and juveniles of the Osoyoos Lake Sockeye salmon population:

- The estimation of returning adult numbers is underpinned by dam counts and dam count ratios along the Columbia River, with adjustments for harvest. Dam counts are imperfect, often requiring calibrations (i.e., from 16-hour to 24-hour counts). Moreover, dam counts are subjected to several intra- and inter-dam adjustments, each of which incorporates some uncertainty (Judson et al., 2023; Bailey et al.,2025.)[9]. For example, instances exist in which Sockeye salmon counts at a dam were slightly greater than the dam immediately downstream, which could be due to miscounts, strays and/or fall-backs at one or both dams, although fallback does not seem to be a source of much uncertainty (Jeff Fryer, pers. comm.). As many of these uncertainties are typically unquantifiable, there remains some (possibly compounded) uncertainty in the net abundance of a given Sockeye salmon stock returning to the mouth of the Columbia River.

- Ascribing estimated returns to the mouth of the Columbia River to a given lake in the Okanagan River basin is an additional source of uncertainty. After dam passage was improved between Osoyoos and Skaha Lakes, there has been the potential for spawners to stray between the two systems. Uncertainty in the number of straying individuals in a given year may influence the results of the spawner recruit models. Where sufficient data existed, Bailey et al. (in prep.)[9] estimated annual stray rates in both directions based on limited years of data. For example, they found that Skaha-reared hatchery-origin spawners were detected on the lower Okanagan River spawning grounds (i.e., below McIntyre dam in 2018 and 2020), or conversely, natural-origin spawners that could only be Osoyoos-reared were detected on the middle or upper Okanagan River spawning grounds (2009-2012; Bailey et al., in prep.). The weighted mean Osoyoos-to-Skaha stray rate, based on those few years, was 6.0% (range 2.5% in 2012 to 7.8% in 2010). These straying rates were applied to all years in which annual stray rate estimates were not possible, in order to adjust the numbers of returns (and thus recruits by brood year) to the mouth of the Columbia River, in addition to the apportioning of Osoyoos and Skaha lake populations on the basis of their relative proportions on the spawning grounds. It should be noted that the rate may be positively related to total Okanagan Sockeye salmon spawner abundance. The weighted mean Skaha stray estimate was 4.1% (range 3.4 – 4.3%), which was applied to all years in which Skaha-to-Osoyoos straying was possible (i.e., 2012-2017, 2019, 2021). More field research is required to specifically assess and quantify the scale of straying and sources of inter-annual variation.
- The spatio-temporal overlap of Sockeye and Kokanee salmon spawning (especially in Penticton Channel) presents challenges associated with counting Sockeye salmon spawners because: i) precociously spawning Sockeye salmon (“jacks” and “jills”) resemble Kokanee salmon in size and color in this population, and ii) both ecotypes breed and produce hybrid offspring. The first point was addressed in part by the combined information from length measurements and otolith analyses, which was used to identify ocean entry years as a means of discriminating between Kokanee and Sockeye salmon. However, F1 hybrid individuals typically do not exhibit anadromy, and they overlap in size with both Kokanee and Sockeye salmon (Chang et al., 2022; Veale and Russello, 2016). In the absence of genetic data, misidentifying hybrid spawners as either Kokanee or Sockeye salmon has the potential to bias spawner-presmolt production estimates or spawner-to-adult estimates, given that hybrid progeny may be erroneously ascribed to the wrong parental ecotype. More information is needed on the scale and trends of hybridization over time. In a recent study, Chang et al. (2022) reported that in 2019, 31% of the Skaha spawners were hybrids, based on their Genotyping-in-Thousands by Sequencing (GT-seq) analysis.
- The acoustic trawl surveys operate under the assumption that sampled (i.e., captured) fish are representative of those in the lake. However, the relatively slow speed of the trawls and the gear designed for targeting juvenile fishes enables larger and faster fishes to evade capture more readily. Surveys have therefore classified Sockeye salmon into age classes based on two juvenile size thresholds (i.e., fork length (FL) < 9 cm = age-0, and 9 cm < FL < 15 cm = age-1) (Hyatt et al., 2021b), which likely underestimates the abundance of age-1 fish (Scott Akenhead, 2023, Fisheries and Oceans Canada (retired), pers. comm.). In-lake age-composition of presmolts is critical to accurately ascribe fish abundances to the correct return cohort, and associated errors may bias our understanding of smolt production and/or juvenile survival and growth.

8. CONSIDERATIONS FOR BIOLOGICAL BENCHMARKS AND CANDIDATE MANAGEMENT TARGETS

8.1. COMPARISON OF THREE METHODS PRESENTED

In this paper, we presented three potential methods for identifying reference points for the Sockeye salmon spawning in the Okanagan River basin, namely:

1. Spawning capacity estimates based on stream assessments that were developed for all three populations,
2. Rearing capacity estimates based on bioenergetics that were developed for Osoyoos and Skaha lake populations, and
3. Spawner-recruitment models that were fit for the Osoyoos Lake population.

The spawning capacity estimates were built on extensive field work that included mapping the quality of spawning habitat on a fine grid (0.1 by 0.1 meter), measuring water levels, and determining segment gradients and gravel size (O'Sullivan and Alex, 2024). These surveys were updated as recently as 2023 to ensure that they captured the most up-to-date estimate of current spawning capacity, which is especially relevant for this case of potentially rapid range expansion and ongoing habitat restoration. Their method has the added benefit that it could be applied to all three lake populations and was not affected by uncertainties in the estimates of spawner abundance, juvenile abundance, or total returns. The Skaha Lake population still has ongoing hatchery supplementation and a short time series, meaning that any possible stock-recruitment modelling may not capture the biology of the self-sustaining natural population that will hopefully exist there in the near future. The Okanagan Lake population is even earlier in its recolonization and rebuilding, and we currently do not have any useful population-level data to estimate what an established, naturally-sustaining population there may look like. The adopted spawning habitat-based method does not require population data, and therefore can be uniformly applied to all three populations, despite large differences in the stage of rebuilding and amount of data available for each one.

The lake rearing capacity estimates, based on modeling food web interactions, have some of the same benefits as the spawning capacity model, but require extensive zooplankton, juvenile nerkid, and nerkid spawner data, and therefore could not be implemented for the Okanagan Lake population. The lake rearing capacity estimates were also based on snapshots in time of a very dynamic system and covered a short time span. Additionally, the most recent data included in the analysis were from 2017. Moreover, the lake rearing capacity estimates were inferred based on unique combinations of physical and biological conditions, whose recurrence frequency remains unknown.

The SR models for the Osoyoos Lake population were fit using a relatively short time series (only 13 brood years for the spawner-to-adult model and nine brood years for spawner-to-smolt models). Furthermore, the SR-based estimates of biological benchmarks were found to be highly sensitive to alternative prior assumptions (i.e., neither version of the SR data provided a clear signal of density-dependent declines in recruitment at the upper end of observed spawner abundances). Benchmark estimates were also found to differ substantially based on the spawner-adult and spawner-smolt models. Contributing factors for the poor model fit included the short time series after quality filtering, estimate uncertainties (e.g., stock identification in total Sockeye salmon returns to Bonneville dam), extreme environmental conditions (e.g., highly variable mortality during juvenile downstream migration), and lack of observations at larger spawner abundances than the observed range. Furthermore, this method could not be applied to all three lake populations, as sufficient data do not exist for Skaha and Okanagan Lake populations.

Given these challenges with the lake-rearing capacity estimates and the poor performance of SR model fits for the Osoyoos Lake population, we chose to use the spawning habitat capacity estimates as the basis for biological benchmarks and candidate management reference points. However, this does not mean that the other two models are lacking in potential utility. The results of the lake rearing capacity model for the Okanagan and Skaha Lake populations provided a corroboration of the spawning habitat. The lake-rearing capacity model seems to align with our spawning-capacity estimate for the Skaha Lake population Table 13. For Osoyoos Lake, the lake-rearing-habitat model indicates a higher spawner capacity than the spawning capacity estimate. Given that spawner numbers have exceeded both of these capacity estimates only a few times, this observation provides some preliminary indication that we are likely in the right approximate range with both values.

Table 13. Comparison of lake-population-specific in-river habitat-based estimates of spawner capacity.

Lake	**Sockeye Salmon Spawning Capacity Estimate**	**Kokanee Salmon-Adjusted Sockeye Salmon Spawning Capacity Estimate**	**Lake Rearing-based Sockeye Salmon Spawner Capacity Estimate**
Osoyoos	108,977	108,977*	131,619
Skaha	35,998	27,880	30,391
Okanagan	49,569	36,904	N/A

*It is assumed that the spawning capacity of Osoyoos Lake is not significantly affected by Kokanee salmon.

8.2. SCALE OF ASSESSMENT

The ongoing rebuilding and range expansion of Okanagan Sockeye salmon presents an uncommon situation in the evolving policy framework for Canadian Pacific salmon. This creates practical challenges in how we approach status assessments under the Wild Salmon Policy (DFO, 2005), Limit Reference Points (LRP) under the Fish Stock Provisions of the modernized *Fisheries Act* (2019) and candidate reference points for management (e.g., escapement goals).

To illustrate how different levels of aggregation compare in identifying capacity estimates (and associated candidate reference points), we show how observed spawner abundance compared to habitat-based capacity estimates (and proportions thereof) for each of the three-lake population separately, for combined Osoyoos and Skaha Lake populations, and for the sum of all three Lake populations (and therefore the entire Osoyoos-Skaha-Okanagan (OSO) CU/Okanagan Sockeye salmon SMU; Table 14; Figures 22 to 26).

Table 14. Candidate benchmarks and targets for three alternative groupings of Sockeye salmon in the Okanagan River watershed. Habitat-based Smax estimates are reported as medians, with lower and upper bounds at 25th and 75th percentiles. The table also lists various proportions of the median habitat-based Smax, which could be used as status benchmarks or management reference points (e.g., Med20p is 20% of the value in the median column). 20% and 40% of median Smax can be used as lower and upper benchmarks for the relative abundance metric in WSP status assessments as precautionary approximations of Sgen and 80% SMSY (Grant et al., 2020, 2011; Grant and Pestal, 2013). Therefore, some value above 40% Smax could be used as a management target to approximate an MSY objective when estimates of SMSY are not available (e.g., an escapement goal range spanning 60%-80% of median Smax).

(a): Habitat-based estimate of spawning capacity (S_{max})

Grouping	Lower	Median	Upper
Osoyoos Lake population	97,549	107,080	118,240
Osoyoos + Skaha lakes	132,820	143,017	155,293
Osoyoos + Skaha + Okanagan lakes (OSO CU / Okanagan Sockeye salmon SMU)	180,754	192,453	205,588

(b): Candidate benchmarks and targets based on proportions of median Habitat-Based S_{max}

Grouping	Med20p	Med40p	Med60p	Med80p
Osoyoos Lake population	21,416	42,832	64,248	85,664
Osoyoos + Skaha lake populations	28,603	57,207	85,810	114,414
Osoyoos + Skaha + Okanagan lake populations (OSO CU / Okanagan Sockeye salmon SMU)	38,491	76,981	115,472	153,962

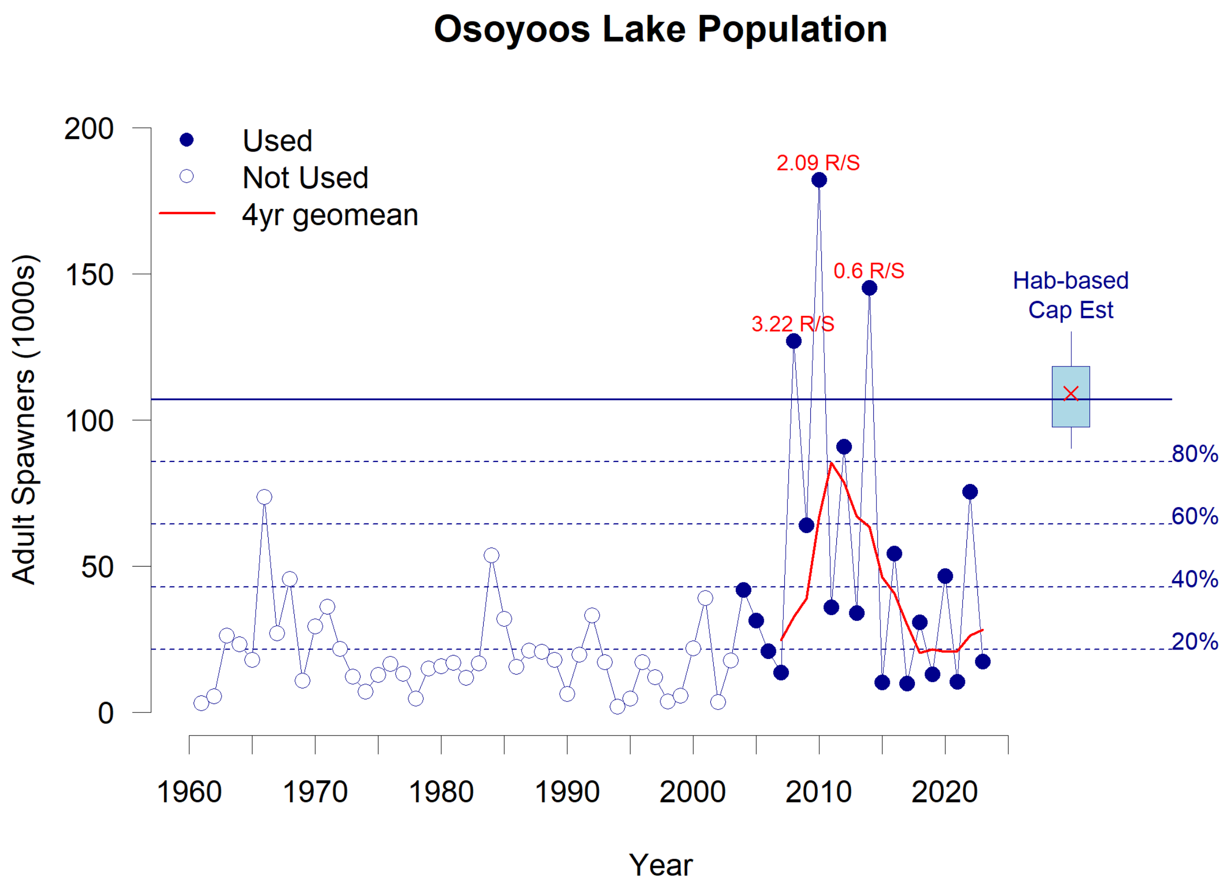

Figure 22. Spawner abundance compared to the habitat-based estimate of spawning capacity for the Osoyoos Lake population. The time series shows all available spawner estimates. Only estimates starting in return year 2004 (filled circles) , denoting the tmix^{w}-centred period, are considered relevant for comparison to the current habitat capacity estimates and were used for SR modelling. Red solid line represents the 4-year running geometric mean. Boxplot for habitat capacity shows the median (horizontal line), mean (red x), 25th and 75th percentiles (box), and 10th and 90th percentiles (whiskers). Horizontal dashed lines mark candidate benchmarks and targets defined in terms of the percentage of the median habitat-based spawning capacity estimates (secondary y-axis). Table 14 lists the specific values for each of the horizontal reference lines.

