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Recovery Potential Assessment for the Okanagan Chinook Salmon (*Oncorhynchus tshawytscha*) (2019)

Amelia Mahony[1], Wendell Challenger[2], David Robichaud[2], Howie Wright[3],
Richard Bussanich[3], Rishi Sharma[4,5], and Joe Enns[3]

[1] Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

[2] LGL Limited
9768 Second St.
Sidney, BC V8L 3Y8

[3] Okanagan Nation Alliance
3535 Old Okanagan Hwy
Westbank, BC V4T 3L7

[4] National Oceanic and Atmospheric Administration
1201 NE Lloyd Blvd Ste. 1100
Portland, OR 97232

[5] Marine and Inland Fisheries Branch, NFI
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla
00153 Rome, Italy

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Foreword

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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Okanagan Chinook Salmon (*Oncorhynchus tshawytscha*) are the only Columbia River population in Canada and are genetically distinct from all other Canadian Chinook Salmon populations. Okanagan Chinook (Ntytix) are considered a “first food” and of high importance to the Syilx Okanagan Nation. These fish were formerly the subject of an important First Nations food fishery and commercial trade, but today few persist in the wild. The Okanagan Nation Alliance (ONA) has been actively involved in the study and conservation of Okanagan Chinook Salmon, and has been enhancing Chinook Salmon spawning habitat by installing spawning beds at Oliver and Penticton, and by working to remove migration barriers at dams and in tributaries.

The minimum spawner abundance of Okanagan Chinook Salmon averaged ~9 individuals from 2008-2012, and then increased to an average of ~50 individuals from 2013-2017 (with a maximum estimate of 61 in 2015). In 2018, the number of spawners returned to 2008-2012 levels (10 spawners). In addition to the above, there is new evidence that a Spring Chinook Salmon population is present in the Okanagan watershed, this paper considers only the Ocean-type Summer Run Okanagan Chinook.

Currently, there is enough spawning habitat in the Okanagan River to accommodate a maximum of 1,460 spawning pairs. Considering the numbers of returning Okanagan Chinook Salmon are in the 10’s of fish, it is unlikely that physical habitat availability will be a constraint in the near future, though the successful return of hatchery-derived adults could eventually impact the availability of habitat to wild fish. Cold water refugia, such as those in tributary areas, are noted as being important, especially given the warming climate.

Numerous threats were identified, including impacts due to resource use, climate change, dams, ecosystem modifications\habitat loss, and invasive species. Rescue potential from other populations is considered unlikely. Under the current conditions, Population Viability Analysis (PVA) indicates that the population will not reach the recovery target of 1,000 spawners. Even with the complete cessation of all fishery-related mortality the population would still require aggressive management interventions (habitat improvements and/or a hatchery supplementation program) to meet the recovery target. If no other management actions were implemented, a supplementation program of ≥ 250,000 smolts released per year would be required to meet recovery targets with a high likelihood (assumes equal fitness between wild and hatchery-derived smolts; if fitness of hatchery fish is lower, larger numbers would need to be released to compensate). Hatchery supplementation programs could be reduced (e.g., 150,000 full-fitness hatchery smolts per year) if combined with other management actions that reduce juvenile or adult mortality.

Restoration initiatives are underway, and include, among others: returning channelized portions of the river to a more natural state; creation of spawning beds in Penticton channel; improving fish passage at dams; and hatchery production.

There remain a number of gaps in the understanding of basic life history characteristics for Okanagan Chinook Salmon. In particular, studies are needed to assess the importance of juvenile rearing habitat for the survival or recovery of a Canadian population, including the impact of invasive species. A comprehensive habitat update should be undertaken to assess the location and importance of groundwater input and estuary use. Moreover, limitations from temperature and oxygen regimes should be investigated as part of a habitat and dam passage assessment.

INTRODUCTION

CONTEXT

The Okanagan River is part of the Columbia River Basin. The Okanagan River originates in British Columbia, Canada, flowing out of the southern end of Okanagan Lake. It flows approximately southwards for 115 km, through Skaha, Vaseux, and Osoyoos lakes (Osoyoos Lake spans the Canada–United States border), is joined by waters from the Similkameen River, and then flows into the Columbia River between Chief Joseph Dam and Wells Dam in Washington State. The spelling of the river's name changes at the border from "Okanagan" to "Okanogan". The Okanagan River runs through three dams in B.C. (Penticton, Okanagan Falls, and McIntyre dams) and one in Washington State (Zosel Dam). Water from the Okanagan River mixes with that from the Upper Columbia River (UCR), and passes through nine dams in the mainstem Columbia River before entering the Pacific Ocean at the western border between Washington State and Oregon.

Okanagan River Chinook Salmon (*Oncorhynchus tshawytscha*) are the only Columbia River population in Canada and are genetically discrete from all other Canadian Chinook Salmon populations (it is a designatable unit or "DU", COSEWIC 2018)[1]. This population of Chinook salmon have a summer ocean-type life history. Okanagan Chinook Salmon are considered a Conservation Unit (CU) under Canada's Policy for Conservation of Wild Pacific Salmon, as they are considered sufficiently isolated from other groups that, if extirpated, are very unlikely to recolonize naturally within an acceptable timeframe; DFO 2005).

Okanagan River Chinook were formerly the subject of an important First Nations food fishery and commercial trade (Vedan 2002). The Syilx Okanagan Nation consider these fish (which they call Ntytix) a first food and of high importance. Today, there are few Okanagan Chinook Salmon in the wild. Okanagan Chinook Salmon are currently listed under national and provincial bodies. In May 2005, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the Okanagan Chinook as Endangered in an Emergency Assessment. COSEWIC re-examined the status of Okanagan Chinook in April 2006 and designated the population as Threatened due to the potential for rescue from nearby populations of Chinook Salmon from the UCR (COSEWIC 2006). In 2010, the Federal Minister of Environment recommended that the Okanagan Chinook population not be listed under the Federal Species at Risk Act. Reasons not to list Okanagan Chinook included substantial losses in revenue to the BC economy ($19 million per year) and the fact that in the complete absence of fisheries exploitation the recovery potential was considered to be low (Government of Canada 2010). In 2017, COSEWIC reassessed the status as Endangered (COSEWIC 2017), stating that rescue via straying from nearby populations is considered unlikely, given the uncertain status of the source population and the unknown viability of the potential strays. In B.C., Okanagan Chinook Salmon are listed as 'apparently secure' – not at risk of extinction – however the population has a relatively high conservation priority under the B.C. Ministry of Environment Conservation Framework Priority (B.C. Conservation Data Centre).

Provincial and federal statutes and policies exist to protect fish and their freshwater and marine habitats. The *British Columbia Water Act* controls the diversion, usage, and storage of surface waters in British Columbia, which aims to provide protection to spawning and rearing habitat in

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[1] As per COSEWIC (2017), the DU is focused on the summer migrating, ocean-type Chinook Salmon in the upper Columbia that return to freshwater in the summer and spawn in October.

the Okanagan River. The federal *International Boundary Waters Treaty Act* and International Rivers Improvement Act regulate the diversion, damming, and obstruction of international waterways, such as the Okanagan River and Osoyoos Lake, and provide protection for migratory routes. Canada's *Fisheries Act* regulates fishing and protects fish habitat from harmful alteration, disruption or destruction, and thus protects fish and their habitats throughout Canada.

The Okanagan Nation Alliance (ONA) has been involved in the study and conservation of Okanagan Chinook Salmon since 2002. Enumeration data and biological samples were collected as part of annual Sockeye Salmon (*Oncorhynchus nerka*) counts. Habitat data were collected in the Okanagan River mainstem and tributaries in association with the Okanagan Basin Monitoring and Evaluation Program (OBMEP). Habitat data were modeled using the Ecosystem Diagnosis and Treatment (EDT) model in 4-year iterations starting in 2004 (OBMEP 2019). Environmental DNA (eDNA) was collected in tributaries to the Okanagan River in collaboration with the Colville Confederated Tribes and the United States Geological Service (Laramie et al. 2015).

The ONA has been enhancing Chinook Salmon spawning habitat by installing spawning beds at Oliver and Penticton, part of the Okanagan River Restoration Initiative (ORRI). As well, the ONA has increased the quantity of habitat available to Chinook Salmon by working to remove migration barriers at McIntyre Dam (2009; Rivard-Sirois et al. 2013) and Skaha Dam (2014; Dunn & Folks 2015), as well as barriers in tributaries including Shingle Creek (2014; Enns 2015).

When COSEWIC designates aquatic species as threatened or endangered, DFO, as the responsible jurisdiction under SARA, is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the feasibility of its recovery. The ONA has produced a number of documents specific to the conservation of Okanagan Chinook Salmon that aid in the development of COSEWIC and RPA documents. In 2006, the ONA collaborated on the production of the Recovery Potential Analysis in coordination with Fisheries and Oceans Canada, Columbia River Intertribal Fish Commission, and Summit Environmental (Davis et al. 2007). A compilation of information related to Okanagan Chinook Salmon (2006-2010) was produced in 2010 (Davis 2010). In 2016, the ONA produced the Okanagan Chinook Recovery Plan (Bussanich et al. 2016).