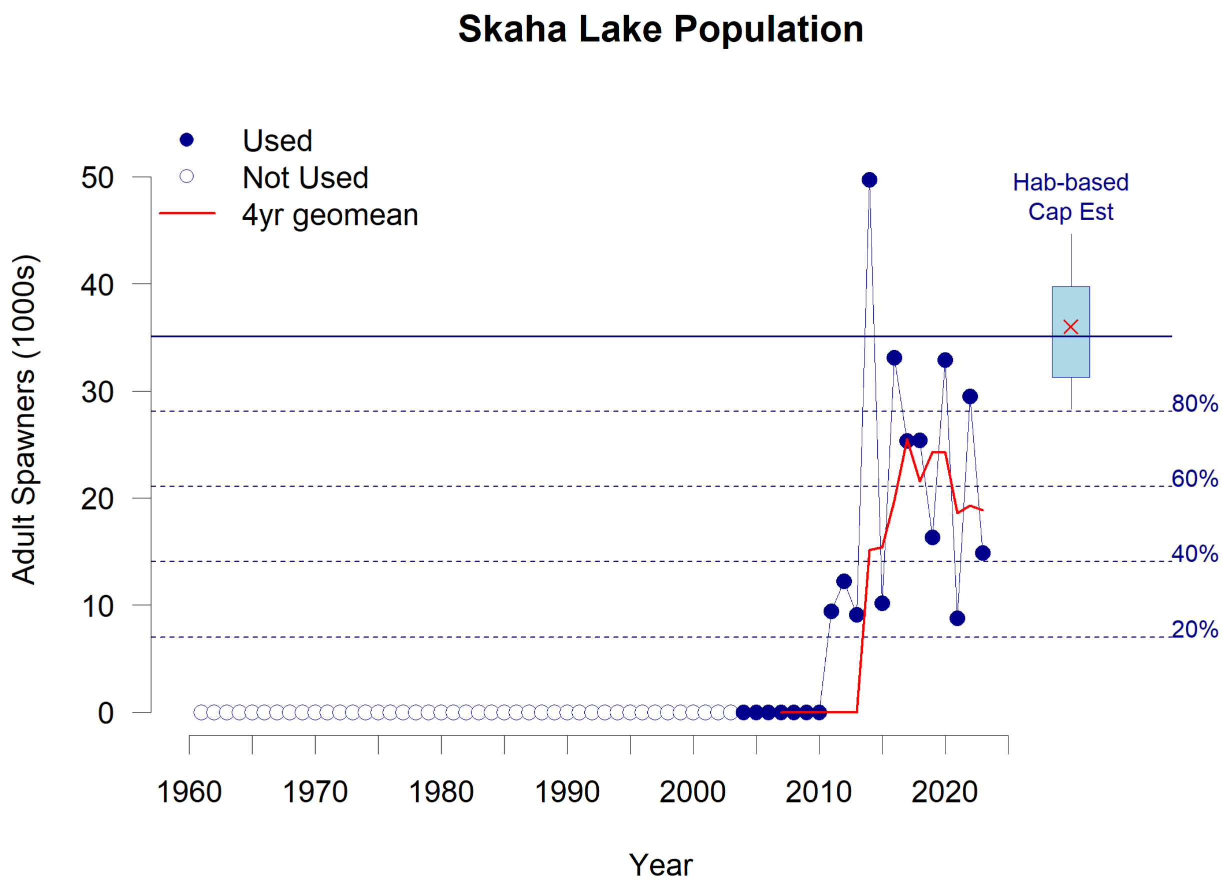

Figure 23. Spawner abundance compared to habitat-based estimate of spawning capacity for the Skaha Lake population. The time series shows all available estimates, but only estimates starting in 2004 were (filled circles) , denoting the tmix^w-centred period, are considered relevant for comparison to the current habitat capacity estimates. Values before 2011 are true zeroes, because Skaha Lake and tributaries were not accessible to Sockeye salmon. Red solid line represents the 4-year running geometric mean. Boxplot for habitat capacity shows the median (horizontal line), mean (red x), 25th and 75th percentiles (box), and 10th and 90th percentiles (whiskers). Horizontal dashed lines mark candidate benchmarks and targets defined in terms of the percentage of the median habitat-based spawning capacity estimates (secondary y-axis). Table 14 lists the specific values for each of the horizontal reference lines.

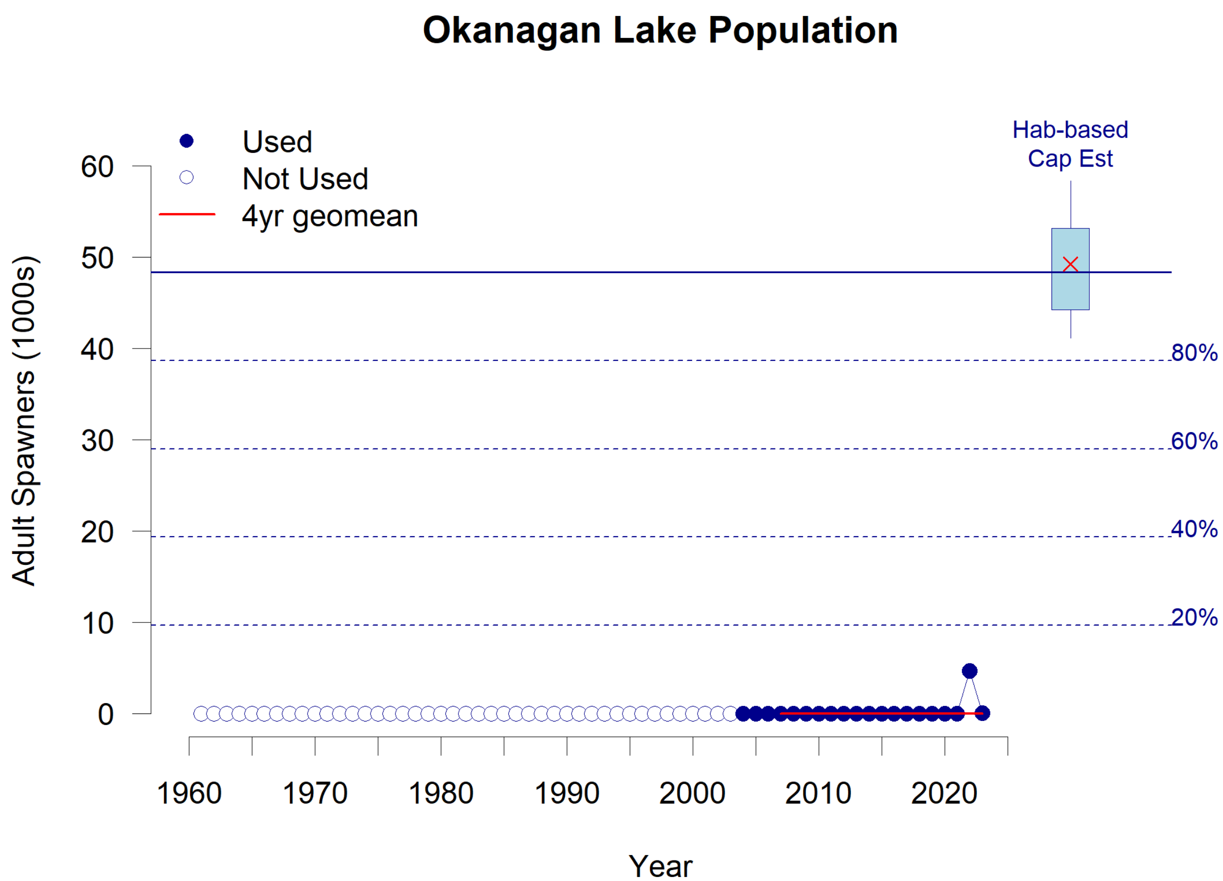

Figure 24. Spawner abundance compared to habitat-based estimate of spawning capacity for the Okanagan Lake population. The time series shows all available estimates, but only estimates starting in 2004 (filled circles), denoting the tmix^{w}-centred period, are considered relevant for comparison to the current habitat capacity estimates. Values before 2022 are true zeroes, because Okanagan Lake and its spawning grounds were not accessible to Sockeye salmon before then. Red solid line represents the 4-year running geometric mean. Boxplot for habitat capacity shows the median (horizontal line), mean (red x), 25th and 75th percentiles (box), and 10th and 90th percentiles (whiskers). Horizontal dashed lines mark candidate benchmarks and targets defined in terms of the percentage of the median habitat-based spawning capacity estimates (secondary y-axis). Table 14 lists the specific values for each of the horizontal reference lines.

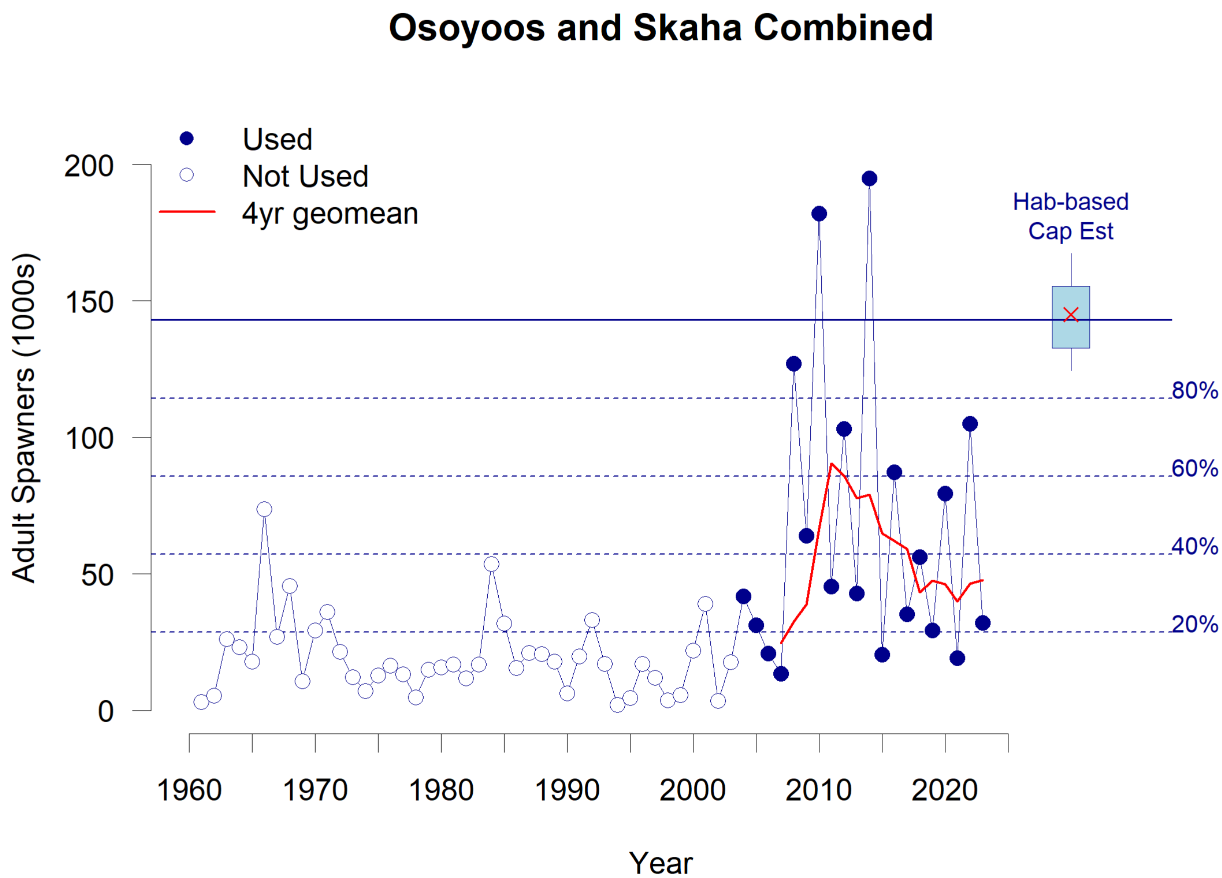

Figure 25. Spawner abundance compared to the habitat-based estimate of spawning capacity for the Osoyoos and Skaha combined indicator. The time series shows all available estimates, but only estimates starting in 2004 (solid circles) , denoting the tmix^{w}-centred period, are considered relevant for comparison to the current habitat capacity estimates. Values before 2011 include only spawners from the Osoyoos Lake population, because the Skaha Lake population had 0 spawners in those years. Boxplot for habitat capacity shows the median (horizontal line), 25th and 75th percentiles (box), and 10th and 90th percentiles (whiskers). Red solid line represents the 4-year running geometric mean. Boxplot for habitat capacity shows the median (horizontal line), mean (red x), 25th and 75th percentiles (box), and 10th and 90th percentiles (whiskers). Horizontal dashed lines mark candidate benchmarks and targets defined in terms of the percentage of the median habitat-based spawning capacity estimates (secondary y-axis). Table 14 lists the specific values for each of the horizontal reference lines. Note also that before there was free passage into Okanagan Lake, hatchery-origin juveniles that were released into Okanagan Lake tributaries would be expected to return as adult spawners mainly to Penticton Channel, which is just below Okanagan Lake, and is also the main spawning area for Skaha Lake.

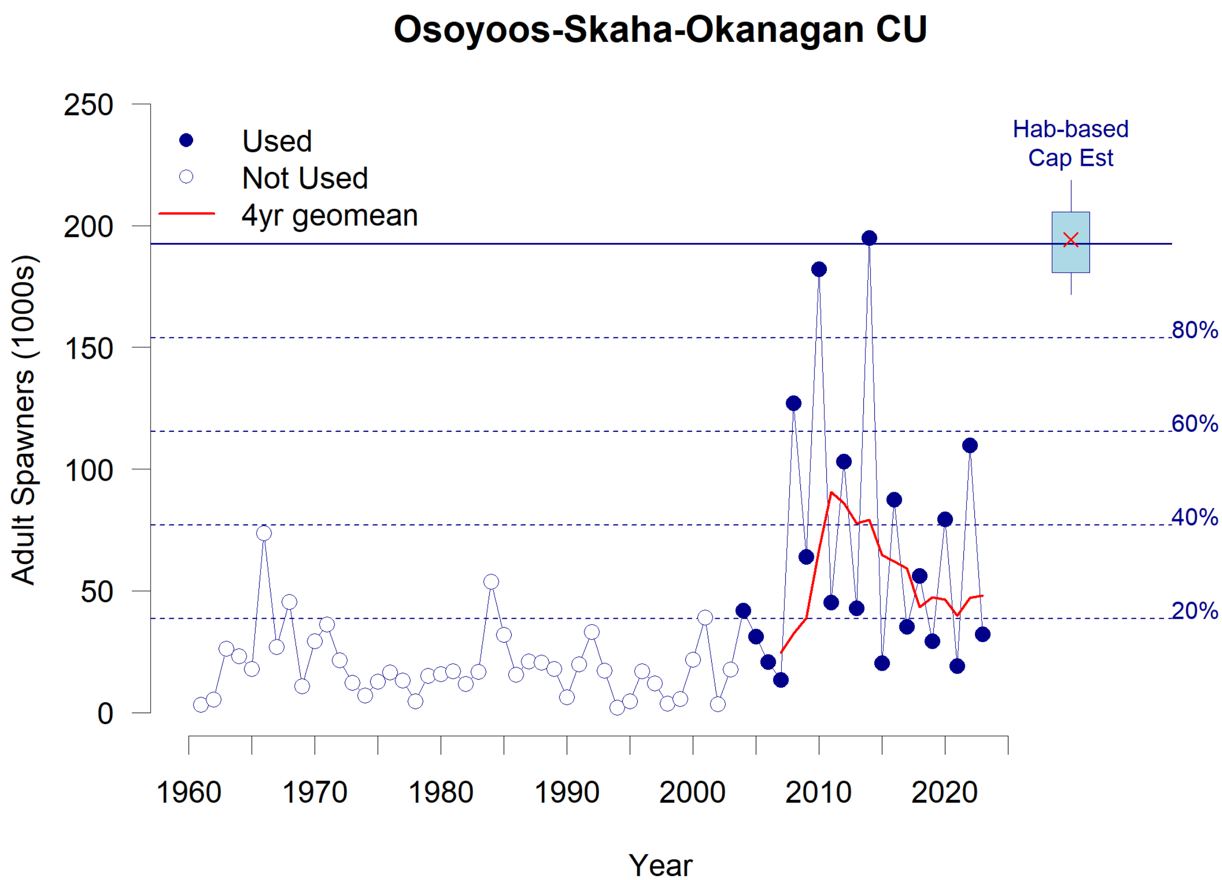

Figure 26. Spawner abundance compared to habitat-based estimate of spawning capacity for the Osoyoos-Skaha-Okanagan CU. The time series shows all available estimates, but only estimates starting in 2004 (solid circles), denoting the tmix^{w}-centred period, are considered relevant for comparison to the current habitat capacity estimates. Values before 2011 include only spawners from the Osoyoos Lake population. Values from 2011 to 2021 include spawners from the Osoyoos Lake and Skaha Lake populations. Values starting 2022 include spawners from the Osoyoos Lake, Skaha Lake, and Okanagan Lake populations. Red solid line represents the 4-year running geometric mean. Boxplot for habitat capacity shows the median (horizontal line), mean (red x), 25th and 75th percentiles (box), and 10th and 90th percentiles (whiskers). Horizontal dashed lines mark candidate benchmarks and targets defined in terms of the percentage of the median habitat-based spawning capacity estimates (secondary y-axis). Table 14 lists the specific values for each of the horizontal reference lines.

9. WILD SALMON POLICY STATUS

9.1. WSP STATUS OF THE OSOYOOS-SKAHA-OKANAGAN SOCKEYE SALMON CU

Status assessments under the WSP are applied at the CU level and generally focus on four standard metrics: relative abundance, absolute abundance, long-term trend, and percent change over three generations (DFO, 2016, 2015; Grant et al., 2020, 2011; Grant and Pestal, 2013; Holt, 2009; Holt et al., 2009). For the relative abundance metric, CU-specific estimates of S_{gen} and 80% S_{MSY} are used as the lower and upper benchmarks, respectively, when SR models of sufficient quality can be estimated. Alternatively, these benchmarks can be approximated using other methods. Watershed-area-based benchmarks are commonly used for Chinook salmon, assuming an empirical relationship between watershed area and S_{MSY} and S_{eq} (Parken et al., 2006). Alternatively, 20% and 40% of S_{max} (Grant et al., 2020, 2011; Grant and Pestal, 2013) or specific percentiles of the distribution of observed spawner abundances (Holt et al., 2018) have been used to approximate lower and upper biological benchmarks. In cases in which estimates of spawner abundance are not available for the entire CU, status assessments can be based on indicator systems within the CU. For example, recent status assessments of WCVI Chinook used a subset of spawning sites (only those where PNI, the proportionate natural index, is larger than 51%) and used habitat-based benchmark estimates for those sites as the basis for the relative abundance metric (C.A. Holt et al., 2023; K.R. Holt et al., 2023).

To be consistent with previous work, the choice of which level of aggregation to use for assessing CU status should be guided by data quality and the level of hatchery influence. However, there is no precedent in WSP status assessments for handling a situation like the very recent reintroductions to Skaha and Okanagan lakes. We chose to use the combined Osoyoos and Skaha time series as the basis for status assessment, because that captures almost all the natural spawners in the CU in recent years. This combined time series has consistent spawner estimates starting in 2012, so 2015 is the first available four-year generational average for status assessment. Once a self-sustaining natural spawning population is fully established in Okanagan Lake, the time series used for status assessment should be reconsidered.

A standard template for summarizing CU status information is being developed by DFO's State of the Salmon Program (Sue Grant, Fisheries and Oceans Canada, Science Branch, Pacific Region, Vancouver, B.C., pers. comm.). Key elements of the template are included in APPENDIX C, but it should be noted that most of the required information for the template was already covered elsewhere in this document and will not be repeated there.

Population-specific benchmarks for the relative abundance metric are available, using 20% and 40% of habitat-based S_{max}. This is consistent with previous status assessments for the Chilliwack-ES Sockeye salmon CU, where the spawner-recruit time series was too short for fitting SR models, but an estimate of S_{max} was available from freshwater production studies (Grant et al., 2020, p. 160). The absolute abundance metric does apply in our case, because the combined Osoyoos and Skaha time series captures almost all of the spawners in the CU. The trend metrics are applicable given the quality of the estimates, but the quality-controlled time series of spawners started only in 2012, so there aren't enough years yet to calculate the long-term trend, and the percent change over three generations was available only for 2023.

When available, status determinations are generally driven by the relative abundance metric, comparing the best available spawner timeseries to lower and upper biological benchmarks. The generational average spawner abundance was just above 40% of the habitat-based S_{max} plus a 10% buffer for 2015, resulting in Green status for that year. It then subsequently dropped below that threshold but stayed above 20% of S_{max}, resulting in *Amber* status starting in 2016. Status for 2023 is *Amber* with *High Confidence.*

9.2. HARVEST AND STATUS

The increase in the number of Sockeye salmon returns to the Columbia River (predominantly Okanagan Sockeye salmon) starting in 2008 (Figure 6), resulted in an increase in harvest; yet, harvest rates lagged by a few years (Table 15), providing the fish an opportunity to partially recover. Nevertheless, harvest rates since then have, on average, continued to be high even when the abundance of returning OSO CU Sockeye salmon decreased after 2017 (Figure 6). In fact, harvest was high even though the status for the whole OSO CU has been Amber since

2016 (Table 15). Harvest in those years averaged 64,254 (range 4,185 – 175,863), with many of the recent years experiencing harvest numbers greater than spawner abundance (Table 15). Furthermore, even though the status for the whole OSO CU based on generational average spawner abundance was Amber from 2016 to present, in some of those years (i.e., 2015, 2019, 2021, and 2023), the annual spawner abundance was below or close to the lower benchmark for the relative abundance metric (Figure C1 in APPENDIX C). Nevertheless, the harvest in those four years averaged 24,343 (range 4,185 – 53,022). Figure 27 shows the number of spawners, harvest, run size, harvest rate, and total mortality rate for the Osoyoos Lake Sockeye salmon population along with those for the entire OSO CU.

Table 15. Comparison of spawner abundance, status, and harvests for the OSO CU. Note that spawner estimates prior to 2011 include only the Osoyoos Lake population, estimates from 2011 to 2021 include the Osoyoos Lake and Skaha Lake populations, and estimates since 2022 include all three lake populations.. Status assessments used the combined Osoyoos and Skaha spawner abundance and started in 2012 to ensure that the time series was consistent, because the 2011 Skaha spawner estimate is considered highly uncertain. Note that data prior to 2004 (pre-recovery period) may not be directly comparable to data after 2004 (tmix^{w}-centred period) due to changes in stock structure, water management, and stock assessment methods.

Year	Spawners	Spawners 4-year geometric average	Status	Harvest
1980	15,807	-	-	443
1981	16,938	-	-	1,330
1982	11,703	-	-	595
1983	16,761	15,138	-	1,498
1984	53,721	20,554	-	28,575
1985	31,946	24,087	-	48,531
1986	15,472	25,829	-	6,818
1987	21,090	27,356	-	45,023
1988	20,653	21,541	-	37,950
1989	17,947	18,649	-	937
1990	6,261	14,874	-	714
1991	19,738	14,630	-	1,663
1992	33,184	16,471	-	1,538
1993	17,151	16,286	-	2,460
1994	1,977	12,207	-	217
1995	4,581	8,473	-	329
1996	17,035	7,172	-	1,125
1997	11,996	6,559	-	1,544
1998	3,708	7,676	-	263
1999	5,648	8,088	-	642
2000	21,838	8,606	-	2,502
2001	39,024	11,558	-	6,333
2002	3,560	11,441	-	728
2003	17,753	15,234	-	989
2004	41,791	17,918	-	3,698
2005	31,260	16,951	-	2,405
2006	20,819	26,360	-	1,166
2007	13,490	24,611	-	1,313

Year	Spawners	Spawners 4-year geometric average	Status	Harvest
2008	126,972	32,493	-	9,729
2009	64,024	38,871	-	25,399
2010	182,122	66,851	-	68,857
2011	45,326	90,509	-	21,544
2012	103,098	85,916	-	153,471
2013	42,930	77,746	-	24,026
2014	194,937	79,079	-	119,878
2015	20,415	64,783	Green	74,407
2016	87,371	62,157	Amber	101,981
2017	35,257	59,172	Amber	12,079
2018	56,175	43,354	Amber	51,613
2019	29,251	47,432	Amber	4,185
2020	79,399	46,311	Amber	87,201
2021	19,231	39,799	Amber	28,086
2022	109,644	47,042	Amber	175,864
2023	32,144	48,164	Amber	53,022

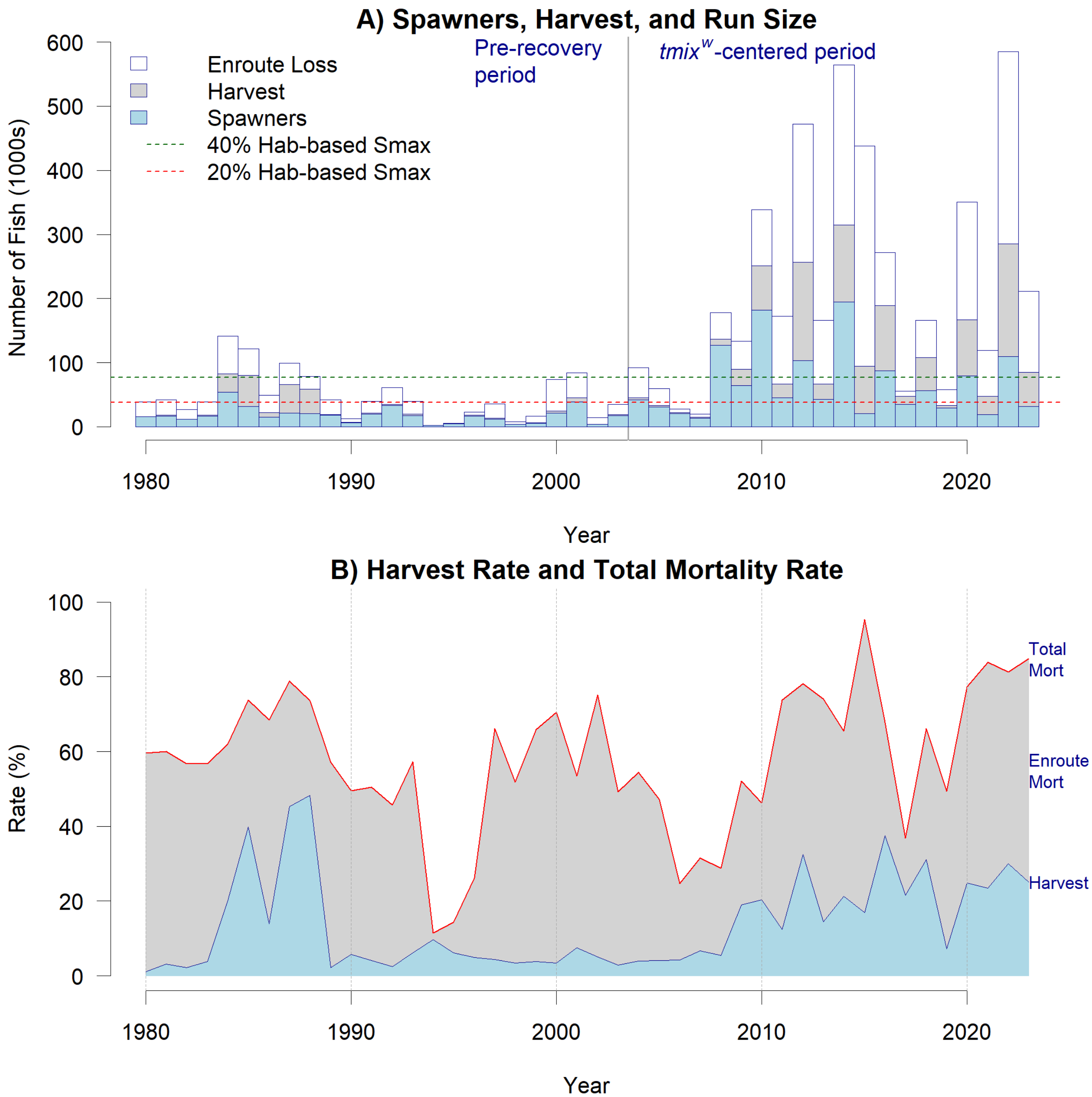

Figure 27. Summary of spawners, harvest, run size, harvest rate, and total mortality rate for the Osoyoos-Skaha-Okanagan Sockeye salmon CU. (A) Stacked bars show annual share of total run size that made it to the spawning grounds, was harvested in-river, or was assumed to have been lost during upstream migration to other sources of mortality. Annual spawner abundances can be compared to the habitat-based lower and upper benchmarks, but note that the status designations in Table 15 use 4-yr running geometric means. (B) shaded areas show annual harvest rate and enroute mortality components of the total mortality (red line).

9.3. LIMIT REFERENCE POINT FOR THE OKANAGAN SOCKEYE SALMON SMU BASED ON CU STATUS

Limit Reference Points under the Fish Stock Provisions in DFO's modernized Fisheries Act (2019) are evaluated at the level of SMUs, which include one or more CUs, and are used to trigger rebuilding plans. The recommended approach for assessing whether a Pacific Salmon

SMU has fallen below its LRP is based on the WSP status of the component CUs. It is recommended that when any CU falls within the Red status zone, the SMU is considered to be below its LRP (C.A. Holt et al., 2023; K.R. Holt et al., 2023). Therefore, for cases like Okanagan Sockeye salmon, where the SMU includes only one CU, the status of the CU determines whether the SMU is above its LRP.

Based on the data, the SMU is not considered to be below the LRP, given that the 2023 status was Amber. However, serious future threats to the CU have been identified (Section 11.1). We therefore recommend that the status of the OSO Sockeye salmon CU (and therefore also the status of the Okanagan Sockeye salmon SMU relative to its LRP) be reviewed annually. Annual updates should include an update of the spawner time series, recalculation of standard metrics, and reapplication of the status algorithm. Since our current relative abundance benchmark is based on the spawning capacity model, if there are substantial habitat changes, this should be revisited as well. If this routine update identifies a drastic change in one of the metrics, or a change in status, then a more detailed evaluation of status should be initiated.

Changes in observed spawner abundance for the component populations of the CU provide important context for the CU-level status assessment. The sharp decline in Osoyoos Lake spawners since 2010 is a concerning trend that needs to be monitored closely. On the other hand, the reintroduction of a self-sustaining Sockeye salmon population in Skaha Lake is an important success story and needs to be highlighted in status discussions for this SMU. Similarly, if a self-sustaining spawning population can be established in Okanagan Lake, this would be an important part of the status picture for this CU.

10. CANDIDATE MANAGEMENT REFERENCE POINTS FOR THE OKANAGAN SOCKEYE SALMON SMU

10.1. CANDIDATE MANAGEMENT TARGETS FOR OKANAGAN SOCKEYE POPULATIONS AND SMU

How management reference points align with CU and stock delineations is highly variable among Pacific Salmon in Canada. Recently, an SMU has been defined as a group of one or more CUs and is intended to map management more closely onto the CU structure, which is determined by biological considerations (genetics, life-history, ecotype). For example, abundance-based harvest rules for Fraser River Sockeye salmon were previously specified for four management groups, principally delineated based on run timing, which have since been defined as four SMUs. However, Chum salmon escapement goals are commonly set for individual river systems within a CU (DFO, 2023a), resulting in multiple distinct management targets for components of an SMU.

Given the ongoing range expansion and observed difference in the spawner trends for the Osoyoos and Skaha lake populations, we have provided candidate management reference points for all three lake populations separately, as well as for the overall SMU, based on alternative proportions of the estimates of spawning habitat capacity (assumed to be a proxy for S_{max}).

A target range to guide the identification of an escapement goal for each lake population could be based on an objective of maximum sustainable yield (MSY). With the available information, S_{MSY} could be approximated as 50% of the habitat-based S_{max}, given that 40% of S_{max} has been used to approximate 80% of S_{MSY} (Grant et al., 2020, 2011; Grant and Pestal, 2013), and the target range could span 10% on either side (i.e., 40% to 60% of the habitat-based S_{max}).

Alternatively, a target range for each lake population could be set at 90% to 110% of the habitat-based S_{max} estimate, which would approximate an objective of maximizing total production.

When aggregating reference points across populations, it is important to know the level to which the component populations co-vary. If component populations are perfectly correlated, and the current stock composition matches the relative size of the population-specific reference points, then simply summing across reference points may be sufficient to generate an aggregate reference point. However, if component populations vary independently from each other, then a higher aggregate reference point is required to achieve a high probability that all component populations reach their individual reference points simultaneously. Since two of the populations are at different stages of reintroduction, we are not yet able to determine the level of covariation among lake populations. Therefore, if aggregate target reference points for the whole SMU are required for management purposes, then the target reference points need to be higher than the sum of the individual lake target reference points. Therefore, an S_{MSY} target range for the Okanagan Sockeye salmon SMU could be set at 50%-70% of the habitat-based S_{max} estimate for the SMU, which would provide a 10% buffer above the sum of lake-specific values, to account for variable stock composition. Similarly, a target range at 100% to 120% of the habitat-based S_{max} estimate for the SMU would provide a 10% buffer above the sum of lake-specific S_{max} values.

Table 16 lists the numerical values for each of these candidate target ranges. Note that while the well-established Osoyoos Lake population, and the rapidly growing Skaha population, have met or exceeded estimated capacity values in recent years, the Okanagan Lake component is early in its rebuilding, and is therefore unlikely to reach any of these candidate management reference points in the near future.

Table 16. Examples of candidate management reference points for Okanagan Sockeye salmon in the Okanagan River watershed. Target ranges use alternative proportions of the median habitat-based S_{max} estimate, rounded to the nearest 1,000. For individual lakes, approximate S_{MSY} target is set at 40% to 60% of the habitat-based S_{max} estimate, and the S_{max} target is set at 90% to 110% of the habitat-based S_{max}. For the overall SMU, higher percentage values are used to account for variable stock composition (50%-70% for S_{MSY}, 100%-120% for S_{max}). Note: the performance of these examples of candidate targets has not been tested in forward simulation.

Grouping	**Approximate S_{MSY} Target**	**S_{max} Target**
Osoyoos Lake	43,000 to 64,000	96,000 to 118,000
Skaha Lake	14,000 to 21,000	32,000 to 39,000
Okanagan Lake	19,000 to 29,000	43,000 to 53,000
Okanagan Sockeye salmon SMU	96,000 to 135,000	192,000 to 231,000

10.2. AN ALTERNATIVE VIEW OF REFERENCE POINTS

The ONA strongly believes that we need to learn from the salmon and to be mindful of them (Shayla Lawrence, Fisheries Biologist, Okanagan Nation Alliance, Westbank, BC, pers comm 2024). “Know the ways of the ones who take care of you, so that you may take care of them. Be accountable as the one who comes asking for life. Ask permission before taking. Abide by the answer. Never take the first. Never take the last. Take only what you need. Take only that which is given. Harvest in a way that minimizes harm. Use it respectfully. Share. Give thanks for what you have been given. Sustain the ones who sustain you and the earth will last forever” (Kimmerer, 2015).