This Recovery Potential Assessment (RPA) is the formulation of scientific advice and allows for the consideration of peer-reviewed scientific analyses into SARA processes. The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits, agreements and related conditions, as per sections 73, 74, 75, 77 and 78 of SARA. Thus, the objective of this report is to provide up-to-date information, and associated uncertainties, to address the 22 elements described in the Terms of Reference with the best science advice possible given the information that can be assembled for Okanagan Chinook Salmon (DFO 2014a). The advice generated via this process will also update and/or consolidate any existing advice regarding this species. The *Guidance for the Completion of Recovery Potential Assessments (RPA) for Aquatic Species at Risk* (DFO 2014a) was followed for the completion of this report.

OVERVIEW OF DAMS IN THE OKANAGAN AND MAINSTEM COLUMBIA RIVER

Modifications to the Okanagan River began in 1910 with changes to the outlet of Okanagan Lake to satisfy competing demands for water (Symonds 2000, Shepherd et al. 2006, Machin et al. 2015). Since then, dams on the Okanagan River have been constructed at the outlets of

Okanagan Lake (Penticton Dam), Skaha Lake (Okanagan Falls Dam), Vaseux Lake (McIntyre Dam), and Osoyoos Lake (Zosel Dam in the U.S.). Zosel Dam is regularly passable to upstream migrating fish, and fish passage was provided at McIntyre Dam in 2009, allowing salmonids to access the habitat upstream of Vaseux Lake. This has increased the available spawning and rearing habitat by 11 river km. Nine additional large hydroelectric dams are found within the Columbia River Basin in the U.S.: four that are federally operated by the U.S. government (Bonneville, Dalles, John Day, and McNary) and five that are operated by U.S. Public Utility Districts (Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells; Table 1, Figure 1).

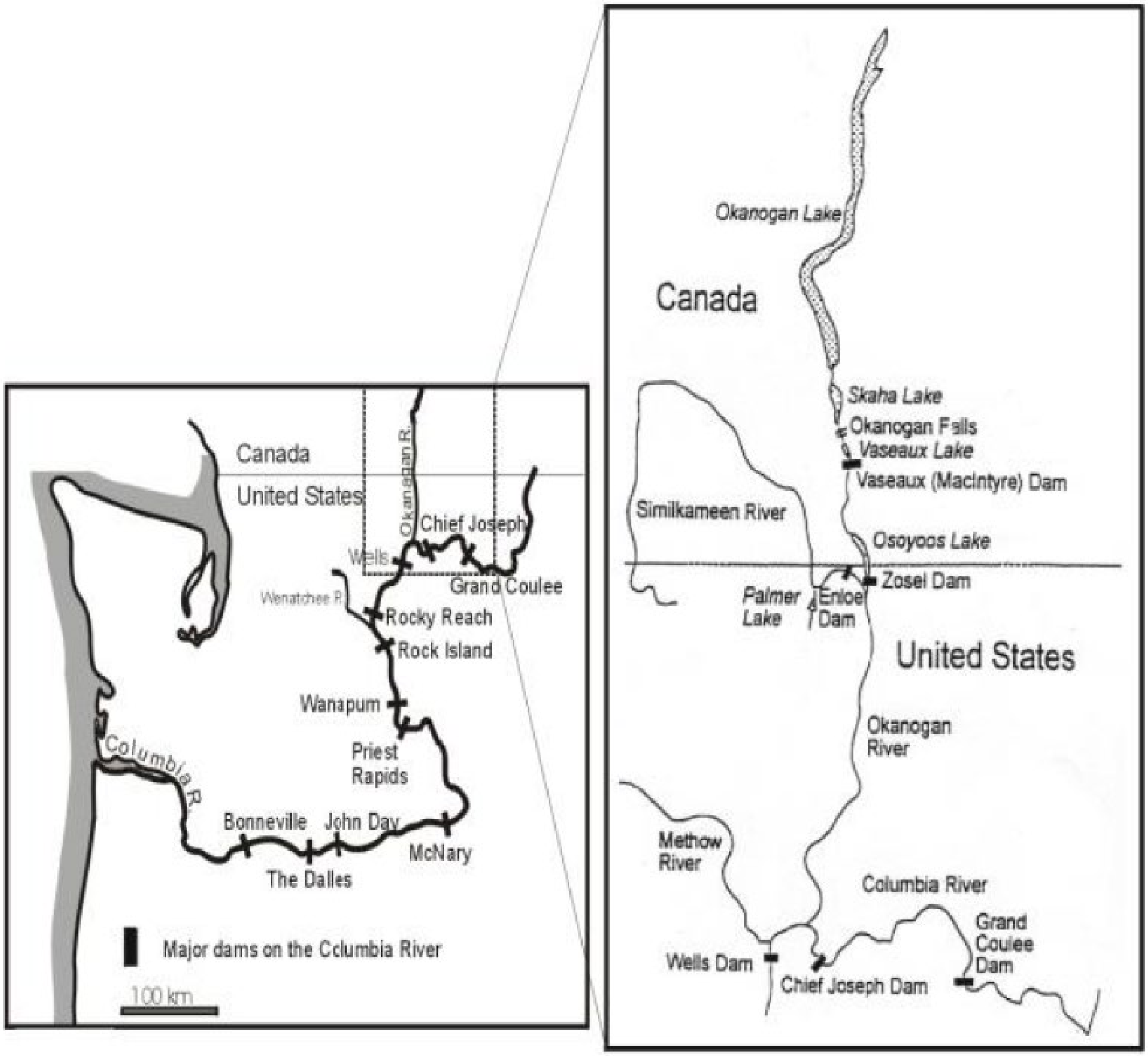

Figure 1. Locations of dams along the mainstems of the Columbia and Okanagan rivers.

Table 1. Significant dam operations on the Columbia River in the U.S. and Canada.

Dam	*Country*	*Year*	*Type*	*Height (m)*
Okanagan	Canada	1914/20/28	Gravity	
Skaha	Canada	1953	Gravity	
McIntyre	Canada	1941/54	Gravity	1.7
Zosel	U.S.	1926	Gravity	
Wells	U.S.	1967	Gravity	49
Rocky Reach	U.S.	1969	Gravity	40
Rock Island	U.S.	1933	Gravity	41
Wanapum	U.S.	1963	Gravity/ Embankment	56
Priest Rapids	U.S.	1961	Gravity/ Embankment	54
McNary	U.S.	1954	Gravity	56
John Day	U.S.	1971	Gravity	56
The Dalles	U.S.	1957	Gravity	61
Bonneville	U.S.	1937	Gravity	60

All nine of the major Columbia River dams downstream of the Okanogan River junction are passable by salmon. In the 1960s, considerable efforts were put forward to improve the passage of salmon above the dams. The previous DFO recovery potential analyses (Davis et al. 2007) suggested that an estimated 80-85% of adult Chinook Salmon survive upstream migration; whereas only 43% of the juveniles survive downstream passage. Many agreements and initiatives have been undertaken and resulted in favourable changes to Chinook Salmon populations. For example, Hanford Reach Fall Chinook Salmon, which spawn downstream of Priest Rapids Dam, are a relatively healthy population that benefitted from the Vernita Bar Settlement Agreement. Implementation of the Vernita Bar Settlement Agreement in 1984 controlled discharge from the Priest Rapids Dam (Harnish et al. 2014), which provided significant benefits to the Chinook Salmon population when management of minimum discharge rates during inter-gravel development (larval stage) was considered. Moreover, dampening of discharge fluctuations during periods of offshore rearing also increased the productivity of Fall Chinook Salmon in Hanford Reach (Harnish et al. 2014).

OVERVIEW OF HATCHERIES IN THE OKANAGAN AND MAINSTEM COLUMBIA RIVER

Many hatchery operations are located in the U.S. portion of the Okanogan River(Table 2), as well as one newly operational hatchery in Penticton, B.C. All hatchery Summer and Fall Chinook in the Upper Columbia River are adipose clipped and most are also Coded-Wire tagged (CWT; Casey Baldwin, pers. comm.).

Hatchery-reared salmon represent a potential threat because they are considered less fit than wild salmon (Araki et al. 2008, Beamish et al. 2012, Drenner et al. 2012, Eliason and Farrell 2016). Because of how they are reared, hatchery fish experience different selection pressures, and are thus different genetically from the wild fish. Recently, DFO has concluded that natural production of Canadian Pacific Chinook Salmon declines with increasing hatchery program size due to genetic impacts on fitness, and due to lowered reproductive success of hatchery fish in the wild (Withler et al. 2018). And while improved hatchery practices can increase the survival of hatchery-reared salmon, this can also create competition for resources with the wild fish.