The ONA understands that the Sockeye salmon knew that the current targets of escapement (35,500) were inaccurate. The salmon in the past 15 years have shown us this with much higher spawning returns. We need to learn from them. Sockeye salmon are a relative, and like our relatives, we want them to live full and complete lives. Salmon also do not exist just for humans; they also feed the land, the plants, the water, the bears, and the birds. The four-food chief story tells the ONA that Chief *nitytix,* along with all the chiefs, laid down their lives for the people to be. Salmon feed not only the people but also the entire ecosystem and have done so since time immemorial. So a proper lower limit of the Okanagan River basin Sockeye salmon numbers should first take into account how many Sockeye salmon are needed to nurture all the *tmx^{w}ulax^{w}* (land) and *tmix^{w}* (all living beings) in the Okanagan watershed.

Hereditary Chief of the Osoyoos Indian Band, Chief Baptiste Cheanut (cianut Batiste George), wrote to the Royal Commission of Indian Affairs in 1914, "we spoke to you about our trouble when your commission was here Oct 9th. The Indians need fish every day, a short time after we take the land (interpreted as the reserve system) somebody takes the river away from us (interpreted as the Haynes reserve expropriation)." Chief cianut reminds us that the Okanagan Syilx People never consented to being disconnected from the river, and his words touch on the importance of fish to the Syilx community. The Okanagan Nation chooses to be in the rebuilding phase until the Okanagan Sockeye salmon are allowed to go home (be within their traditional territory) in numbers that support the Nation members' access to their traditional food. The Okanagan Nation behaves differently than the governments, as we want the salmon to be there for many generations to come.

11. CONSIDERATIONS FOR THE FUTURE

11.1. FUTURE CLIMATE

11.1.1. Impacts on adult migration and survival

Future climate change poses a major threat to Okanagan adult Sockeye salmon migration and subsequent spawning success. There are three key climate change vulnerabilities along the migration corridor of Okanagan Sockeye salmon that are likely to exert disproportionate impacts on adult Sockeye salmon migration. These include:

1. the warmest reaches of the Columbia River mainstem, which are associated with the reservoirs behind Bonneville, The Dalles, John Day and McNary dams in the lower Columbia River;
2. the temperature in Lake Pateros (also called "Wells Pool" reservoir), which forms above Wells Dam, where adult Sockeye salmon are often constrained to hold before entering the Okanogan River watershed because of a thermal barrier in the latter (Hyatt et al. 2003; 2020); and
3. the 115-km Okanogan River (WA), in which summer water temperatures are typically 3-5 °C warmer than those in Lake Pateros and form a thermal barrier to migration (Hyatt et al., 2020; Stiff et al., in prep.)[15].

Another location that may be negatively impacted by temperature increases is Osoyoos Lake, given its shallowness and tendency to stratify and to develop a deep hypoxic hypolimnion (Cohen and Kulkarni, 2001; Hyatt et al., 2003; Hyatt and Rankin, 1999; Nelitz et al., 2007).

[15] Stiff, H.W., Hyatt, K.D., Stockwell, M.M., and Ogden, A.D. In preparation. Trends in Water Temperature Exposure Indices for Adult Salmon Migration and Spawning in the Okanagan Watershed, 2010-2099. Can. Tech. Rep. Fish. Aquat. Sci.

Adult Sockeye salmon passage in the lower Columbia River is primarily concentrated between June and July. In June, mean daily water temperatures rarely exceed 18 °C in the Bonneville forebay but rise to an average of 20 °C in July due to seasonal warming (CBR-DART). An analysis of the historical record shows that July water temperatures in the lower Columbia River have increased by 2.6 °C since 1949 (USEPA, 2018). Increases in the frequency of dates with elevated thermal conditions of that magnitude are known to negatively affect migration speed, timing, fitness, spatial distribution, and disease profiles of migrating Sockeye salmon (Martins et al., 2012; Miller et al., 2014; Quinn et al., 1997). These temperature-related impacts most likely negatively affected the adult Sockeye salmon in the Columbia River mainstem in 2015, when Bonneville temperatures in June were 3.4 °C above the 10-year average. That year, 61% of the total run was exposed to temperatures greater than 20 °C. In cool, wet years, the percentage of Sockeye salmon exposed to 20 °C temperatures at Bonneville is on average 0.1% of the run (e.g., 1993, 1999, 2011, and 2012). It typically increases to 10-20% in strong El Niño years (1987, 1992, 1998) (CBR-DART). In 2015, Sockeye salmon mortality between Bonneville and McNary dams was approximately twice[16] as high as the multi-year mean recorded for 2006-2014 (Fryer et al., 2017), with mass die-offs of salmon recorded at multiple locations in the basin (NOAA, 2016). A final estimate of the percentage of Okanagan-bound Sockeye salmon that reached the spawning grounds from the mouth of the Columbia River was less than 5% that year (Fryer et al. 2017; Hyatt et al. 2020).

Statistically downscaled Global Climate Model (GCM) projections[17] (Abatzoglou and Brown, 2012) of daily mean air temperature at key sites along the Okanogan/Okanagan River migration corridor (Hyatt et al., 2020) suggest that by 2040-2069, the potential temperature increase during July and August in the lower Okanogan River (near Malott, Washington) will be 3-5°C relative to the 1971-2000 reference period irrespective of emissions scenario (i.e., Representative Concentration Pathway (RCP) trajectory 4.5 or 8.5) (Stiff et al., in prep)[15]. Moreover, the projected increases in water temperatures will also lead to an increase in the frequency and duration of the dates for which the Okanogan River will exceed water temperature thresholds that are stressful (i.e., 18 °C) or fatal (24 °C) for salmon (Cooke et al., 2004; Hinch et al., 2012; Hinch and Martins, 2011). With regard to upstream migration, predictions have shown that during 2040-2069, the median number of dates between June and August when the Okanogan River temperatures will exceed the 22 °C threshold, which blocks upstream migration, is expected to reach 43-51 days as compared to <20 days in the reference period (1971-2000). Additionally, future projections indicate that the median duration of these “thermal barrier” events may rise from 10 days per event (in the reference period) to about 20 days (range: 12-42 days) by the 2040-2069 period. It is therefore expected that natural migration will be impeded in many years due to high summer water temperatures in the Okanogan River (Alexander et al., 1998; Chapman et al., 1995).

A key temperature influence in the Okanogan River watershed is the Similkameen River tributary, which provides 75-80% of Okanogan River flows during peak freshet in May-June from

[16] Inter-dam adult Sockeye salmon ‘survival’ estimates (i.e., dam count conversion rates) between Bonneville and Wells dams averaged 60% between 2006-2017, but dropped to 29% in 2015 (Fryer et al. 2018).

[17] Based on GCM air temperature time-series (January 1, 1950 - December 31, 2099) from an ensemble of 20 CMIP5 GCMs obtained from the University of California Climatology Lab data portal, using a modified Multivariate Adaptive Constructed Analogs (MACA v2) method for GCM data downscaling and bias-correction (Abatzoglou and Brown 2012). Downscaled and bias-corrected GCM air temperature data were statistically converted to water temperature via nonlinear regression modelling (Hyatt et al. 2015, 2020; Stiff et al. unpub.).

the snowy Cascade Mountain range to the west. This inflow exerts a strong cooling effect on the lower Okanogan River[18] during June (and again in autumn), usually maintaining temperatures 3-4 °C lower than in the upper Okanogan River (i.e., above the Similkameen confluence)[19] until freshet flows diminish, usually in mid-July (Stiff et al., in prep.)[15]. Adult Sockeye salmon may take refuge in the lower Similkameen River when temperature conditions in the last 5-10 km of the Okanogan River prohibit movement upstream into Osoyoos Lake (Fryer et al., 2017). However, in years with low winter precipitation and/or warm spring weather, snow-pack levels are reduced and/or the spring freshet ends early (e.g. 2015, 2016, 2019, 2021), thus limiting the cooling effect of Similkameen flows in late spring and early summer on Okanogan River water temperatures (Fryer et al., 2017). Future climate predictions have shown that the currently tolerable July-August water temperatures in the Similkameen (median <18-19 °C) will likely exceed 20 °C by the 2050s (Stiff et al., in prep.)[15]. It is likely that as climate warms, the middle of the run of returning adults will not persist.

Finally, one must also account for the future impacts that climate change may have on the marine survival of the Okanagan Sockeye salmon. While there are no specific studies that quantify these impacts, we know that marine survival is a key factor that has affected Sockeye salmon recovery in the Okanagan River basin (Murauskas et al., 2021). Based on the findings of Hinch & Martins (2011), the majority of the Pacific Sockeye salmon stocks assessed were expected to see a possible decrease in the survival of immatures in the ocean and a very likely decrease in the survival of returning adults.

11.1.2. Impacts on spawning, incubation, and smolt outmigration

The life stages of salmon that are considered most vulnerable to climate change are the returning adult stage and the egg stage (McDaniels et al. 2010).Thermally stressed migrating adults that are able to clear the Okanogan River will have to deal with suboptimal temperature and dissolved oxygen levels in the south and central basins of Osoyoos Lake. It is expected that climate change may also impact Sockeye salmon reproductive success by elevating water temperatures in the Okanagan River spawning grounds during late September and October. The optimum water temperature range for Sockeye salmon spawning is between 10 and 13 °C (Oliver and Fidler, 2001). Future predictions into 2040-2069 estimate a 2-3 °C warming relative to the reference period (1971-2000) (Stiff et al., in prep.)[15]. This increase will be associated with a rise in the frequency of dates with temperatures >15 °C between the last week of September and the end of October. The frequency of exceedance is projected to increase from a mean of 8-9 days to 11-14 days in the 2050s, reaching 13-20 days in the 2080s, depending on the emissions scenarios (i.e., RCP trajectory). The projected change in spawning temperatures could increasingly delay spawning activity, shift peak spawn timing later, and/or restrict the area of suitable spawning habitat, with likely negative impacts on Sockeye salmon reproductive success.

Little research has been devoted so far to potential climate impacts on juvenile life stages of the Okanagan Sockeye salmon. However, the *Climate Projections for the Okanagan Region* report (RDO 2020) projects year-round precipitation increases in the Okanagan region, except for precipitation decreases in summer, with the largest increases expected during the spring and autumn months. On average, the region can expect between 10% and 20% more precipitation

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[18] Okanogan River at Malott, WA (USGS 12447200) - June mean water temperatures: 16.2 ± 3.2 °C (2008-2021).

[19] Okanogan River at Oroville, WA (USGS 12439500) - June mean water temperatures: 20.0 ± 2.2 °C (2008-2021).

during these seasons by the 2080s. Combined with higher temperatures, snowfall will be increasingly replaced by rain events, and snowpack levels will be reduced, affecting the annual hydrograph. Spring melt will occur a month earlier, changing peak freshet flows from April to March. These hydrographic changes would likely result in more winter and spring flood and scour events, which would have the potential to negatively impact Sockeye salmon egg incubation, but might also result in fewer events of desiccation and freezing of incubating eggs.

Winter air temperatures are also projected to increase in the region (RDO 2020), but no modeling of how those temperature ranges will alter water temperatures has yet been conducted. However, these increases in air temperature can be expected to increase river temperatures. Optimum water temperatures for egg incubation range from 4-13 °C (British Columbia Ministry of Environment, 2001). Whereas maximum mean monthly winter water temperatures in the Okanagan River in recent decades (2003-2021) ranged from 3-9 °C in March (ECCC Station 08NM085[20]), projected regional air temperature increases of 2-4 °C by the 2050s and 4-6 °C by the 2080s (RDO 2020) will increase egg incubation degree-days, thereby influencing egg maturation and fry emergence timing. Water temperature increases during incubation are expected to result in smaller fry, earlier emergence, and lower survival in general (Healey, 2011). Earlier emergence timing, in combination with the expected increases in late winter to spring flow rates, will have unknown synergistic effects which might be clarified if new models are developed that estimate the influences of projected temperatures and flows on incubation, emergence and survival.

OSO CU smolt outmigration occurs between April and June, with peak migration around mid-May. Climate change projections indicate that the mean frequency of dates in which mean daily water temperatures exceed 15 °C during outmigration could increase from 25-35 days currently to 41-45 days by the 2050s, mostly in May and June (Stiff et al., in prep.)[15].

11.1.3. Temperature-oxygen "squeeze" in Osoyoos Lake

Of the three rearing lakes, Osoyoos Lake is the most vulnerable to experiencing a temperature-oxygen "squeeze." The temperature-oxygen squeeze occurs when summer hypolimnetic (bottom) oxygen concentrations fall below 4 ppm and the epilimnetic (near-surface) temperatures exceed 17 °C. This squeezes the juvenile Sockeye salmon and migrating Sockeye salmon adults into a small suitable area within the water column (Brett et al., 1969; Brett and Blackburn, 1981). During the squeeze, the deeper waters of the lake no longer mix with surface waters due to thermal stratification, and the dissolved oxygen levels in the deep waters start to decrease because of the decomposition of organic materials and algal cellular respiration. It is hypothesized that if regions of high surface temperatures overlap with the deep hypoxic waters, then the growth and survival of juvenile Sockeye salmon may be compromised, potentially contributing to declines in total returns (Hyatt and Stockwell, 2010). Note that all three basins (south, central, and north) of Osoyoos Lake experience the temperature-oxygen squeeze to varying degrees, with the south and central basins exhibiting almost constant squeezes (entire water column >17°C and <4 ppm dissolved oxygen) during the summer (Hyatt et al., 2017b; Stockwell et al., 2001). Historical acoustic and trawl surveys have shown that during warm summer periods, the south and central basin juvenile Sockeye salmon fry densities were greatly reduced due to high temperatures and very low dissolved oxygen concentrations in the water column. A majority of the fry population appeared to be rearing in the north basin (deeper and cooler). For example, fall Sockeye salmon densities in the south and central basins

[20] Real-Time Hydrometric Data Graph for OKANAGAN RIVER NEAR OLIVER (08NM085) [BC] - Water Level and Flow - Environment Canada (ec.gc.ca)

in 1997 and 1998 averaged only 110 ha^{-1} and 99 ha^{-1}, respectively, compared to 1,005 ha^{-1} and 4,036 ha^{-1} in the north basin (Hyatt & Rankin, 1999; Rensel, 1988, 1996; summarized in Stockwell et al. 2001). It is assumed that the south and central basins of Osoyoos Lake are no longer useable rearing habitat for juvenile Sockeye salmon.

While juvenile Sockeye salmon may be proficient at vertically migrating to water strata with suitable conditions, the squeeze can significantly diminish the amount of suitable habitat. During 2003, the suitable habitat area in the northern basin was less than 30 $x10^6$ m^3. Uncertainty remains regarding whether interannual changes in the squeeze conditions would potentially compromise juvenile Sockeye salmon growth and survival and contribute to declines in total returns. Future projections suggest that both climate-change induced reductions of river inflow and increased nutrient loading to Osoyoos Lake from human development are expected to have substantial and negative impacts on Sockeye salmon returns over the coming decades (Hyatt et al., 2003; Merritt et al., 2006; Daniel Selbie, Head, Lakes Research Program, DFO, pers. comm.).

Although currently under investigation through a long-term monitoring program on the lake, the data so far suggest that the depth of the 17 °C isopleth may be associated with wind speed and epilimnetic water temperature. Although both wind speed and water temperature are beyond the control of fisheries managers, potential future effects of climate warming may be cause for concern. Historical data also show that the factors which regulate the depth of the low-oxygen layer may be associated with river discharge rates. The latter are also known to affect water clarity, productivity, and the food web of the lake McQueen et al. (in prep.)[11].

11.2. FUTURE WORK

The future trajectory of Okanagan Sockeye salmon remains uncertain given the ongoing changes occurring in the Okanagan River basin as well as the Columbia River watershed as a whole. The ongoing range expansion, and the success of the hatchery program in establishing a robust Sockeye salmon population in Skaha Lake, provide optimism that Sockeye salmon will be re-established in Okanagan Lake. Nevertheless, it is critical to continue to track how quickly the Okanagan Lake Sockeye salmon population rebuilds itself.

Competition with resident Kokanee salmon over spawning areas needs to be monitored, particularly in river reaches and creeks that have spawning beds with fine gravel sizes. Competition for spawning habitat between Kokanee and Sockeye salmon spawners is likely in some of those beds. In this study, we provided an initial estimate of the spawning requirements of the ten-year averaged Kokanee salmon populations in Skaha and Okanagan lakes. More field data are needed to better understand the level of competition that may occur over spawning beds between the two ecotypes. So far, field observations have not shown signs of competition over spawning areas in the Skaha Lake spawning beds and grounds (Karilyn Alex, Fisheries Biologist and Fluvial Geomorphologist, Okanagan Nation Alliance, Westbank, BC, pers. comm.). However, this has been largely due to strong Sockeye salmon returns during even years and strong Kokanee salmon spawning during odd years (Karilyn Alex, pers. comm.). Whether this pattern will continue to hold in the future is uncertain. Future monitoring activities should also continue to monitor the abundance of stream spawning Kokanee salmon in Skaha and Okanagan lakes. Instances of in-lake shore spawning of Sockeye salmon and/or redd superimposition there should also be documented if they occur.