Table 2. Hatchery programs in the Upper Columbia region (above Yakima) in 2016. From Maier (2017).

Program	***Sub-basin***	***Objective***	***Production Goal***
Summer/Fall Chinook Salmon			
Priest Rapids Fall Chinook	Columbia	Harvest	7,300,000
Ringold Springs Fall Chinook	Columbia	Harvest	3,500,000
Chelan Falls Summer Chinook	Columbia	Harvest	576,000
Wells Summer Chinook	Columbia	Harvest	804,000
Wenatchee Summer Chinook	Wenatchee	Harvest	500,000
Entiat Summer Chinook	Entiat	Harvest	400,000
Methow Summer Chinook	Methow	Harvest	200,000
Chief Joseph Summer/Fall Chinook	Columbia	Harvest	900,000
Chief Joseph Summer/Fall Chinook	Okanogan	Conservation/Harvest	1,200,000
TOTAL Summer/Fall Chinook			**15,380,000**

Program	**Sub-basin**	**Objective**	**Production Goal**
Spring Chinook Salmon			
Wenatchee Spring Chinook	Wenatchee	Conservation	269,026
Wenatchee Spring Chinook	Wenatchee	Safety-Net	98,670
Methow Spring Chinook	Methow	Conservation	223,765
Winthrop Spring Chinook	Methow	Safety-Net	400,000
Leavenworth Spring Chinook	Wenatchee	Harvest	1,200,000
Chief Joseph Spring Chinook	Okanogan	Harvest	700,000
Chief Joseph Spring Chinook	Okanogan	Reintroduction	200,000
TOTAL Spring Chinook			**18,471,461**

The observation of marked (adipose fin not present) fish on the Okanagan River spawning grounds is evidence of straying from hatcheries. These hatchery salmon represent both a potential threat and a potential benefit to the wild salmon. Despite these negative effects, hatchery practices are likely an important consideration in the survival of Okanagan Chinook Salmon. To meet recovery goals will likely require considerable augmentation from U.S. populations through a hatchery program, which would also accelerate recovery times.

BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS

ELEMENT 1: SUMMARIZE THE BIOLOGY OF OKANAGAN CHINOOK SALMON

Biometrics and Life History

Chinook Salmon (Salmonidae: *Oncorhynchus tshawytscha*) are one of seven species of the genus *Oncorhynchus* native to North America (Crête-Lafrenière et al. 2012). Chinook Salmon are the largest of the *Oncorhynchus* species and can be over 1 m in length as adults, and weigh up to 45 kg. Chinook Salmon can be distinguished from other salmonid species by the presence of small black spots on the top and bottom lobes of the caudal fin, and black gums at the base of the teeth in the lower jaw (Healey 1991). Fish morphology and colour changes considerably prior to spawning. Like most other *Oncorhynchus* species, males grow large kypes (elongation of the upper jaw) and develop a dorsal hump. Females are the most fecund (up to 10 000 eggs per individual) and have the largest eggs (single wet egg mass > 400 mg) of all *Oncorhynchus* species (Einum et al. 2003).

Chinook Salmon have two life history types, stream-type and ocean-type, which differ in the migratory timing of the juvenile life stages. Chinook Salmon have four distinct life stages: egg, larval, juvenile, and adult. Eggs are deposited in gravel- and cobble-sized substrate in rivers in late summer and early fall. Eggs incubate over the fall and winter months, and hatch and emerge as larvae in the spring. Juvenile life stages begin following yolk absorption and include fingerlings, fry and parr. These life stages rear in freshwater for either one year (stream-type) or 2-5 months (ocean-type) and then migrate out to the ocean. Juveniles are typically planktivores (feeding primarily on plankton) in fresh water, but eventually become piscivorous (feeding on fish) in the marine environment. Juveniles undergo physiological changes (the smoltification process) in preparation for a transition from freshwater to saltwater. Ocean residence times range from 1-6 years. Adults return to freshwater to spawn as 3 to 7 year-olds, but most commonly as 4 or 5 year-olds. Age-at-maturity is measured from the time when eggs are deposited to their return as spawners.

Wild summer ocean-type Okanagan Chinook Salmon return to freshwater as adults in the summer, and most out-migrate to the ocean as juveniles 2-5 months after emergence (ocean-type life history). Okanagan Chinook Salmon spawn in the fall (Wright et al. 2002), likely initiated by a reduction in water temperatures below 16°C (Healey 1991), which occurs in the Okanagan River in late September or early October (Hyatt and Rankin 1999). Chinook Salmon populations are often categorized by their dominant life history strategy; therefore wild Okanagan Chinook are considered a ‘summer-migrating ocean-type’ population, and this report will focus on that life history group. Recent visual surveys and PIT tag detections in Okanagan River tributaries (OBMEP 2019) have shown that ‘spring-migrating stream-type’ individuals are also present in the watershed, however these fish are not considered in this document.

Physiology

Chinook Salmon are ectothermic, whereby changes in water temperature and oxygen availability modify physiological functions (e.g., growth, swimming performance, metabolic rate) that can in turn influence survival (Healey 1991, Farrell et al. 2008). These two variables likely constitute the greatest challenges for salmon to overcome in adapting to warmer conditions; ultimately determining the rate at which fish tissues can take up enough oxygen to meet the demand (by an unknown mechanism; Wang et al. 2014). Temperature and oxygen saturation are inextricably linked through solubility chemistries and thresholds. Higher thermal performance in fish is predicted to be due to sufficient oxygen delivery to the heart that enables an increase in heart rate above resting values (Eliason and Farrell 2016). Heat shock proteins are expressed during thermal stress (~22-25°C) in salmonids leading to significant protein damage, heat-shock response (Lund et al. 2002), an increase in disease susceptibility, impaired ovulation, and increased stress hormone levels (Young et al. 2006, Jonsson and Jonsson 2009, Bradford et al. 2010a,b). Okanagan River Chinook returning to spawn must either tolerate sub-optimal in-river temperatures in September (16-22°C), or hold downstream of the Okanagan River until water temperatures decrease to approximately 16ºC in early October (COSEWIC 2017). Successful survival of egg fertilization, hatch and emergence has been documented as >84% when exposed to temperatures between 13 and 16.5°C (Geist et al. 2006). The same study also found that incubation temperature of 17°C yielded high fertilization to eyed egg development rates, but poor (<2.5%) hatch, and emergence survival rates. Exposure to heat can increase disease susceptibility, impair ovulation and increase stress hormone levels in salmonids (Young et al. 2006, Jonsson and Jonsson 2009, Bradford et al. 2010a).

Oxygen utilization is required at all stages of the salmonid life cycle. Water percolation (maintenance of temperature and oxygen levels) through spawning gravel is critical for egg and alevin survival; a requirement that can be severely compromised by siltation of spawning beds (Healey 1991). One study which used lower Columbia River Chinook Salmon eggs concluded that when percolation rates ranged between 0.4 ft/s (12.2 cm/s) to 2.2 ft/s (67.1 cm/s), almost all eggs hatched (~96%; Shelton 1955). During other life stages, oxygen demand remains a limiting factor. In addition to temperature, other anthropogenic effects put pressure on the demand for oxygen and increase the demand for oxygen delivery to tissues. Hydroelectric dams which produce high flow rates can result in more frequent burst swimming by a migrating salmon, a high energy and oxygen-demanding activity (Eliason and Farrell 2016). Pathogens are also known to increase oxygen demand in Pacific salmon (Tierney and Farrell 2004, Wagner et al. 2005).

Osmoregulatory preparation is critical during the initial transition between fresh and salt water and the reverse occurs during adult migration. These periods in the life cycle of a salmon are one of the more energy-demanding transitions as cells from many tissue types reconfigure and restructure membrane and protein layers to cope with the rapid change in salt content (McCormick and Saunders 1987, McCormick 1994, Perry 1997). Pacific salmon, including Chinook Salmon have been shown to tolerate a range of salinity exposures and seawater acclimation is variable and plastic (Zaugg 1982, Clarke and Shelbourn 1985), being affected by rearing temperature, and metabolic cost increased with increasing salinity exposure (Morgan and Iwama 1991). These costs are likely to be confounded with water temperatures (Clarke and Shelbourn 1985).

Very few studies are available looking at the effects of ocean acidification (decreased pH) on Pacific salmon. One study reared Chinook Salmon alevins and fry in different pH environments and found differences in growth rates as indicated by otolith width measurements. Greater than 90% of eggs hatched at all tested pH ranges (4.5-7); however fry transferred from 6.2 to 4.5 displayed changed in growth (Geen et al. 1985).

Modelling of fish physiology has also started to have practical benefits for estimating energy use and mortality rates (Hague et al. 2011). Migration success models have also been used to determine effects of changing environmental conditions on migrating Pacific salmon (Rand et al. 2006). Additionally, maximum oxygen consumption models have been successfully applied to the energy use and growth rates of wild populations of Pacific salmon, including Chinook Salmon (Trudel et al. 2004, Trudel and Welch 2005).

Research into the physiology of Pacific salmon, including Chinook Salmon, is plentiful and has reached a point where physiology requirements of a given species can start to drive ecological and management decisions. We strongly advise that physiological requirements of Chinook Salmon are a primary component of any recovery management strategy given temperatures predicted under climate change models.

Acclimation and Adaptation

Pacific salmon are well known to be locally adapted to their specific environments (Taylor 1991, Eliason et al. 2011). Different populations experience a vast array of conditions from migration distances, prey availability, predator, geography, hydrological conditions, and anthropological pressures. Acclimation is an animal’s ability to immediately cope with an environment while adaptation is applied to the species as a whole is able to genetically change in response to changing conditions. The former occurs on shorter time scales; within an individual’s lifetime, while successful evolutionary adaptation takes place over many generations. Examples of life systems under pressure to both acclimate and adapt are respiratory, immune, circulatory and reproductive. Spawning migration is likely to be under large adaptive pressure, as the physical and biological stresses are greatest at this time (temperature, oxygen, energy depletion extremes are most likely encountered; Eliason and Farrell 2016).

Lower and upper water temperatures for 50% pre-hatch mortality of Chinook Salmon embryos are 3°C and 16°C, respectively (Alderdice and Velsen 1978). Recent studies have shown that juvenile Chinook Salmon reared at a developmental temperature of 4°C greater than average current conditions (i.e., at 12°C rather than 8°C) gave better cardiac performance measures when tested at temperatures that were 2°C warmer (Muñoz et al. 2014).

Moran et al. (2013) suggest that many Chinook Salmon life history traits are either highly plastic or evolutionary labile. Such variation in life history characteristics also suggests a high degree of adaptability (Healey 1991). Maternal effects have been found to be critical to determining physiological variation of the offspring. A study of Chinook Salmon sourced from Vancouver Island showed that increases in egg size was associated with a change in the scope of heart rate (Sopinka et al. 2014, Muñoz et al. 2014, 2015). These data suggested that adaptation to thermal pressures is possible through maternal influences. Adaptive heat shock responses have also been found in other *Oncorhynchus* species. For example, in Western Australia, management programs have allowed for the passive selection of 19 generations of Rainbow Trout (*Oncorhynchus mykiss*), resulting in a more thermally tolerant population (Molony et al. 2004, Chen et al. 2015).

Cardiac capacity does not display the same plastic or genetic variation as other physiological systems. Overall, 24.5°C is the upper thermal limit for Pacific salmon cardiac performance (Muñoz et al. 2015). To avoid cardiac failure at these temperatures, salmon will have to undergo adaptation of thermal tolerance biochemical mechanisms to avoid loss of aerobic scope (capacity between resting and maximum metabolic rates; Muñoz et al. 2015). Muñoz et al. (2015) predicted a 17% chance of complete loss of the population by 2100. This predication is likely applicable to other Chinook Salmon populations such as the Okanagan Chinook.

Genetic Population Structure

Chinook Salmon exhibit high population genetic diversity (Braun et al. 2016) and a complex population structure in Canada (Moran et al. 2013). Genetic history, life history and freshwater habitat variation provide a foundation for the strong population structure. Population structure for Chinook Salmon has been described using life history and genetic studies that examine variation in these traits among populations. Salmon populations are often categorized into two broad life history types: populations with stream- or ocean-type juvenile life histories. Further differences among populations in their adult return timing to freshwater can influence population structure. Return timing to freshwater (e.g., spring, summer and fall months) have some genetic basis (Waples et al. 2004). For example, for interior Columbia River Chinook (U.S. and Canadian populations east of the Cascade Mountains), life history type explains a large amount of the genetic variation among groups of populations (Waples et al. 2004). Okanogan, Similkameen, Hanford, Methow and Wenatchee populations in the U.S. are summer and fall migrating ocean-type populations that are part of the upper Columbia summer and fall (UCSF) Evolutionarily Significant Unit (ESU). These fish are genetically different from the Chinook Salmon populations that make up the stream-type upper Columbia River ESU that spawn in some of the same watersheds (Beacham et al. 2006). These findings suggest that while there are no geographical barriers between the populations of these two ESUs, there are reproductive barriers that prevent population mixing.

The Canadian Okanagan Chinook population is genetically distinct within Canada, and there are no other Columbia River Basin Chinook populations found in Canada. Historically, this population may have been genetically distinct from other U.S. ESUs (or equivalents within the Fraser basin) due to distinct regional glacial histories and geographic isolation (Myers et al. 1998, Waples et al. 2004). However, the genetic relatedness of Upper Columbia summer/fall-run Chinook Salmon populations was homogenized during the construction of Grand Coulee Dam. From 1939-43, all Chinook Salmon were intercepted at Rock Island Dam and either transported to surrogate spawning sites or held in hatchery facilities for artificial propagation. Returning summer-run adults were transported to enclosed sections of the Wenatchee or Entiat rivers to spawn naturally, but none were transported to the Okanagan River. Artificially propagated fry and fingerlings were planted in the Wenatchee, Entiat, and Methow rivers during this period, but again, none were implanted in the Okanagan River. The reintroduction of summer-run fish into the Okanogan River resulted from later transplantations or recolonization by straying fish after the termination of trapping activities at Rock Island Dam in late 1943 (Mullan 1987, Myers et al. 1998). Okanagan Chinook Salmon are confirmed to have high levels of heterozygosity and allelic richness, indicating that they are not a small inbred or depauperate population, but part of a larger meta population of Upper Columbia River Chinook (they receive genetic input from a larger population; Ruth Withler, DFO pers. comm.). Evidence of straying from US is supported by observed hatchery (adipose-clipped) Chinook on the spawning grounds (Davis et al. 2007). By contrast, DNA analysis of samples collected from Okanagan Chinook indicated that some of the spawning in Canada resulted in progeny that returned to the Canadian spawning sites. Nevertheless, the Okanagan population is unlikely to be a longstanding remnant population that is independent from nearby populations in the Okanagan drainage.

The low level of genetic differentiation of the Okanagan River fish from nearby upper Columbia summer/fall Chinook populations make these neighbouring populations the most likely source of gene flow into the Okanagan River (Withler 2006[2], Davis et al. 2007). Nevertheless, the large numbers of adults returning from a few families in 2005-2006 indicated that successful spawning (in terms of producing returning adults) has occurred recently in the Okanagan River. The reason for this is largely unknown; however, it is thought that the fish present in the Canadian portion of the river were considered to be part of a much larger metapopulation and are currently receiving, or have recently received, gene flow from a larger nearby population. This nearby population is likely the Similkameen River population (Davis et al. 2007).

In summary, and for the purposes of this RPA, it must be noted that it is highly unlikely that a genetically distinct, original Okanagan River-sourced population of Chinook Salmon is still reproductively viable. Much of the scientific advice generated for this report considers this information and is directed at recovery of any wild-sourced spawning Chinook Salmon in the Okanagan River basin.

Feeding and Diet

In a freshwater environment, Chinook Salmon fry feed on terrestrial insects, crustacea, chironomids, corixids, caddisflies, mites, spiders, aphids, phantom midge larvae, and ants (Scott and Crossman 1973, Healey 1991). The macrozooplankton community in Osoyoos Lake, upon which rearing Okanagan Chinook feed in part, is dominated by cyclopoids and diaptomids, with substantial populations of *Daphnia* and *Bosmina* (Wright et al. 2002, Wright and Long 2005). Okanagan Chinook Salmon have also been found to be piscivorous, feeding on Sockeye

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[2] Withler, R.E. 2006. Genetic analysis of Okanagan Chinook Salmon. (2006 samples included). Internal DFO report.

Salmon fry (ONAFD, unpublished data, 2005). Some studies have found that dietary fatty acid composition can affect the osmoregulatory development of Chinook Salmon (Grant et al. 2010).

In the marine environment, juvenile Chinook Salmon eat mainly fish, particularly Pacific Herring (*Clupea harengus)*, with invertebrates (squids, amphipods, shrimp, euphausiids, crab larvae) comprising the remainder of their diet (Scott and Crossman 1973, Healey 1991). The relative abundance of fish in the stomach contents of commercially caught Chinook Salmon increases with the size of the fish. In general, invertebrate taxa form a relatively small component of the diet of adult Chinook Salmon in the ocean, although there is considerable seasonal and regional variation in diet composition (Healey 1991). The peak feeding periods for Chinook Salmon in the ocean appear to be spring and summer, with spring being the best period in the southern part of their North American range, and summer being the best period along the coast of Canada (Healey 1991). Ocean- type Chinook Salmon may experience competition with Pink Salmon (*O. gorbuscha*) during marine residence, and the degree of competition may be a function of climate (e.g., greatest during strong El Nino events; Ruggerone and Goetz 2004).