The spawning capacity estimates used in this paper to determine status and candidate management reference points represent a snapshot in time in a system that is undergoing range expansion assisted by a hatchery program. Moreover, ONA's plans to build upon the successes of the ORRI may affect future status assessments and require revisiting the proposed candidate management reference points. ONA's vision to "put the rivers back and put the fish back" into their traditional territory (*suxqʷaʔqʷaʔlulaxʷ* ; according to the Syilx traditional ecological knowledge keepers) foresees continuing to improve fish passage and efficiency for all life stages of all anadromous salmonids at all dams within the Okanagan River basin, while accounting for the impacts of climate change within future study designs. This vision also includes the intention to increase fish access up the valley beyond Okanagan Lake, thus opening more spawning and rearing habitat opportunities (Karilyn Alex, pers. comm.).

Past efforts aimed at quantifying the lakes' production (by phytoplankton and zooplankton) and consumption (by nerkids and mysids) rates should continue into the future, given the recorded inter-annual variability of the estimated rearing capacity. Even in the short time series for Osoyoos and Skaha lakes, there was evidence that both lakes may have reached their rearing capacities in specific but different years. In both lakes, high river flows were suspected to have caused a drop in zooplankton abundances. Thus, future work should assess the frequency of extreme flow events and how they affect the lakes' productivity in order to determine lake-specific rearing capacities that are based on acceptable probabilities of the capacity being exceeded in some years. Moreover, the impacts of future climate change on the temperature-oxygen squeeze in Osoyoos Lake should be better quantified and continuously monitored. Significant reductions to available suitable habitat in Osoyoos Lake may prove to be more limiting than prey availability in certain years. The nutrient statuses, and associated limnologies of the Okanagan lakes are changing, and may provide poorer rearing habitat in future, particularly under projected climate changes (Daniel Selbie, pers. comm.). When more data are available, covering a wider range of conditions under different years, a formal sensitivity analysis on the bioenergetic model results should also be implemented.

Additional data on spawners, smolts, and recruits are needed to update the current SR model for the Osoyoos Lake population. Moreover, a SR model should be developed for the populations of Sockeye salmon in Skaha and Okanagan lakes once the relevant data become available. One main uncertainty in the current SR model was the lack of accurate and long-term data needed to quantify the rate of spawner straying between the three populations. Without such data, it is possible that lake-specific spawner estimates may be over- or underestimated, thus confounding our assessment of the status and productivity of each individual population. Finally, there is a need to continue to monitor the impacts of recent increases in harvest on the Okanagan River Sockeye salmon, especially for years in which the 'thermal barrier' forces the spawners to hold in Wells Pool, delaying their entry into Okanagan River and increasing harvest rates on the US side of the border. In some years over the past decade, harvest has exceeded the number of adults reaching the spawning grounds. Overall, our knowledge of this system would be improved if a quantitative model were developed that could estimate how environmental factors and harvesting impact the survival, productivity, and long-term sustainability of Sockeye salmon in the Okanagan River basin.

11.3. MANAGEMENT RECOMMENDATIONS

Although the current WSP status is Amber for this CU, managers should be aware that in return years 2015, 2019, 2021, and 2023, the annual spawner abundance was at or below the lower benchmark for relative abundance, and given the variability within the system, the status of the CU is in danger of becoming Red in the near future.

As we have shown, this CU/SMU is currently undergoing substantial changes due to range expansion, spawning habitat improvements, hatchery-origin releases, and fluctuations in relation to ongoing variations in local climate, especially regarding increased temperatures, smaller snowpacks, and other changes in the timing of water inputs to the system. All of these influences demand that escapements and harvests be very carefully monitored each year by fisheries scientists and managers. Also, these instabilities make it difficult to advise on a specific number of years after which the next escapement goal review should occur. Instead, we recommend close annual attention to the SMU itself to guide when it is appropriate to conduct the next escapement goal review, and when to bring this issue to the tripartite (ONA, DFO, and Province of BC) Canadian Okanagan Basin Technical Working Group (COBTWG) table.

Given climate projections that suggest the middle of the Okanagan Sockeye salmon run is especially threatened by high temperatures in the longer term, and that thermal barriers may become more common throughout the Columbia River watershed, with unpredictable timing, it will be important to protect phenotypic diversity in run timing. Ensuring the survival and reproduction of Sockeye salmon with a variety of run timings may increase the odds of successful migration in the future, as thermal windows of opportunity change. It is also essential to account for thermally stressful sections of the lower Columbia River (e.g., Bonneville Dam), and for the thermal barrier that occurs in the lower Okanogan River above Wells Dam during upstream migration in nearly every year, and that likely will occur earlier and last longer in the future due to climate change. For example, when the returns hold at the mouth of the Okanogan River, or in the Wells Dam forebay due to the upstream thermal barrier, they become subject to opportunistic harvest. Furthermore, when temperatures are high during upriver migration, fisheries-related incidental mortality (FRIM) at these holding locations should be taken into account as catch-and-release can be a death sentence: “The magnitude of the effect of temperature on FRIM can be such that 100% mortality occurs, particularly if high temperatures (e.g., >19°C for Sockeye salmon) are sustained for several days (Gale et al., 2014; Robinson et al., 2013)” (Patterson et al., 2017). In general, opening a fishery when the migration corridor is greater than 16°C will cause FRIM losses that won’t be accounted for by typical harvest reporting.

Because of the projected lower temperatures in Skaha and Okanagan lakes relative to Osoyoos Lake and further downstream (Stiff et al., in prep.)[15], these two lakes may be the future of the CU. Accordingly, the spawning areas associated with them should be allowed to have consistently large escapements to allow for genetic diversification in spawning strategies and migration timing that have the potential to improve the probability of the CU to persist in the longer term.

We recommend the adoption of harvest management rules that explicitly take projected mortality into account. For example, the harvest rules for Fraser River Sockeye salmon prescribe a total allowable mortality that changes with abundance and that is assessed both pre-season and in-season, while developing estimates of en-route mortality. Specifically, the DFO Environmental Watch (EWatch) Program[21] provides scientific advice to managers regarding Pacific salmon harvest in the Fraser River that takes into account environmental factors that occur during in-river migration of returning spawners. The OSO CU would benefit from something similar.

11.4. CONCLUSIONS

The objectives of this CSAS process were to

1. assess the status of the Osoyoos-Skaha-Okanagan Sockeye salmon CU,
2. determine status relative to the Limit Refence Points for the Okanagan Sockeye salmon SMU,

[21] Fraser River environmental watch | Pacific Region | Fisheries and Oceans Canada

3. determine candidate spawning escapement goals for the entire basin, and
4. examine and identify uncertainties in the data and methods that led us to these results.

We have used three different methods to evaluate carrying capacity and to suggest candidate management reference points. Spawning habitat capacities were quantified for all three lake populations that make up the Osoyoos-Skaha-Okanagan Sockeye salmon CU. For the Osoyoos and Skaha lake populations, lake rearing habitat capacities were also determined. Only the Osoyoos Lake Sockeye salmon population had enough data to fit SR models. The SR models proved to be highly sensitive to prior assumptions about the capacity parameter of the Ricker model.

WSP status of the Osoyoos-Skaha-Okanagan CU has been consistently *Amber* since 2016, because generational average spawner abundances have fallen between the lower and upper abundance benchmarks, set at 20% and 40% of the habitat-based S_{max} estimate. However, due to significant climate-related threats, there is a high risk of the CU's status declining to *Red* in the near future. It will therefore be extremely important to track status annually and to identify any changes rapidly.

The habitat-based candidate target ranges presented here reflect contemporary and recent conditions in the Okanagan River basin and are therefore subject to future changes in the abundance and quality of available habitat. Most notably, future habitat restoration projects are anticipated to improve both salmonid passage and spawning habitat, which will undoubtedly increase the system's capacity for Sockeye salmon. The extent to which these restoration objectives will affect the Okanagan River basin's spawning capacity is, however, unquantifiable at present and will likely require follow-up analyses after the selected areas are restored. Similarly, the candidate target ranges presented here do not account for the impacts of future climate change on Okanagan Sockeye salmon. Climatic projections suggest that both the Okanogan and Similkameen rivers will trend towards frequently stressful and potentially lethal conditions for Sockeye salmon in as little as three decades. Recent observations (e.g., 2015) of extreme in-river, temperature-related mortality emphasizes this issue clearly. While the abundance of fish returning to the mouth of the Columbia River underpins many of the models explored here, we can anticipate increasing discordance between estimates of adult returns and the adult escapement on the spawning grounds as migratory habitats become increasingly less hospitable. Moreover, climate-related changes in oceanic conditions are also likely to influence patterns of marine survival. Together, these considerations underscore that climate change is, inescapably, the context in which the Okanagan SMU should be managed. Furthermore, it must be stressed that any management targets that are adopted on the basis of this report should be considered as representing a snapshot of current and recent conditions in the basin.

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13. REFERENCES CITED

Abatzoglou, J.T., and Brown, T.J. 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology. 32: 772–780.

Alex, K.I., and Lukey, N. 2023. Okanagan River Restoration Initiative (ORRI) sq̓awsitkʷ Restoration and Conservation – Refreshing the Vision (Year 2). Prepared by the Okanagan Nation Alliance for the Okanagan River Restoration (ORRI) Initiative Steering Committee, Westbank, BC.

Alex, K.I., Williams, K., and Davis, S. 2020. Okanagan Lake tributaries: prioritization for fish restoration. Prepared for the Colville Confederated Tribes, Okanogan Sub-basin Habitat Improvement Program. Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Alex, K.I., Mathieu, C., and O'Sullivan, A.M. 2024. Okanagan Lake tributary Sockeye Spawning Habitat Assessment. Okanagan Nation Alliance Fisheries Department. Prepared for Federal Fisheries and Oceans CSAS process & Upper Columbia Habitat Improvement Program (UCHIP), Westbank, BC.

Alexander, C.A.D., Alameddine, I., Machin, D., and Alex, K. (*In press*). A weight-of-evidence approach for understanding the recovery of Okanagan Sockeye salmon. Environmental Management.

Alexander, C.A.D., and Hyatt, K.D. 2013. The Okanagan Fish-and-Water Management Tool (Ok-FWMT) record of design (v. 2.4.000). Canadian Okanagan Basin Technical Working Group (COBTWG) and Douglas County Public Utility District No. 1 (DCPUD), Kamloops, BC.

Alexander, C.A.D., Webb, and T.W., Marmorek, D.R. 1998. The Fish Forestry Interaction Project Management Model (FFIP – MM) Preliminary Model Description and an Application to Carnation Creek, British Columbia. Vancouver, BC.

Andrusak, H., Andrusak, S., Matthews, S., Wilson, A., White, T., Askey, P., Sebastain, D., Scholten, G., Woodruff, P., Webster, J., Vidmanic, L., and Stockner, J. 2008. Okanagan Lake Action Plan Years 11 (2006) and 12 (2007) Report (Fisheries Project Report No. 123). Ecosystems Branch, Ministry of Environment, Province of British Columbia.

Armstrong, J. 2020. Living from the land: Food security and food sovereignty today and into the future. In Turner, N.J. (Ed.), Plants, People and Places: The Roles of Ethnobotany and Ethnoecology in Indigenous Peoples' Land Rights in Canada and Beyond (pp. 36–50), McGill-Queen's Press.

Atlas, W.I., Ban, N.C., Moore, J.W., Tuohy, A.M., Greening, S., Reid, A.J., Morven, N., White, E., Housty, W.G., Housty, J.A., Service, C.N., Greba, L., Harrison, S., Sharpe, C., Butts, K.I.R., Shepert, W.M., Sweeney-Bergen, E., Macintyre, D., Sloat, M.R., and Connors, K. 2021. Indigenous Systems of Management for Culturally and Ecologically Resilient Pacific Salmon (*Oncorhynchus spp.*) Fisheries. BioScience. 71: 186–204.

Bailey, C.J., Stiff, H.W., Thompson, P.L., Judson, B., and Ogden, A.D. 2025. Osoyoos Lake Sockeye Salmon (*Oncorhynchus nerka*) return abundance (1977-2023), adult age composition (1985-2023), and marine survival (1998-2021). Can. Manuscr. Rep. Fish. Aquat. Sci. 3282: vi + 49 p.

Batal, M., and Decelles, S. 2019. A scoping review of obesity among Indigenous peoples in Canada. Journal of Obesity. 9741090.

Beauchamp, D.A., Stewart, D.J., and Thomas, G. 1989. Corroboration of a bioenergetics model for sockeye salmon. Transactions of the American Fisheries Society. 118: 597–607.

Berkes, F., Colding, J., and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological applications. 10: 1251–1262.

Blanchet, R., Batal, M., Johnson-Down, L., and Johnson, S. Okanagan Nation Salmon Reintroduction Initiatives, Willows, N. 2021. An Indigenous food sovereignty initiative is positively associated with well-being and cultural connectedness in a survey of Syilx Okanagan adults in British Columbia, Canada. BMC Public Health. 21: 1–12.

Bocking, R.C., Link, M.R., Baxter, B., Nass, B.L., and Jantz, L. 2002. Meziadin Lake biological escapement goal and considerations for increasing yield of sockeye salmon (*Oncorhynchus nerka*). DFO Can. Sci. Advis. Sec. Res. Doc. 2002/124. 55 p.

Borgmann, U., Shear, H., and Moore, J. 1984. Zooplankton and potential fish production in Lake Ontario. Canadian Journal of Fisheries and Aquatic Sciences. 41: 1303–1309.

Brett, J.R., Blackburn, J.M. 1981. Oxygen Requirements for Growth of Young Coho (*Oncorhynchus kisutch*) and Sockeye (*O. nerka*) Salmon at 15 °C. Canadian Journal of Fisheries and Aquatic Sciences. 38: 399–404.

Brett, J.R., Shelbourn, J.E., and Shoop, C.T. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. Journal of the Fisheries Board of Canada. 26: 2363–2394.

British Columbia Ministry of Environment. 2001. British Columbia Water Quality Guidelines For Temperature. Water Protection and Sustainability Branch Environmental Sustainability and Strategic Policy Division. Ministry of Environment Overview Report. 12 pp.

Bull, C.J. 1999. Fisheries habitat in the Okanagan River phase 2: Investigation of selected options. Public Utility District of Douglas County, WA, East Wenatchee, WA.

Bull, C.J. 2000. Okanagan River Habitat Restoration Feasibility. Prepared for Public Utility District No. 1 of Douglas County, Washington and Ministry of Environment, Lands and Parks, Kamloops, BC.

Chang, S.L., Ward, H.G.M., Elliott, L.D., and Russello, M.A. 2022. Genotyping-in-Thousands by sequencing panel development and application for high-resolution monitoring of introgressive hybridization within sockeye salmon. Scientific Reports. 12. 3441.

Chapman, D.W., Peven, C., Giogi, A., Hillman, T., Utter, F., Stevenson, J., and Miller, M. 1995. Status of sockeye salmon in the mid-Columbia region. Don Chapman Consultants Inc, Boise, ID.

Regional Districts of the Okanagan (RDO). 2020. Climate Projections for the Okanagan Region. Regional Districts of North Okanagan (RDNO), Central Okanagan (RDCO), and Okanagan Similkameen (RDOS). February 2020.

Clemens, W., 1939. The fishes of Okanagan Lake and nearby waters. A biological survey of Okanagan Lake, British Columbia. Fish. Res. Board Can. Bull. 56: 27–38.

Cohen, S., Kulkarni, T., 2001. Water management and climate change in the Okanagan basin. Environment Canada and University of British Columbia.

Connors, B.M., Bradley, C.A., Cunningham, C., Hamazaki, T., and Liller, Z.W. 2023. Estimates of biological reference points for the Canadian-origin Yukon River mainstem Chinook Salmon (*Oncorhynchus tshawytscha*) stock aggregate. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/031. iv + 105 p. (Erratum: March 2025)

Cooke, S.J., Hinch, S.G., Farrell, A.P., Lapointe, M.F., Jones, S.R., Macdonald, J.S., Patterson, D.A., Healey, M.C., and Van Der Kraak, G. 2004. Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, British Columbia. Fisheries. 29: 22–33.

Cooley, J., Moore, J., and Geiling, W. 1986. Population dynamics, biomass, and production of the macrozooplankton in the Bay of Quinte during changes in phosphorus loadings. Canadian Special Publication of Fisheries and Aquatic Sciences. 166–176 p.