Ecology (Interspecific Interactions)

Freshwater

Predation on juvenile Chinook Salmon is common in freshwater, especially by piscivorous birds and fishes (Healey 1991). In addition, invertebrate predators have been observed to kill or injure juvenile salmon, but invertebrate predation outside of hatchery conditions is not well documented. Mortality rates of 70-90% among fry and fingerling salmon have been recorded for several rivers in the Pacific Northwest (Healey 1991).

Juvenile Chinook Salmon in Osoyoos Lake can be preyed upon by introduced Bluegill (*Lepomis macrochirus*), Black Crappie (*Pomoxis nigromaculatus*), Smallmouth Bass (*Micropterus dolomieui*), Yellow Perch (*Perca flavescens*), and Largemouth Bass (*Micropterus salmoides*; Wright et al. 2002). However, between 2007 and 2009, 203 Yellow Perch were collected for stomach content analysis to determine if juvenile Chinook Salmon were being consumed, and only 1 had stomach containing a salmonid or coregonid, suggesting that Yellow Perch may not be major predators (likely competitors) of juvenile Okanagan Chinook (Davis 2010). Non-native predators such as the Striped Bass (*Morone saxatilis*) have been documented as predating on Chinook Salmon in the Mokelumne River, California as a result of habitat alterations (Sabal et al. 2016).

Okanagan Chinook may also interact with Sockeye Salmon on spawning grounds. Recent and substantial increases in abundance of Okanagan River Sockeye Salmon, and the observation of Sockeye spawning over top of Chinook Salmon redds (i.e., redd superimposition), are a cause for concern (Davis 2010). If such an interaction disturbs or displaces Chinook Salmon eggs, there would be a subsequent reduction in egg-to-fry survival.

Marine

Transitioning from freshwater to seawater not only has large physiological costs for outmigrating salmon, but the fish also must adjust to new prey, predators, and entirely new habitats (Weitkamp et al. 2015).

Adult Chinook Salmon comprise 70-80% of the diet of Resident Orcas (*Orcinus orca*) during the summer when they range along the coast of British Columbia (Ford and Ellis 2006). Frequency of Chinook Salmon in Orca diets has increased over time, suggesting a shift in preference for this food type (Adams et al. 2016). While there are no empirical data showing that Orcas selectively forage on Upper Columbia River Summer Chinook Salmon, this ESU comprises a large proportion of ocean-type fish in the Columbia River Basin (McClure et al. 2003a) that is available for Orca feeding off the North Pacific Coast.

Mortality from marine mammals and terrestrial and avian predators has likely increased since the damming of the mainstem Columbia River (McClure et al. 2003a). Predator control measures have been conducted on the Columbia River as a means of improving downstream smolt survival (Zimmerman 1999, Zimmerman and Ward 1999) and upstream adult survival (Keefer et al. 2012). Predation risk by pinnipeds (California Sea Lions *Zalophus californianus*, and Steller Sea Lions *Eumetopias jubatus*) on Upper Columbia River Chinook Salmon is low due to relatively low predator densities during the timing of the spawning migration (Keefer et al. 2012).

Recent modelling suggests that in Puget Sound, four marine mammal species are responsible for the increased consumption of Chinook Salmon from 68 to 625 metric tonnes from 1970-2015 (Chasco et al. 2017a). Migration patterns of Okanagan Chinook Salmon through this area are unknown, but there is a reasonable expectation that they would pass through the area, given that the ocean outlet from the Columbia River is located at this location. Marine mammals continue to consume salmon along their migration route from California to Alaska (Adams et al. 2016).

Other species that have been known to prey on Chinook Salmon in the ocean are Pacific Herring (Ito and Parker 1971), and Salmon Sharks, *Lamna ditropis* (Nagasawa 1998).

Reproduction

The Canadian population spawns entirely within Canada although anadromous individuals migrate through the Columbia River from the Pacific Ocean. Within the Columbia River system, adult Chinook Salmon must migrate upstream past nine mainstem U.S. dams before entering the Okanagan River. They enter the Okanagan River in June/July and hold until they spawn in October (Wright and Long 2005). This is typical of ocean-type populations in the Upper Columbia River basin (Healey 1991). Peak spawning typically occurs in the third week of October when water temperatures are about 10-14°C. Chinook Salmon spawning habitat includes a broad range of water depths, water velocities, and substrates (Table 3). Spawning is often erratically distributed within apparently uniform reaches, suggesting that other factors, such as intra-gravel flow, may be critical (Geist and Dauble 1998).

Table 3. Known habitat attributes for spawning Chinook Salmon and associated characteristics of the Okanagan River. Mean values are ± SD if noted. Values relate to Pacific Summer Chinook Salmon populations.

Life stage / Attribute	***Water Depth (m)***	***Water Velocity (m/s)***	***Substrate (mm)***	***Redd Size (m^2)***	***Temp (°C)***	***Preferred Attributes***
Spawning Redds	0.49±0.16 [3] 0.06-0.88m [6] >0.3 [5]	0.65±1.19 [7] 0.16-1.25 [6] 0.32-1.09 [5]	40-90 [7] 13-102 [5]	6.0-7.0 [1] 2.5-6.5 [9]	~16 [2] 10-17 [5]	Near riffle/bar crests [7]
Egg incubation	0.24 [5]	3-6 [7]	25.4-76.2 [8]	18-20 [5,7]	5-14.4 [5]	<20% fine particles (<6.35mm) [5]

Data from: 1 – Riebe et al. (2014); 2 – Alderdice and Velsen (1978); 3 – Briggs (1953), Collings et al. (1972); 4 – Vronskiy (1972); 5 – Bjornn and Reiser (1991); 6 – Wright and Long (2005); 7 – Davis et al. (2007); 8 – Kondolf and Wolman (1993) and 9 – Burner (1951).

There is evidence for successful reproduction of Chinook Salmon in the Canadian Okanagan River. Immature fry/juveniles of more than one age have been captured, and fish of greater than one year of age were discovered “residualizing” in Osoyoos Lake. Genetic analysis (Withler 2006, Davis et al. 2007) confirmed that the juveniles sampled were the result of two different spawning events, as sibling relationships were not apparent between two age classes of juveniles. Moreover, a single female Chinook Salmon has been observed above the McIntyre dam in 2010. She constructed a redd; however, no males were observed and therefore, spawning was not likely successful (Davis 2010).

Chinook Salmon have been shown to be more fecund than other Pacific salmon species. Examination of several studies suggest a spawning Chinook Salmon carries a range of 4,347-9,427 eggs (Healey 1991). Healey and Heard (1984) found a range of 2,148-7,705 eggs when examining 62 Columbia River Chinook Salmon, and Beacham and Murray (1993) reported 5,086 ± 91 when examining three Chinook Salmon from the Upper Columbia River.

ELEMENT 2: EVALUATE THE RECENT SPECIES TRAJECTORY FOR ABUNDANCE, DISTRIBUTION, AND NUMBER OF POPULATIONS

Distribution by Age

Little information is available on the age distribution of spawners in the Okanagan River. In the Okanagan River watershed, most of the small Chinook Salmon that have been caught in Osoyoos Lake have been identified as two-year-olds (Okanagan Nation Alliance Fisheries Department [ONAFD], unpublished data, 2005). Prior to 2005 (Table 4), seven large Chinook Salmon from the Okanagan River were aged; one was a four-year-old (sex unknown), while the other six (three males and three females) were at least five years old (Wright and Long 2005). Of the 23 Chinook Salmon sampled from the Okanagan River in 2005, 43% were three-year-olds (5 males, 5 females), 48% four-year-olds (4 males, 7 females), and 9% five-year-olds (1 male, 1 female; ONAFD, unpublished data, 2005). In 2006, 28 Chinook Salmon were caught in the river and aged. Five fish were 2 years old (20%; 2 males and 3 females) 12 fish were 3 years old (48%; 5 males and 7 females), 10 fish were 4 years old (40%; 3 males and 7 females) and 1 female fish was not aged (ONAFD, unpublished data, 2006). Corresponding maturity data are not available, but the sampled fish were presumably mature adults. Three and 4-year old fish made up the dominant age of fish caught during these years (not based on brood year). Data from Wells Hatchery (which may be based on combined spring and summer-run fish, i.e., lumped yearling and subyearling data) suggested that the proportion of mature 4-year olds has been increasing over 1998-2011, based on brood year (11.4% of 4-year olds were mature in 1998, increasing to 50.6% in 2011). Returning year-5 fish were all mature (TC technical committee, Antonio Velez-Espino, unpublished data).

Table 4. Age structure for adult-sized Chinook Salmon sampled in the Okanagan River watershed.