Correia, M.D., Alexis, S., and Dulic, A. 2024. Bringing the Salmon Home: Case Study of Cross-Cultural Collaboration in the Syilx Okanagan Territory of British Columbia. Ecology and Society Journal 29, 15. Bringing the salmon home: a study of cross-cultural collaboration in the Syilx Okanagan Territory of British Columbia.

Cox-Rogers, S., Hume, J., Shortreed, K., and Spilsted, B. 2010. A risk assessment model for Skeena River sockeye salmon. Can. Manuscr. Rep. Fish. Aquat. Sci. 2920: viii + 60 p.

Cusson, M., Plante, J.,and Genest, C. 2006. Effect of different sampling designs and methods on the estimation of secondary production: A simulation. Limnology and Oceanography: Methods. 4: 38–48.

Deslauriers, D., Chipps, S.R., Breck, J.E., Rice, J.A., and Madenjian, C.P.., 2017. Fish bioenergetics 4.0: an R-based modeling application. Fisheries. 42: 586–596.

DFO. 2005. Canada's Policy for Conservation of Wild Pacific Salmon.

DFO. 2015. Wild salmon policy biological status assessment for conservation units of interior Fraser River Coho Salmon (*Oncorhynchus kisutch*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/022.

DFO. 2016. Integrated Biological Status of Southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) Under the Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/042.

DFO. 2023a. Southern Salmon Integrated Fisheries Management Plan 2023/2024. 23–2280: 639p.

DFO. 2023b. Biological Benchmarks And Building Blocks For Aggregate-Level Management Targets For Skeena And Nass Sockeye Salmon (*Oncorhynchus nerka*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/008.

DFO. 2024. Rapid Status Approximations for Pacific Salmon Derived from Integrated Expert Assessments under Fisheries and Oceans Canada Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Sci. Resp. 2024/004.

Enzenhofer, H.J., and Hume, J.M. 1989. Simple closing midwater trawl for small boats. North American Journal of Fisheries Management. 9: 372–377.

Ernst, A. 1999. Okanagan Nation Fisheries Commission Dam Research: Final Draft. Okanagan Nation Fisheries Commission, Westbank, BC.

Ernst, A. 2000. Aboriginal fisheries information within the Okanagan basin. Okanagan Nation Fisheries Commission by the Okanagan Nation Alliance, Westbank, B.C.

Fenton, L. 1960. The sum of log-normal probability distributions in scatter transmission systems. IRE Transactions on communications systems. 8: 57–67.

Ferguson, R. 1949. The interrelations among the fish populations of Skaha Lake, British Columbia and their significance in the production of Kamloops trout (Salmo gairdnerii kamloops Jordan). Department of Zoology. University of British Columbia, Vancouver.

Freshwater, C., Holt, K.R., Huang, A.-M., and Holt, C.A. 2020. Benefits and limitations of increasing the stock-selectivity of Pacific salmon fisheries. Fisheries Research. 226: 105509

Fryer, J.K. 1995. Columbia Basin sockeye salmon: Causes of their past decline, factors contributing to their present low abundance, and future outlook. University of Washington, Seattle, WA.

Fryer, J.K., Kelsey, D., Wright, H., Folks, S., Bussanich, R., Hyatt, K.D., Selbie, D.T., and Stockwell, M.M. 2017. Studies into factors limiting the abundance of Okanagan and Wenatchee Sockeye Salmon in 2015 (No. 17– 06), Columbia River Inter-Tribal Fish Commission Technical Report. Columbia River Intertribal Fish Commission (CRITFC), Portland, OR.

Gale, M.K., Hinch, S.G., Cooke, S.J., Donaldson, M.R., Eliason, E.J., Jeffries, K.M., Martins, E.G., and Patterson, D.A. 2014. Observable impairments predict mortality of captured and released sockeye salmon at various temperatures. Conservation Physiology. 2(1), PMC4806721.

Grant, S.C.H. & G. Pestal. 2013. Integrated Biological Status Assessments Under the Wild Salmon Policy Using Standardized Metrics and Expert Judgement: Fraser River Sockeye Salmon (*Oncorhynchus nerka*) Case Studies. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/106. v + 132 p.

Grant, S.C.H., Holt, C.A., Pestal, G., Davis, B.M. and MacDonald, B.L. 2020. The 2017 Fraser Sockeye Salmon (*Oncorhynchus nerka*) Integrated Biological Status Re-Assessments Under the Wild Salmon Policy Using Standardized Metrics and Expert Judgment. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/038. vii + 211 p.

Grant, S.C.H., MacDonald, B.L., Cone, T.E., Holt, C.A., Cass, A., Porszt, E.J., Hume, J.M.B., and Pon, L.B. 2011. Evaluation of Uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy Status using Abundance and Trends in Abundance Metrics. DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/087. viii + 183 p.

Hamazaki, T. 2023. Pacific salmon escapement goal analyses. Shiny App.

Hanson, P.C., Johnson, T.B., Schindler, D.E., Kitchell, J. 1997. Fish Bioenergetics 3.0 for Windows.

Hartman, K.J., and Kitchell, J.F. 2008. Bioenergetics modeling: progress since the 1992 symposium. Transactions of the American Fisheries Society. 137: 216–223.

Hawkshaw, M.A. 2018. Evaluating the impacts of current and alternative harvest strategies on salmon populations and fishing fleets using the Skeena river as a case study. University of British Columbia.

Healey, M. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Canadian Journal of Fisheries and Aquatic Sciences. 68: 718–737.

Hewes, G.W., 1998. Fishing, in: Handbook of North American Indians. Smithsonian Institution, Washington, D.C., pp. 620–640.

Hilborn, R., and Walters, C.J. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Springer US, Boston, MA.

Hilborn, R., Bue, B.G., and Sharr, S., 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences. 56: 888–896.

Hinch, S.G., and Martins, E.G. 2011. A review of potential climate change effects on survival of Fraser River sockeye salmon and an analysis of interannual trends in en route loss and pre-spawn mortality (No. Cohen Commission Tech. Rept. 9). Vancouver, B.C.

Hinch, S., Cooke, S., Farrell, A., Miller, K., Lapointe, M., and Patterson, D. 2012. Dead fish swimming: a review of research on the early migration and high premature mortality in adult Fraser River sockeye salmon Oncorhynchus nerka. Journal of Fish Biology. 81: 576–599.

Holt, C.A., 2009. Evaluation of benchmarks for Conservation Units in Canada's Wild Salmon Policy: Technical documentation. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/059. x + 50 p.

Holt, C., Cass, A., Holtby, B., and Riddell, B. 2009. Indicators of status and benchmarks for conservation units in Canada's Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/058. viii + 74 p.

Holt, C.A., and Ogden, A. 2013. Software for assessing status of Conservation Units under Canada's Wild Salmon Policy: Instructional manual. Can. Tech. Rep. Fish. Aquat. Sci. 3058: v + 43 p.

Holt, C.A., Davis, B., Dobson, D., Godbout, L., Luedke, W., Tadey, J., and Van Will, P. 2018. Evaluating Benchmarks of Biological Status for Data-limited Conservation Units of Pacific Salmon, Focusing on Chum Salmon in Southern BC. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/011. ix + 77 p.

Holt, C.A., Michielsens, C.G. 2020. Impact of time-varying productivity on estimated stock–recruitment parameters and biological reference points. Canadian Journal of Fisheries and Aquatic Sciences. 77: 836–847.

Holt, C.A., Holt, K., Warkentin, L., Wor, C., Connors, B., Grant, S., Huang, A.-M., and Marentette, J. 2023. Guidelines for Defining Limit Reference Points for Pacific Salmon Stock Management Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/009. iv + 66 p.

Holt, K.R., Holt, C.A., Warkentin, L., Wor, C., Davis, B., Arbeider, M., Bokvist, J., Crowley, S., Grant, S., Luedke, W., McHugh, D., Picco, C., and Van Will, P. 2023. Case Study Applications of LRP Estimation Methods to Pacific Salmon Stock Management Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/010. iv + 129 p.

Holt, R.D., and Polis, G.A. 1997. A theoretical framework for intraguild predation. The American Naturalist. 149: 745–764.

Holtby, L.B., and Ciruna, C. 2007. Conservation units for pacific salmon under the wild salmon policy. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/070. viii + 350 p.

Hatchery Scientific Review Group (HSRG). 2009. Columbia River Hatchery Reform System-Wide Report. Bonneville Power Administration (BPA), Portland, OR, Portland, Oregon.

HSRG, 2014. On the Science of Hatcheries: An updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest.

Huang, A-M., Pestal, G., and Guthrie, I. 2021. Recovery Potential Assessment for Fraser River Sockeye Salmon (*Oncorhynchus nerka*) – Nine Designatable Units: Probability of Achieving Recovery Targets - Elements 12, 13, 15, 19-22. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/043. x + 96.

Hyatt, K.D., and Rankin, D.P., 1999. A habitat based evaluation of Okanagan sockeye salmon escapement objectives. Canadian Stock Assessment Secretariat. 99/91: 59 p.

Hyatt, K.D., and Stockwell, M.M. 2010. Fish and Water Management Tool project assessments: Record of management strategy and decisions for the 2006 - 2007 water year. Can. Manuscr. Rep. Fish. Aquat. Sci. 2913: ix + 65 p.

Hyatt, K.D., and Stockwell, M.M. 2013. Fish and Water Management Tools project assessments: Record of management strategy and decisions for the 2007 – 2008 water year. Can. Manuscr. Rep. Fish. Aquat. Sci. 3022: ix + 70 p.

Hyatt, K.D., and Stockwell, M.M. 2019. Chasing an Illusion? Successful restoration of Okanagan River Sockeye Salmon in a sea of uncertainty, in: Krueger, C.C., Taylor, W.W., Youn, S. (Eds.), From Catastrophe to Recovery: Stories of Fish Management Success. American Fisheries Society, Bethesda, MD, 65–100 pp.

Hyatt, K.D., Stockwell, M.M., and Rankin, D.P. 2003. Impact and Adaptation Responses of Okanagan River Sockeye Salmon (*Oncorhynchus nerka*) to Climate Variation and Change Effects During Freshwater Migration: Stock Restoration and Fisheries Management Implications. Canadian Water Resources Journal 28: 689–713.

Hyatt, K.D., Alexander, C.A.D., and Stockwell, M.M. 2015. A decision support system for improving “fish friendly” flow compliance in the regulated Okanagan Lake and River System of British Columbia. Canadian Water Resources Journal. 40: 87–110

Hyatt, K.D., Machin, D., Stockwell, M.M., Mathieu, C., Reimer, S., and White, T., 2017a. Okanagan Fish and Water Management Tools (FWMT) year 2016-2017 (Prepared for the FWMT Steering Committee and Douglas County PUD). Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Hyatt, K.D., McQueen, D.J., Rankin, D.P., Stockwell, M.M., Wright, H., Lawrence, S., Stevens, A., Mathieu, C., and Weins, L. 2017b. Methods and summary data for limnology and food web structure in Osoyoos Lake, B.C. (2005-2013); Revised. Can. Data Rep. Fish. Aquat. Sci. 1274: vii + 73 p.

Hyatt, K.D., McQueen, D.J., and Ogden, A.D., 2018a. Have invasive mysids (*Mysis diluviana*) altered the capacity of Osoyoos Lake, British Columbia to produce sockeye salmon (*Oncorhynchus nerka*)? Open Fish Science Journal. 11: 1–26.

Hyatt, K.D., Ogden, A., Stockwell, M.M., 2018b. Impacts of the 2010 Testalinden Dam Breach on Aquatic Food Webs and Planktivores (*Oncorhynchus nerka and Mysis diluviana*) at Osoyoos Lake. 2018 WA-BC Annual Meeting, 22 March 2018, Kelowna, BC.

Hyatt, K.D., Withler, R., and Garver, K. 2018c. Review of recent and proposed Okanagan Sockeye Salmon (*Oncorhynchus nerka*) fry introductions to Skaha and Okanagan lakes: history, uncertainties, and implications. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/014. vi + 38 p.

Hyatt, K. D., Stiff, H. W. and Stockwell, M. M. 2020. Historic water temperature (1924-2018), river discharge (1929-2018), and adult Sockeye Salmon migration (1937-2018) observations in the Columbia, Okanogan, and Okanagan rivers. Can. Manuscr. Rep. Fish. Aquat. Sci. 3206: xv + 203 p.

Hyatt, K.D., McQueen, D.J., Ogden, A.D., Benson, R., Yaniw, N., Mathieu, C., Stockwell, M.M., Wiens, L., and Wright, H. 2021a. Methods, Summary Data (2014-2017), and Errata (2005-2013) for Limnology and Food Web Structure in Skaha Lake, B.C. Can. Data Rep. Fish. Aquat. Sci. 1327: viii + 61 p.

Hyatt, K.D, McQueen, D.J., Ogden, A.D., Benson, R., and Wright, H. 2021b. Age-Structured Interactions among Reintroduced Sockeye Salmon, Resident Kokanee, Invasive Mysids, and their Zooplankton Prey in Skaha Lake, British Columbia. North American Journal of Fisheries Management. 41: 1246–1273.

Jensen, E.V., Sokal, M., St. Hilaire, D., Rieberger, K., and McQueen, D., 2012. Water quality assessment and objectives for Osoyoos Lake: a first update. British Columbia Ministry of the Environment.

Joint Columbia Rivers Management Staff (JCRMS), 2022. 2022 Joint Staff Report: Stock Status and Fisheries for Spring Chinook, Summer Chinook, Sockeye, Steelhead, and Other Species. Oregon Department of Fish & Wildlife and Washing Department of Fish & Wildlife, Salem, OR.

Judson, B., Willard, C., and Stiff, H. 2023. Age composition, size, migration timing, and estimation of smolt-to-adult survival of natural-origin Sockeye Salmon (*Oncorhynchus nerka*) in the Wenatchee River (WA) watershed (1997-2019). Can. Manuscr. Rep. Fish. Aquat. Sci. 3269: xi + 43 p.

Kennedy, D., and Bouchard, R.T. 1998. Northern Okanagan, Lakes and Colville, in: Handbook of North American Indians. Smithsonian Institution, Washington, D.C., pp. 238–252.

Kimmerer, R. 2015. Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants. Milkweed editions, Minneapolis, MN.

Kondolf, G.M. 1997. Application of the pebble count notes on purpose, method, and variants. Journal of the American Water Resources Association. 33: 79–87.

Korman, J., and English, K.K. 2013. Benchmark analysis for Pacific salmon Conservation Units in the Skeena Watershed (Prepared for Pacific Salmon Foundation). Ecometric Research Inc. and LGL Ltd., Vancouver, BC.

Kuo, J., Soon, A.Y., Garrett, C., Wan, M.T., and Pasternak, J.P. 2012. Agricultural pesticide residues of farm runoff in the Okanagan Valley, British Columbia, Canada. Journal of Environmental Science and Health, Part B 47” 250–261.

Levy, D.A. 1990. Sensory Mechanism and Selective Advantage for Diel Vertical Migration in Juvenile Sockeye Salmon, *Oncorhynchus nerka*. Canadian Journal of Fisheries and Aquatic Sciences. 47: 1796–1802.

Lo, C.F. 2013. WKB approximation for the sum of two correlated lognormal random variables. Applied Mathematical Sciences. 7: 6355–6367.

Long, K. 2005. History and configuration of Okanagan Falls, BC. Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

MacLennan, D.N., and Simmonds, E.J. 1992. Fisheries acoustics: theory and practice, 2nd ed. Chapman and Hall, London.

Major, R., and Mighell, J. 1967. Influence of Rocky Reach Dam and the temperature of the Okanogan River on the upstream migration of sockeye salmon: Fish Bulletin. v. 66.

Martins, E.G., Hinch, S.G., Cooke, S.J., and Patterson, D.A. 2012. Climate effects on growth, phenology, and survival of sockeye salmon (*Oncorhynchus nerka*): a synthesis of the current state of knowledge and future research directions. Rev Fish Biol Fisheries. 22: 887–914.

Mathieu, C., Machin, D., Ogden, A., King, K., Reimer, S., Louie, C., and Alex, K.I. 2023. Okanagan Fish and Water Management Tools (FWMT) year 2022-2023, Prepared for the FWMT Steering Committee and Douglas County PUD. Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

McDaniels, T., Wilmot, S., Healey, M., and Hinch.,S. 2010. Vulnerability of Fraser River sockeye salmon to climate change: A life cycle perspective using expert judgments. Journal of Environmental Management. 91(12): 2771-2780.

McQueen, D.J., and Yan, N.D. 1993. Metering filtration efficiency of freshwater zooplankton hauls: reminders from the past. Journal of Plankton Research. 15: 57–65.

Merritt, W.S., Alila, Y., Barton, M., Taylor, B., Cohen, S., and Neilsen, D. 2006. Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia. Journal of Hydrology. 326: 79–108.

Miller, K.M., Teffer, A., Tucker, S., Li, S., Schulze, A.D., Trudel, M., Juanes, F., Tabata, A., Kaukinen, K.H., and Ginther, N.G. 2014. Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. Evolutionary Applications. 7: 812–855.

Miller, S.E., G. Pestal, J. A. Bednarski, J. Mackenzie-Grieve, T. Wallace, K. Carlick, C. Frocklage, K. Courtney, A. W. Piston, E. L. Jones III, and B. Waugh. 2024. Estimates of a Biologically-Based Spawning Goal and Management Benchmarks for the Canadian-Origin Stikine River Sockeye Salmon Stocks. Pacific Salmon Comm. Tech. Rep. No. 55: 45 p.

Murauskas, J., Hyatt, K.D., Fryer, J., Koontz, E., Folks, S., Bussanich, R., and- Shelby, K. 2021. Migration and survival of Okanagan River Sockeye Salmon Oncorhynchus nerka, 2012–2019. Animal Biotelemetry. 9: 1–16.

Myers, R.A. 2001. Stock and recruitment: generalizations about maximum reproductive rate, density dependence, and variability using meta-analytic approaches. ICES Journal of Marine Science. 58: 937–951.

National Oceanographic and Atmospheric Administration (NOAA), 2022. Rebuilding Interior Columbia Basin Salmon and Steelhead (No. Supplemental Informational Report 3).

NOAA, 2016. 2015 Adult Sockeye Salmon passage report (No. Report prepared by NOAA Fisheries in Collaboration with the U.S. Army Corps of Engineers and Idaho Department of Fish and Game). NOAA Fisheries.

Nehlsen, W., Williams, J.E., and Lichatowich, J.A. 1991. Pacific Salmon at the Crossroads: Stocks at Risk from California, Oregon, Idaho, and Washington. Fisheries. 16: 4–21.

Nelitz, M., Alexander, C.A.D.and, Wieckowski, K. 2007. Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Case study perspectives from the Okanagan, Quesnel, Nicola, Cowichan, Nass, and Englishman River watersheds. Pacific Fisheries Resource Conservation Council, Vancouver, B.C.

NOAA, 2016. 2015 Adult Sockeye Salmon passage report (No. Report prepared by NOAA Fisheries in Collaboration with the U.S. Army Corps of Engineers and Idaho Department of Fish and Game). NOAA Fisheries.

Northcote, T.G., Halsey, T.G., and Macdonald, S.J. 1972. Fish as Indicators of Water Quality in the Okanagan Basin Lakes, British Columbia (No. Rep. No. 22.). Okanagan Basin Study Comm.

Northwest Power and Conservation Council (NPCC). 2004. The Okanogan Subbasin Management Plan. Prepared for the Northwest Power and Conservation Council. 124 p.

Okanagan Nation Alliance. 2001. Evaluation of an experimental reintroduction of Sockeye Salmon into Skaha Lake, year 1 of 3. Prepared for the Okanagan Nation Fisheries Commission, Okanagan Nation Alliance, Westbank, B.C.

Okanagan Nation Alliance. 2002. Evaluation of an experimental reintroduction of Sockeye Salmon into Skaha Lake, year 2 of 3. Prepared for the Okanagan Nation Fisheries Commission, Okanagan Nation Alliance, Westbank, B.C.

Okanagan Nation Alliance. 2003. Evaluation of an experimental reintroduction of Sockeye Salmon into Skaha Lake, year 3 of 3. Prepared for the Okanagan Nation Fisheries Commission, Okanagan Nation Alliance, Westbank, B.C.

Okanagan Nation Alliance. 2018. Okanagan Nation Alliance. (accessed 3.20.24).

Okanagan Nation Alliance. 2023. Our Projects – Okanagan Nation Alliance. (accessed 10.24.23).

Okanagan Nation Alliance. 2023. iʔ smymayət tə scwin (Our Salmon Story): Honouring Syilx Responsibilities and Relationships to Salmon. Prepared for the Okanagan Nation Alliance, Westbank, B.C.

Oliver, G.G., and Fidler, L.E. 2001. British Columbia water quality guidelines for temperature. Ministry of the Environment, Lands and Parks, Victoria, BC.

O’Sullivan, A.M., and Alex, K.I. 2024. Establishing present day Sockeye salmon (*Oncorhynchus nerka*| *sćwin*) spawning capacity in the highly impacted sq̓awsitkʷ|Okanagan River to guide population conservation and restoration. River Research and Applications. 1-10.Paloheimo, J.E. 1974. Calculation of instantaneous birth rate. Limnology and Oceanography. 19: 692–694.

Parken, C.K., McNicol, R.E., and Irvine, J.R. 2006. Habitat-based methods to estimate escapement goals for data limited Chinook salmon stocks in British Columbia, 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/083. vii + 67 p.

Patterson, D.A., Robinson, K.A., Raby, G.D., Bass, A.L., Houtman, R., Hinch, S.G., and Cooke, S.J. 2017. Guidance to Derive and Update Fishing-Related Incidental Mortality Rates for Pacific Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/011. vii + 56 p.

Perrin, C.J., and Irvine, J.R., 1990. A review of survey life estimates as they apply to the area-under-the-curve method for estimating the spawning escapement of Pacific salmon. Can. Tech. Rep. Fish. Aquat. Sci. 1733: 49 p.

Pestal, G., MacDonald, B.L., Grant, S.C.H., and Holt, C.A. 2023. State of the Salmon: rapid status assessment approach for Pacific salmon under Canada's Wild Salmon Policy. Can. Tech. Rep. Fish. Aquat. Sci. 3570: xiv + 200 p.

Peterman, R.M., Pyper, B.J., Grout, J.A. 2000. Comparison of parameter estimation methods for detecting climate-induced changes in productivity of Pacific salmon (*Oncorhynchus spp.*). Canadian Journal of Fisheries and Aquatic Sciences. 57: 181–191.

Peterman, R.M., Pyper, B.J., and MacGregor, B.W. 2003. Use of the Kalman filter to reconstruct historical trends in productivity of Bristol Bay sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences. 60: 809–824.

Peters, C.N., Bernard, D.P., and Marmorek, D. 1998. Should sockeye be re-introduced to Okanagan Lake? An exploration of potential benefits, impacts and uncertainties. ESSA Technologies Ltd., Vancouver B.C.

Phare, M.-A.S. 2009. Denying the source: The crisis of First Nations water rights. Rocky Mountain Books Ltd.

Pinsent, M., and Stockner, J. 1974. The Limnology of the Major Okanagan Basin Lakes (No. Tech Suppl. 5). Office of the Study Director, Penticton, BC.

Quinn, T.P. 2018. The Behavior and Ecology of Pacific Salmon and Trout, 2nd ed. University of Washington Press.

Quinn, T.P., Hodgson, S., and Peven, C. 1997. Temperature, flow, and the migration of adult sockeye salmon (Oncorhynchus nerka) in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences. 54: 1349–1360.

Regina v. Sparrow. 1990. 1990 CanLII 104 (SCC) | R. v. Sparrow | CanLII

Regional Districts of the Okanagan (RDO). 2020. Climate Projections for the Okanagan Region. Regional Districts of North Okanagan (RDNO), Central Okanagan (RDCO), and Okanagan Similkameen (RDOS). February 2020.

Rae, R. 2005. The State of Fish and Fish Habitat in the Okanagan and Similkameen Basins. Canadian Okanagan Basin Technical Working Group, Westbank, B.C.

Rae, R. Andrusak, H., 2006. Ten year summary of the Okanagan Lake Action Plan 1996-2005. Ministry of Environment, Penticton, B.C.

Rensel, J. 1988. Water quality of Lake Osoyoos during 1997, fourth annual report. Rensel Associates, Arlington, WA.

Rensel, J. 1996. Second Annual Report: Water quality and sockeye salmon enhancement in Lake Osoyoos during 1995. Rensel Associates, Arlington, WA.

Riebe, C.S., and Sklar, L.S., Overstreet, B.T., and Wooster, J.K. 2014. Optimal reproduction in salmon spawning substrates linked to grain size and fish length. Water Resources Research. 50: 898–918.

Rivard-Sirois, C. 2021. Year 2: Planning of the Okanagan River Restoration Initiative (ORRI) VDS Section in Okanagan Falls. Okanagan River Restoration Initiative (ORRI) VDS Section in Okanagan Falls. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Robinson, K.A., Hinch, S.G., Gale, M.K., Clark, T.D., Wilson, S.M., Donaldson, M.R., Farrell, A.P., Cooke, S.J., and Patterson, D.A. 2013. Effects of post-capture ventilation assistance and elevated water temperature on sockeye salmon in a simulated capture-and-release experiment. Conservation Physiology. 1(1): cot015.

Scheuerell, M.D. 2016. An explicit solution for calculating optimum spawning stock size from Ricker's stock recruitment model. PeerJ. 4: e1623. An explicit solution for calculating optimum spawning stock size from Ricker's stock recruitment model [PeerJ]

Shepherd, B.G. 1999. A case history: the Kokanee stocks of Okanagan Lake, in: Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk. Presented at the Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, BC, B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C., Kamloops, B.C., pp. 609–616.

Slaney, T.L., Hyatt, K.D., Northcote, T.G., Fielden, and R.J. 1996. Status of Anadromous Salmon and Trout in British Columbia and Yukon. Fisheries. 21: 20–35.

Stan Development Team. 2024. Stan Modeling Language Users Guide and Reference Manual, v2.34.1.

Stockner, J., Northcote, T. 1974. Recent limnological studies of Okanagan Basin lakes and their contribution to comprehensive water resource planning. Journal of the Fisheries Board of Canada. 31: 955–976.

Stockwell, M.M. and Hyatt, K.D. 2003. A summary of Okanagan sockeye salmon (*Oncorhynchus nerka*) escapement surveys by date and river segment from 1947 to 2001. Can. Data. Rep. Fish. Aquat. Sci. 1106: 34 p. plus data CD-ROM.

Stockwell, M. M., Hyatt, K. D., and D. P. Rankin. 2001. A compendium of historic physical variable observations including air temperature, water temperature, river discharge, and dissolved oxygen conditions in selected portions of the Okanagan Basin in Canada and the United States. Can. Data. Rep. Fish. Aquat. Sci. 1078: 8 p. + CD-ROM.

Stockwell, M.M., Hyatt, K.D., Alex, K., Louie, C., and Machin, D. 2020. Methods and Summary Observations of Okanagan Sockeye Salmon Spawn Timing, Fry Emergence, and Associated Water Temperatures (Brood Years 2002-2018). Can. Data. Rep. Fish. Aquat. Sci. 1300: vii + 61 p.

Tannant, D.D., and Skermer, N. 2013. Mud and debris flows and associated earth dam failures in the Okanagan region of British Columbia. Canadian Geotechnical Journal. 50: 820–833.

Turner, N.J., Ignace, M.B., and Ignace, R. 2000. Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. Ecological applications. 10: 1275–1287.

United Stated Environmental Protection Agency (USEPA). 2018. Assessment of Climate Change Impacts on Temperature of the Columbia and Snake Rivers. EPA Region 10, Seattle, WA.

Veale, A.J. and, Russello, M.A. 2016. Sockeye salmon repatriation leads to population re-establishment and rapid introgression with native kokanee. Evolutionary Applications. 9: 1301–1311.

Vernon, R.V. 2015. A Native perspective: Food is more than consumption. Journal of Agriculture, Food Systems, and Community Development. 5: 137–142.

Walters, C.J., Hilborn, R., and Christensen, V. 2008. Surplus production dynamics in declining and recovering fish populations. Can. J. Fish. Aquat. Sci. 65: 2536–2551.

Webster, J. 2007. Kokanee stream spawner enumeration of the Okanagan basins main lakes. British Columbia Ministry of Environment, Victoria, B.C.

Withler, R.E., Bradford, M.J., Willis, D.M., and Holt, C. 2018. Genetically Based Targets for Enhanced Contributions to Canadian Pacific Chinook Salmon Populations. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/019. xii + 88 p. (Erratum: October 2023)

Wolman, M.G., 1954. A method of sampling coarse river-bed material. Transactions American Geophysical Union - Wiley Online. 35: 951-956.

Wor, C., Greenberg, S.A., and Pestal, G. 2024. samEst: Salmon Stock Recruitment Estimation Models. R package.

Wright, H., and Smith, H. 2004. Management Plan for Experimental Reintroduction of Sockeye into Skaha Lake; Proposed Implementation, Monitoring, and Evaluation, 2004 Technical Report. Bonneville Power Administration, Portland, OR.

14. APPENDICES

14.1. APPENDIX A

Data Sources, Funding Agencies, and Associated Data Repositories

Table A1. Data sources, funding agencies, and associated data repositories. Abbreviations (alphabetically): British Columbia Ministry of Forests (BC MoF),Chelan County Public Utility District (CCPUD), Columbia River Intertribal Fish Commission (CRITFC), Colville Confederated Tribes (CCT), Douglas County Public Utility District (DCPUD), Fisheries and Oceans Canada (DFO), Grant County Public Utility District (GCPUD). See footnotes for the data that are available online. Additional data will be available online at DFO Library in 2025.

Lake Unit	Data type	Metric	Years	Project Funder	Study area
Osoyoos population	In-lake acoustic1	Nerkid juvenile population estimates	2005-2023	DCPUD, DFO (Pacific Salmon Strategy Initiative)	Osoyoos Lake
Osoyoos population	In-lake trawl1	Nerkid juvenile - length/weight/growth/survival/stomach contents	2005-2023	DCPUD, DFO (Pacific Salmon Strategy Initiative)	Osoyoos Lake
Osoyoos population	In-lake food web dynamics1	Water temperature, dissolved oxygen (DO)/discharge/nutrients	2005-2023	DCPUD	Osoyoos Lake
Osoyoos population	Sockeye salmon spawning enumeration	Nerkid adult spawning population estimates	2000-current	DCPUD, DFO	Okanagan River (Oliver-Osoyoos)
Osoyoos population	Sockeye salmon spawning redd analysis	Spawning distribution, quantities and habitat metrics	2000-2004 & 2008	DCPUD	Okanagan River (Oliver-Osoyoos)

Lake Unit	Data type	Metric	Years	Project Funder	Study area
Osoyoos population	Sockeye salmon deadpitch and biosampling	Adult Sockeye and Kokanee salmon - age, length and fecundity (pre-2013)	2000-current	DCPUD	Okanagan River (Oliver-Osoyoos)
Osoyoos population	Sockeye salmon spawning assessments	Spawning enumeration	2002	BPA	Okanagan River (Oliver-Osoyoos)
Osoyoos population	Juvenile Biosampling - length/weight/stomach contents1	Nerkid juvenile length/weight/stomach contents- length/weight/stomach contents	2005-2024	CRITFC, GCPUD, CCPUD	Osoyoos Lake
Osoyoos population	Mysid & Zooplankton1	Density and biomass; Mysid stomach contents (2005-2017)	2005-2023	GCPUD, CCPUD, DFO	Osoyoos Lake
Skaha population	Mysid & Zooplankton2	Density and biomass; Mysid stomach contents (2005-2017)	2005-2023	GCPUD, CCPUD, DFO	Skaha Lake
Skaha population	In-lake acoustic2	Nerkid juvenile population estimates	2005-2023	GCPUD, CCPUD, DFO	Skaha Lake
Skaha population	In-lake trawl2	Nerkid juvenile - length/weight/growth/survival	2005-2023	GCPUD, CCPUD, DFO	Skaha Lake
Skaha population	Sockeye and kokanee salmon spawning enumerations	Nerkid adult spawning population estimates	2005-2023	GCPUD, CCPUD, DFO	Penticton Channel

Lake Unit	Data type	Metric	Years	Project Funder	Study area
Skaha population	Deadpitch and biosampling	Nerkid adult - length/weight/otoliths for hatchery proporation/genetics archive	2005-2023	GCPUD, CCPUD, DFO	Penticton Channel
Skaha population	Juvenile biosampling - length/weight/stomach contents2	Nerkid juvenile length/weight/stomach contents- length/weight/stomach contents	2005-2025	CRITFC, GCPUD, CCPUD	Skaha Lake
Osoyoos and Skaha populations	Redd assessments, gravel size field and drone surveys	Gravel D50 and D84 sizes.	2019-2024	DCPUD	Okanagan River
Okanagan population	Redd assessments, Particle size measurement through field surveys	Gravel D50 and D84 sizes.	2023	CCT - Okanogan Subbasin Habitat Improvement Program/Upper Columbia Habitat Improvement Program; DFO	Okanagan Lake Tributaries
Okanagan population	Kokanee salmon river spawners enumeration and biosampling	Adult Kokanee salmon - population and distribution	2000-current	BCMoF	Okanagan Lake tributaries

14.2. APPENDIX B

STAN code for the Basic Ricker Model

This version has been modified from the January 2024 version of the *samEst* package (Wor et al., 2024), available at https://github.com/Pacific-salmon-assess/samEst. This model specification is for a static Ricker model without time-varying parameters or autocorrelation in error terms, within the *sr_mod()* function of the package.

```
m="data{
  int<lower=1> N;//number of annual samples (time-series length)
  vector[N] R_S; //log(recruits per spawner)
  vector[N] S; //spawners in time T
  real log_b_mean; // mean for normal distribution of log_b prior
  real log_b_sd; // sd for normal distribution of log_b prior
  real log_b_lb; // lower bound of log_b prior
  real log_b_ub; // upper bound of log_b prior
}
parameters {
// prior tracking as per https://stackoverflow.com/a/57718910
// priors to sample from
    real p_log_a;
    real p_log_b;
    real p_sigma;
// real priors
  real log_a;// initial productivity (on log scale)
  real<lower = log_b_lb, upper = log_b_ub> log_b; // rate capacity
  real<lower = 0> sigma;  //variance components
}
transformed parameters{
  real b;
  b = exp(log_b); //prevents b (density dependence) from being negative (ie. positive)
}
model{
// priors to track
  p_log_a ~ normal(1.5,2.5); //intrinsic productivity - wide prior
  p_log_b ~ normal(log_b_mean,log_b_sd); //per capita capacity parameter - custom prior
  p_sigma ~ normal(0,1); //half normal on variance (lower limit of zero)
//priors
  log_a ~ normal(1.5,2.5); //intrinsic productivity - wide prior
  log_b ~ normal(log_b_mean,log_b_sd); //per capita capacity parameter - custom prior
//variance terms
  sigma ~ normal(0,1); //half normal on variance (lower limit of zero)
   R_S ~ normal(log_a - S*b, sigma);
}
generated quantities{
 vector[N] log_lik;
 real S_max;
 real U_msy;
 real S_msy;
 for(n in 1:N) log_lik[n] = normal_lpdf(R_S[n]|log_a - S[n]*b, sigma);
 S_max = 1/b;
U_msy = 1-lambert_w0(exp(1-log_a));
S_msy = (1-lambert_w0(exp(1-log_a)))/b;
}"
```

14.3. APPENDIX C

Wild Salmon Policy Status Assessment for the Osoyoos-Skaha-Okanagan Sockeye salmon CU

Introduction

The Wild Salmon Policy (WSP) Rapid Status algorithm was developed to approximate the decision process used for consensus status designations in a series of expert workshops (DFO, 2024). The algorithm generates a qualitative CU status (*Red*, *Amber*, *Green*) by following a series of Yes/No questions regarding the available spawner data and a set of standard metrics and benchmarks.