Age	*<2005*	*2005*	*2006*	*Total M*	*Total F*	*Overall*
2	-	-	2 M, 3 F	2	3	5
3	-	5 M, 5 F	5 M, 7 F	10	12	22
4	1 U	4 M, 7 F	3 M, 7 F	7	14	22
5+	3 M, 3 F	1 M, 1 F	-	4	4	8

Freshwater Distribution

Juvenile Distribution and Behaviour

Little information is available regarding current freshwater distribution or downstream migration of juvenile Okanagan Chinook Salmon. Recently, juvenile Okanagan Chinook have been observed migrating downstream from the Okanagan River to Osoyoos Lake in late May and early June (R. Benson, pers. comm., 2017). Newly emerged fry were also captured upstream of Osoyoos Lake in April and May (Wright and Long 2005). Juveniles were observed during snorkel surveys in the lowest reach of Inkaneep Creek, a tributary to Osoyoos Lake (J. Enns, pers. comm., 2019). eDNA surveys showed positive detections of Chinook Salmon DNA in Inkaneep Creek, Vaseux Creek, and Shingle Creek (Laramie et al. 2015). Researchers from

Colville Tribes have observed Okanagan Chinook leaving Osoyoos Lake by capturing individuals in a rotary screw trap set 300 m downstream of Zosel Dam (Andrea Pearl, Colville Confederated Tribes, pers. comm., November 2017). Okanagan Chinook were recorded as an incidental observation to the target species (Sockeye Salmon smolts), and little information was provided other than that spring and summer Chinook Salmon fry were also observed in recent sampling sessions (2012-2015). The specific upstream origin of the observed fry could not be determined.

Fry move downstream primarily at night, however small numbers move during the day (Healey 1991).

Adult Distribution and Behaviour

Historically, Chinook Salmon in the Okanagan River were distributed throughout the watershed (Vedan 2002). First Nations have reported that Chinook Salmon were once heavily fished at Okanagan Falls (i.e., outlet of Skaha Lake), and that fish were able to reach both Skaha and Okanagan Lakes, and numbered upwards of 2-4 million fish per year (Clemens 1939, Ernst and Vedan 2000, Vedan 2002). During the early 1900s, a series of dams and vertical drop structures were placed in the valley for flood control and agricultural water withdrawals. After the dams and vertical drop structures were constructed, the upper limit of Okanagan Chinook Salmon spawning distribution was McIntyre Dam. However, since the installation of a fish passage structure at McIntyre Dam in 2009, small numbers (up to 4 individuals) of Chinook Salmon have been observed as far upstream as the Penticton Channel between Skaha and Okanagan lakes. The current potential distribution of Okanagan Chinook is similar to historical distributions (Ernst and Vedan 2000, Vedan 2002). Chinook Salmon were never present in the Canadian portion of the Similkameen River due to an impassable 6 m waterfall where the Enloe Dam was constructed in the U.S. portion of the river (Ernst and Vedan 2000, Vedan 2002).

Historically, Chinook Salmon were observed arriving in the Okanagan River upstream of Osoyoos Lake in spring and early summer (Vedan 2002, Armstrong 2015). Spring migrants would have likely resided in the lake over the summer and spawned at a similar time to the summer-fall migrating population (Myers et al. 1998). Ongoing environmental DNA studies by Chief Joseph Hatchery staff suggest the use of small tributaries by Chinook Salmon is a characteristic of stream-type (i.e., spring-run) populations (A. Pearl, pers. comm., 2017). Use of small tributaries by spring migrating stream-type Chinook Salmon is confirmed by Indigenous traditional knowledge (Vedan 2002, Armstrong 2015). However, the small number of recent returns and the lack of genetic samples make it unclear if these fish represent a separate population. For example, recent anecdotal observations have been made of Chinook Salmon in Shingle Creek (located upstream of Skaha Lake; R. Benson, pers. comm., ONA; Armstrong 2015), where removal of an old, six-foot high, concrete irrigation dam built in the 1940's has reopened more than 30 km of natural habitat.

Upstream migration of upper Columbia River Chinook, and likely Okanagan River Chinook, occurs from May to July (Keefer et al. 2004) during daylight hours (Healey 1991). Adult radio-tagged Columbia River Summer Chinook Salmon were found to migrate a range of 51-83 km/d from Bonneville to the McNary dams (Keefer et al. 2004).

Marine and Estuarine Distribution

The ocean behaviour of Okanagan Chinook Salmon has not been studied to date. The exact ocean distribution of Okanagan Chinook Salmon is unknown; however, ocean-type fish from Wells Hatchery, a population within the UCSF ESU, have been caught along the Pacific Coast from Oregon to Alaska (Sharma and Quinn 2012). Beamish et al. (2012) identified Chinook Salmon from the Columbia River (by DNA) off the East Coast of Vancouver Island.

Ocean-type Chinook Salmon spend 2-5 years rearing in the ocean. A study looking at migration characteristics of Columbia River Chinook and Coho (*Oncorhynchus kisutch*) salmon suggested three basic migration patterns: 1) to move off-shore and migrate northward very quickly; 2) to remain near shore and migrate slowly northward; or 3) to occupy a wide range of latitudes and rates of movement (Fisher et al. 2014). Upper Columbia River Summer Chinook Salmon likely fall into category three.

Abundance

There is only one summer population of Chinook Salmon in the Okanagan River. The minimum spawner abundance of Okanagan Chinook Salmon (Figure 2) averaged ~9 individuals from 2008-2012, and then increased to an average of ~50 individuals from 2013-2017 (with a maximum estimate of 61 in 2015). In 2018, the number of spawners returned to 2008-2012 levels (10 spawners). Spawner abundance data presented in Figure 2 do not include a small number of adipose fin-clipped fish that have been observed during spawning ground surveys (Figure 3). Fin-clipped fish have been observed in the spawning grounds since 2005. It is unknown as to the specific hatchery and program (i.e., integrated *versus* segregated) produced these fish. Consequently, it is unknown whether these strays provide a positive (increased abundance of wild fish) or negative (genetic and fitness impacts; see Araki et al. 2007) effect on Okanagan Chinook. COSEWIC Guidelines on Manipulated Populations (Guideline #7 – Supplemented Populations) stipulate that adipose fin-clipped fish should not be considered when assessing adult population size.

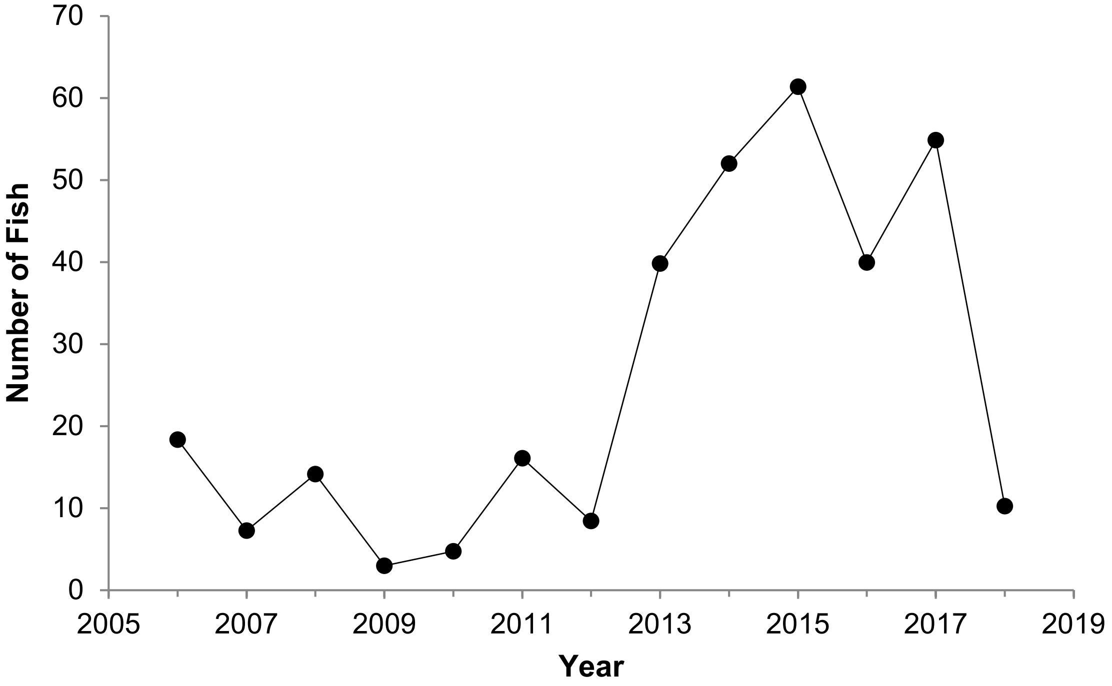

Figure 2. Area under the curve (AUC) escapement estimates for Okanagan Chinook Salmon (2006-2018). AUC was calculated as per Neilson and Geen (1981) and divided by a residency estimate of 7.7. Where AUC could not be calculated (less than 2 values), peak fish count was used. Counts are composed of fish enumerated in the Skaha, 'index' and channelized sections of Okanagan River. Data courtesy of ONAFD. Data prior to 2006 were either not available or not suitable (COSEWIC 2005).