Rapid status assessments include the following steps: (1) data review, (2) calculating four standard metrics (relative abundance, absolute abundance, long-term trend, percent change over 3 generations), (3) applying the algorithm to assess status based on available metrics, (4) reviewing the resulting status and developing a narrative that captures important additional information. This review by CU experts (i.e., DFO stock assessment leads, Indigenous groups, and local experts) is a required step prior to finalizing the status assessment. When a CU is first assessed, the WSP Rapid Status process typically works through these steps iteratively for several rounds before finalizing the status determination. Subsequent annual updates can be easily and quickly generated with the same settings, and a more detailed status review is triggered if one of the metrics or the overall status signal a drastic change, or if some other fundamental change occurs (e.g., extreme event like the Big Bar slide)

Data, Metrics, and Benchmarks

Standard status metrics and benchmarks can be calculated and assessed for the whole CU or for indicator sites within the CU. The Okanagan Sockeye salmon Stock Management Unit (SMU) consists of a single conservation unit (CU) with 3 rearing lakes. Each lake is, for the most part, a geographically distinct population with a unique rebuilding history, different contribution of hatchery-origin spawners, and different data availability (Table C1, and section 4). Note that Holtby and Ciruna (2007) initially defined the CU as just Osoyoos, because at the time that was the only lake with natural spawners. Given reintroductions to Skaha and Osoyoos lakes since then, the CU definition has now been officially revised to include all three lakes and the CU has been renamed *Osoyoos-Skaha-Okanagan Sockeye salmon*.

Over the time period used for status assessment (2004-2023), the contribution of hatchery-origin spawners is small for the Osoyoos Lake population (2004-2023 PNI between 0.79 and 1.00), more substantial for Skaha during the reintroduction phase, with a PNI ranging between 0.54 and 1.00, and high for the Okanagan Lake population, with a PNI of 0.50 in 2022 (Sec 4.4). In status assessments for WCVI Chinook CUs, populations with PNI below 51% were excluded from the spawner abundance indicator series. For other Chinook CUs, any sites with substantial hatchery contribution were excluded. Given these precedents, the Skaha Lake population could be included or excluded, but the Okanagan Lake population is excluded. We chose to use the combined Osoyoos and Skaha time series as the basis for status assessment, because that captures almost all the natural spawners in the CU in recent years. Once a self-sustaining natural spawning population is fully established in Okanagan Lake, the time series used for status assessment should be reconsidered. Table C2 summarizes how the four standard status metrics were calculated for the combined Osoyoos and Skaha spawner time series.

Table C1. Conservation Units included in the Okanagan Sockeye salmon Stock Management Unit.

CU No	CU name	Populations and available data
SEL-01-01	Osoyoos-Skaha-Okanagan Sockeye salmon	The CU contains 3 populations: Osoyoos Lake has continuous spawner abundance estimates starting in 1961, but due to improvements in water management and stock assessment only estimates starting in 2004 were used for SR model fitting and status assessment in this document. Skaha Lake was inaccessible for a long time and the first year with reintroduced spawners was 2011. Okanagan Lake was inaccessible for a long time and the first year with reintroduced spawners was 2022.

Table C2. Specifications for calculating the four standard WSP status metrics. All metrics use a generational average of spawner abundance, calculated as the 4-yr running geometric mean.

Metric	Details
Series	Use the sum of spawner estimates for Osoyoos Lake and Skaha Lake starting in 2012. 2010 and earlier were excluded because the Skaha component of the series didn't have spawners yet. 2011 was excluded because the spawner estimate for Skaha that year is considered highly uncertain. A consistent time series for the sum of Osoyoos and Skaha spawners is available for 2012-2023.
Relative Abundance	Use 20% and 40% of habitat-based Smax for Osoyoos Lake and Skaha Lake combined, with lower benchmark at 28,603 and upper benchmark at 57,207.
Absolute Abundance	Benchmarks are the same for all CUs, set at 1,000 and 10,000 spawners. These values were drawn from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) criteria and developed based on broadly applicable considerations of population biology.
Long-term Trend	Standard benchmarks are 50% and 75% of long-term average. This metric is applicable for this CU, but the time series used for status assessment is too short to calculate it at this time, because the metric requires at least 15 years of data.
Percent Change over 3 Gen	Standard benchmarks are 25% and 15% decline over 3 generations, calculated for log-smoothed time series. This metric is applicable for this CU, but can only be calculated for the last available year (2023) at this time, because it requires 12 years of spawner estimates (3 * dominant age, which is 4-year olds for this CU).

Expert Review Process

Spawner estimates and habitat-based S_{max} estimates for the three rearing lakes were developed in close collaboration with ONA and peer-reviewed through the CSAS process for this Research Document. Rapid status inputs (choice of time series, included year, metrics), status dashboards and resulting status narratives were reviewed with DFO stock assessment experts and technical representatives from ONA.

Rapid Status Summary

The WSP rapid status of the Osoyoos-Skaha-Okanagan CU for 2023 is *Amber*, using the combined spawner abundance of Osoyoos and Skaha lakes. An expert driven narrative providing context for status determination is provided in Table C3 below.

Table C3. WSP rapid status of the Osoyoos-Skaha-Okanagan CU for 2023. WSP status assessment are described in detail in DFO (2024) and Pestal et al. (2023).

WSP Rapid Status (2023)	WSP rapid status node
AMBER, HIGH CONFIDENCE	The current year's WSP rapid status is *Amber* with *High* confidence. The recent generational average escapement falls between the relative abundance metric lower (20% of habitat-based S_{max}: 28,603) and upper threshold (40% of habitat-based S_{max}: 57,207) (Node 37) (Figures C2 & C3; Table C4). The absolute abundance metric is applicable, because the time series captures most of the current wild spawners in the CU. Current generational average escapement falls above the upper threshold (10,000) for the absolute abundance metric. When the relative abundance metric is applicable, the trend metrics are not used in the WSP rapid status algorithm (Figure C3; Table C4). The WSP rapid status was *Green* only for the first year in the available time series of generational averages (2015). In all subsequent years, the status was consistently *Amber*, with *High Confidence* (2016-2023). Percent change (short-term trends) could only be assessed for 2023 and is declining and in the *Red* status zone for this metric. Even though status is currently *Amber*, there is a high risk the CU will turn *Red* in the near future. Major pressures that could push the CU into *Red* status in the near future are increases in water temperatures during adult upstream migration, high temperature in Osoyoos Lake, as well as harvests and harvest-related mortalities. For these reasons, it is important for experts (ONA and DFO) to annually review the WSP rapid status assessment, which will be available in the Scanner, and work together on regular updates. The WSP rapid status assessments are a western science process that does not take into account Okanagan Nation's more refined management practices and goals.

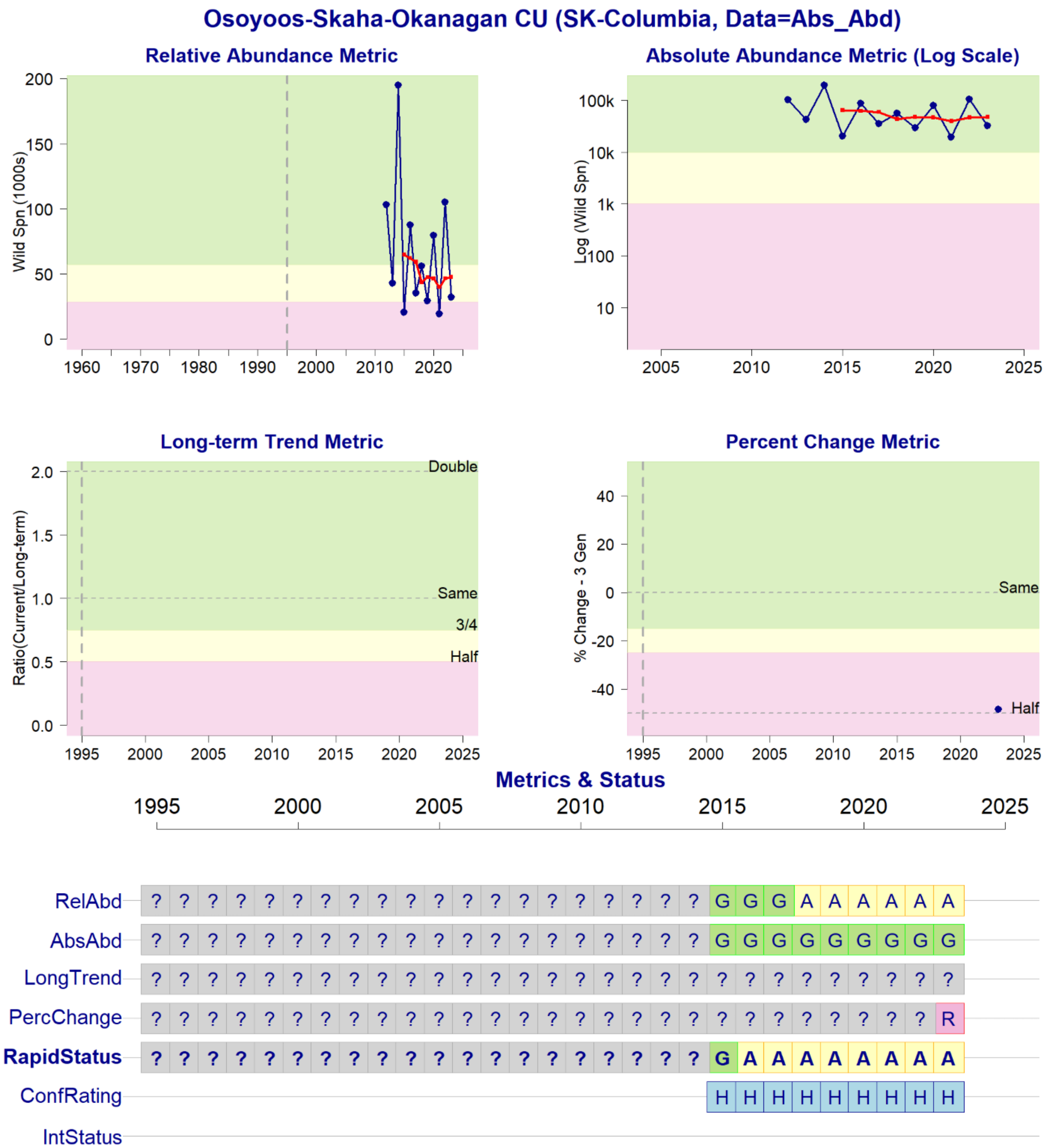

Figure C1. Metrics and Status for the Osoyoos-Skaha-Okanagan CU (SEL-01-01) using the sum of Osoyoos Lake and Skaha Lake as the status indicator. Panels on top show the four standard WSP metrics, calculated based on the available time series of spawner abundances. Bottom panel summarizes the status for each individual metric and shows the resulting rapid status for the CU with a confidence rating. This CU was not previously assessed in an integrated WSP status assessment workshop, so the IntStatus row is empty.

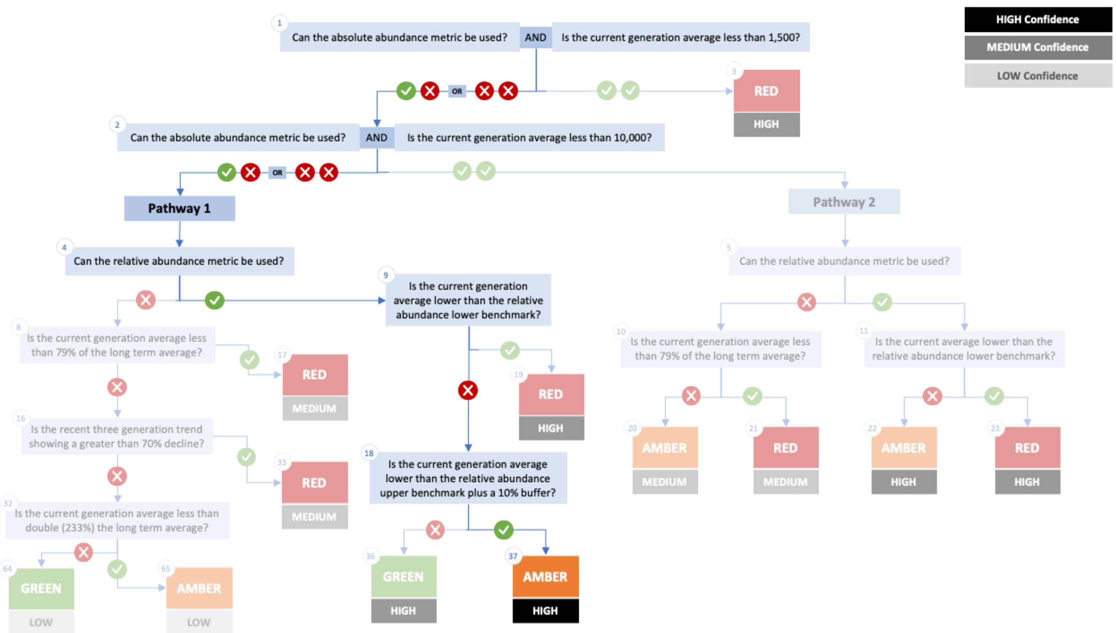

Figure C2. Algorithm pathway taken to assess status for the Osoyoos-Skaha-Okanagan CU (SEL-01-01) in 2023. The absolute abundance metric is well above the upper benchmark of 10,000 (nodes 1 and 2), the relative abundance metric applies here (node 4), and the current generation average abundance falls between the lower and upper benchmarks for the relative abundance metric (nodes 9 and 18), set at 20% and 40% of habitat-based S_{max}. Status for this CU is therefore designated as Amber with High confidence at Node 37.

Table C4: Decision tree path given data and metric values for the Osoyoos-Skaha-Okanagan CU (SEL-01-01) in 2023; this aligns with Figure C4 above. For each node, the algorithm decision is made by comparing the CUs current metric value to the metric threshold and answering Yes or No, running through sequential nodes and decisions until the final WSP rapid status for that CU and year is reached.

Node	Metric	CUs current value	Metric Threshold	Algorithm Decision
1	absolute abundance	GenAvg = 47,636	Less than 1,500	NO
2	absolute abundance	GenAvg = 47,636	Less than 10,000	NO
4	relative abundance	applicable	Is relative abundance metric applicable	YES
9	relative abundance	GenAvg = 47,636	Less than 28,603	NO
18	relative abundance	GenAvg = 47,636	Less than 57,207	YES
37	**FINAL STATUS NODE**			**AMBER**