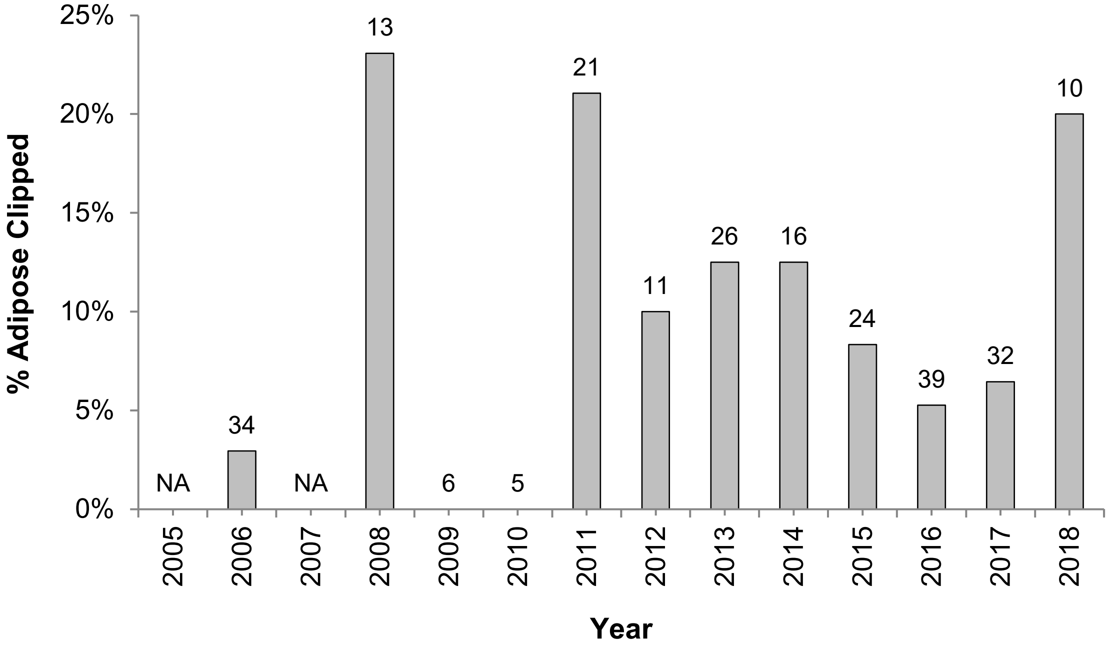

Figure 3. Percentage of adipose-clipped adult Chinook Salmon collected from the Okanagan River from 2005-2018. Sample sizes are denoted above bars. Data deficient years are represented by NA. Data provided courtesy of ONAFD. Data prior to 2006 were either not available or not useful.

The ONA have been routinely monitoring the Okanagan River at the 3 designated sites described in the habitat section below (Figure 4). Primarily, most adult Okanagan Chinook Salmon have been reported spawning in the ‘index’ section of the river, noted as being in the most natural state relative to either the channelized or vertical drop section (VDS), both of which are highly channelized, or to the region above the McIntyre Dam (Skaha section; only accessible after 2009). Survey efforts have been primarily conducted for Sockeye Salmon enumeration; however, Chinook Salmon are also counted. Fewer and fewer fish have been observed utilizing the VDS for spawning since 2006. On the other hand, the index section has shown a steady population of ~40 spawners from 2013 to 2017. Moreover, one or two spawners (likely spring-run fish) have been observed in Shingle creek since 2011, which is within the region above the McIntyre Dam (accessible since 2009), suggesting the fish may continue to return to that area. Overall, it seems apparent that investment into the maintenance and improvement of the ‘index’ area is most valuable in order to protect Okanagan Chinook Salmon spawning habitat.

Survival of juvenile fish has been difficult to determine. The Okanagan Nation Alliance monitors a rotary screw trap located at the outlet to Skaha Lake from late March to early May, and a fyke trap at the Narrows to Osoyoos Lake from late March to early June to monitor juvenile Sockeye Salmon. These sampling sites are upstream of most of the Chinook Salmon spawning habitat, and are therefore of little use in acquiring good juvenile abundance data. Regardless, no Chinook Salmon have been observed in those locations from 2004-2018. Other surveys conducted by the ONA in 2007 using beach seining at Osoyoos Lake have found 24 Chinook Salmon fry (all caught 7 June).

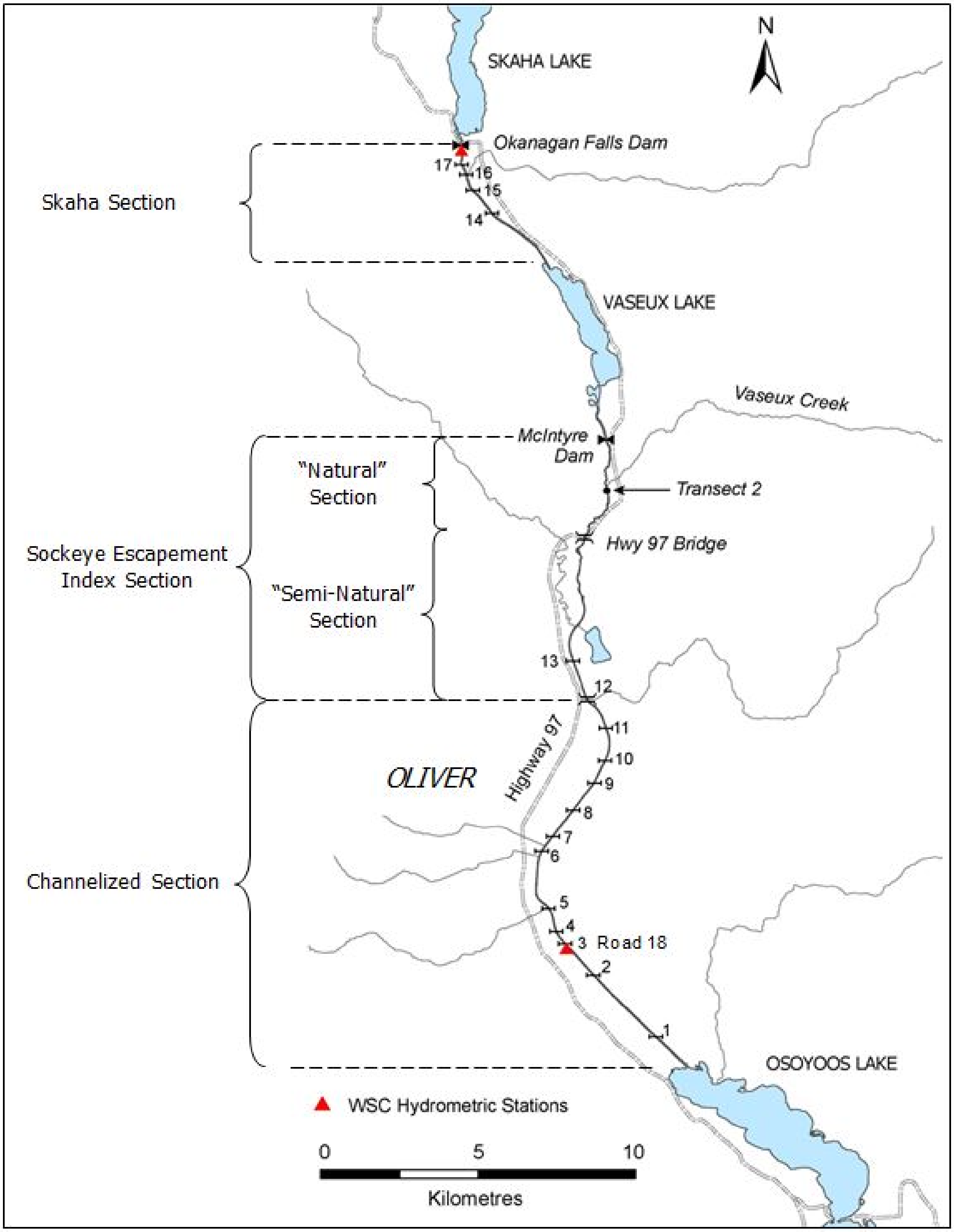

Figure 4. Location of spawning areas of interest for Okanagan Chinook Salmon in British Columbia. Numbered lines located on the river designate vertical drop structures that are built into the channelized sections of the river. Map courtesy of K. Hyatt. Not shown in this figure is a stretch of spawning habitat in the Okanagan River between Skaha and Okanagan lakes.

There is currently insufficient data to conclude whether the Okanagan-sourced Chinook Salmon population is stable, decreasing, or increasing (further described in the Recovery Targets section), as only a few generations of spawners has passed since the last RPA in 2008 and since significant restoration efforts have been in place (see Mitigation Initiatives section). Moreover, if average ocean survival data (1-2%) is applied to the 5 years (2007-2012) where ~10 spawning fish were observed; it is highly unlikely that these fish could have survived to adulthood and built up to a breeding population of 40 fish in later years.

In addition to the above, there is new evidence that a Spring Chinook Salmon population is present in the Okanagan watershed. Spring Chinook Salmon were detected at the Okanagan Channel Passive Integrated Transponder (OKC PIT) array since 2015, increasing from three to thirty between 10 June and 15 September 2018; OBMEP 2019). During the same period less than two Summer Chinook were detected each year (15 September to 19 October).

Rescue potential

Four populations from the U.S. Upper Columbia River ESU (Methow River, Wenatchee River, Hanford Reach, and the U.S. Okanogan River) offer potential rescue of Summer Okanagan River Chinook Salmon through the dispersal of colonizers (McClure et al. 2003b). These populations are considered healthy and total escapement values measure in some cases in the tens of thousands (Table 5). COSEWIC (2017) stated that rescue is theoretically possible from straying of Chinook Salmon from the US, but stated that the status of the source population and the viability of these strays are unknown, and therefore considered rescue unlikely.

Currently there is potential for Chinook Salmon to stray into the Okanagan River from neighbouring wild populations and hatcheries in the Upper Columbia River. In general, stray rates from Upper Columbia Summer Chinook Salmon hatchery programs to non-target tributary populations are very low (for return years 1994 to 2015, the Okanogan/Similkameen program averaged 1-16 strays to non-target spawning areas in the Wenatchee, Entiat, Chelan, and Methow rivers, comprising 0-2.4% of the spawning populations in those areas; Hillman et al. 2017). Likewise, hatchery programs from outside the Okanogan have comprised less than 2% of the spawning population in the U.S. Okanogan and Similkameen rivers (Pearl et al. 2017). Nevertheless, evidence of adipose fin-clipped Chinook Salmon spawning in the Okanagan River also support the possibility of straying (Figure 3). Considering the high adaptability of Chinook Salmon and the close proximity of the Okanagan River to the spawning grounds of other (U.S.) populations, it is possible that these strays would be adapted to the environmental conditions of the Okanagan River. In general, little suitable rearing habitat is available in the Okanagan River, however the spawning habitat that is currently available is not fully seeded.

Hatchery production either from U.S. hatcheries or the Okanagan River may supplement spawner abundance of Okanagan Chinook. Individuals propagated from Penticton, Wells, or Chief Joseph Hatchery (CJH) have the potential to rescue Okanagan River Chinook Salmon by dispersing to the Okanagan River. Since 1993, the Wells Hatchery has been releasing summer-run Chinook Salmon smolts into the Columbia River as part of a segregated program (Snow et al. 2014). On average the Wells Hatchery releases ~370,000 CWT and fin-clipped smolts annually. The CJH Program began operations in 2013, and has integrated and segregated programs releasing up to 2.9 million smolts, the majority of which are adipose-clipped with a subset being tagged with CWT or passive integrated transponder (PIT) tags. Fish are released from the Omak, Similkameen, or Riverside acclimation ponds, or from the Chief Joseph Hatchery on the Columbia River, upstream of the confluence with the Okanogan River (see Initiative 5 under Element 16 below).

Table 5. Natural spawner estimates of U.S. ESU populations that present rescue potential for the Okanagan Chinook Salmon population. Data source: fortress.wa.gov

Year	*Hanford Reach*	*Methow*	*Okanogan*	*Wenatchee*
1990	56,204	1,268	788	10,861
1991	50,730	474	480	10,168
1992	41,269	332	341	11,652
1993	37,254	477	1,395	8,868
1994	62,541	961	3,572	8,476
1995	55,208	1,107	2,738	6,862
1996	43,249	615	5,374	6,002
1997	47,411	697	2,189	5,408
1998	35,393	675	600	4,611
1999	30,607	986	1,274	4,101
2000	47,960	1,550	1,174	4,462
2001	61,361	2,763	4,306	9,414
2002	84,252	4,630	4,346	11,892
2003	110,907	3,930	1,933	10,025
2004	86,860	2,209	5,309	9,220
2005	73,089	2,561	6,441	6,862
2006	50,017	2,733	5,507	16,060
2007	NA	1,364	2,983	3,173
2008	23,336	1,947	2,998	4,452
2009	26,044	1,758	4,204	7,107
2010	NA	2,484	3,189	5,883
2011	65,724	2,917	4,642	8,140
2012	57,631	2,947	4,840	7,318
2013	174,841	NA	NA	7,433
2014	183,759	1,531	10,602	9,968
2015	266,328	NA	10,350	4,072
2016	116,421	NA	8,660	5,902
2017	73,170	NA	5,282	7,425

NA = data not available.

No current DUs within Canada are able to repopulate the Okanagan Chinook population, simply due to a lack of access to this watershed. Transplanting other populations of Canadian Chinook Salmon into the Okanagan River is not a viable option for recovery as Okanagan Chinook Salmon are genetically distinct from other Canadian populations.

Considering that it is unknown whether strays provide positive (increase in the abundance of wild fish) or negative (genetic and fitness impacts) effects on Okanagan Chinook, it is also unknown whether rescue will be successful. While there may be adequate physical habitat for migrants because of large restoration efforts, high water temperatures, water pollution and water withdrawals continue to be problematic and will have to be addressed first in order for rescue to be possible.

Straying is not included as a factor in the VPA analysis (Appendix A).

ELEMENT 3: ESTIMATE THE CURRENT OR RECENT LIFE-HISTORY PARAMETERS FOR OKANAGAN CHINOOK SALMON

Growth and Mortality

Freshwater

In general egg-to-smolt survival can be highly variable in Chinook Salmon populations. One study comprehensively reviewed literature relating to egg-to-smolt survival across seven populations of Chinook Salmon and found that natural mortality (i.e., the complement to survival) was higher for Chinook Salmon than for other *Oncorhynchus* species (ocean-type Chinook = 8.6%; stream-type Chinook = 6.4%; Sockeye Salmon = 2.0%; and Coho Salmon = 1.5%; Bradford 1995). Other controlled studies using artificial redds constructed in the Yakima River have shown egg-to-fry survival of 49-69% (Roni et al. 2015). These among-study differences are likely due to natural versus controlled experimental conditions. Natural conditions would be subject to scouring, low oxygen, and poor egg placement etc. The range in values are reflected as stochasticity in the stock recruitment relationship in the population viability analysis (PVA) presented in Appendix A.

Studies have looked at the impact of dams on the survival of downstream migrating Chinook Salmon. Using PIT tags (which included mainly subyearling [summer-run], but also some yearling [spring-run] fish), it is estimated that Columbia Chinook Salmon had survival rates of 0.64 ± 0.11 (SD) when migrating from Rock Island Dam to McNary Dam from 1998-2014. When migrating from McNary to Bonneville dam, the survival rate was 0.72 ± 0.08 (SD) during 1999-2014 (data from the Fish Passage Centre; fpc.org). Other studies have shown Snake River Chinook Salmon (part of the Upper Columbia system) survival ranging from 0.27 ± 0.2 (SEM) in 2001 to 0.61 ± 0.02 (SEM) in 2006 (Welch et al. 2008). These survival values are highly variable, but for comparison, survival of Chinook Salmon in the Fraser River (not dammed) had a range of 0.02 ± 0.04 (SEM) to 0.32 ± 0.21 (SEM; Welch et al. 2008) suggesting that the source of out-migration mortality is not largely due to dams (Rechisky et al. 2013). A previous recovery assessment potential report noted that only 43% of Columbia River Chinook Salmon survive downstream passage (DFO 2008).

Seawater

Little data exist for growth or survival of Okanagan Chinook Salmon while in the ocean. Weitkamp et al. (2015) found that hatchery Columbia River yearling Chinook had growth rates ranging from <1.1 mm/day to >1.6 mm/day (<2.9% body weight/day to >3.6% body weight/day) when caught in May, 3-4 weeks after ocean entry. Early or late entry into the marine environment played a role in the initial growth rates, but that after one more month of seawater residence, growth rates between the two groups were similar (Weitkamp et al. 2015). Estimates of marine survival range between 1-2% (Bradford 1995).

Fishing Mortality

Several Columbia River stocks are indicators for overall stock health, including the Columbia River Summer Stock (SUM) from Wells Hatchery in Washington, U.S.A. The natural origin of the fish used in the Wells program is the Columbia River mainstem, and tributary production upstream of Rock Island Dam. These natural production areas are the Entiat, Methow, and Wenatchee rivers (Antonio Velez-Espino, pers. comm.). Fishing mortality and exploitation rates, based on coded wire-tagged (CWT) Chinook Salmon released from Wells Hatchery, are summarized in Figure 5. Based on Figure 5, Okanagan Chinook Salmon may face 24% exploitation annual in marine fisheries and 45% exploitation in terminal (freshwater) fisheries. The majority of this fishery-related mortality is within the US, which include Southeast Alaska

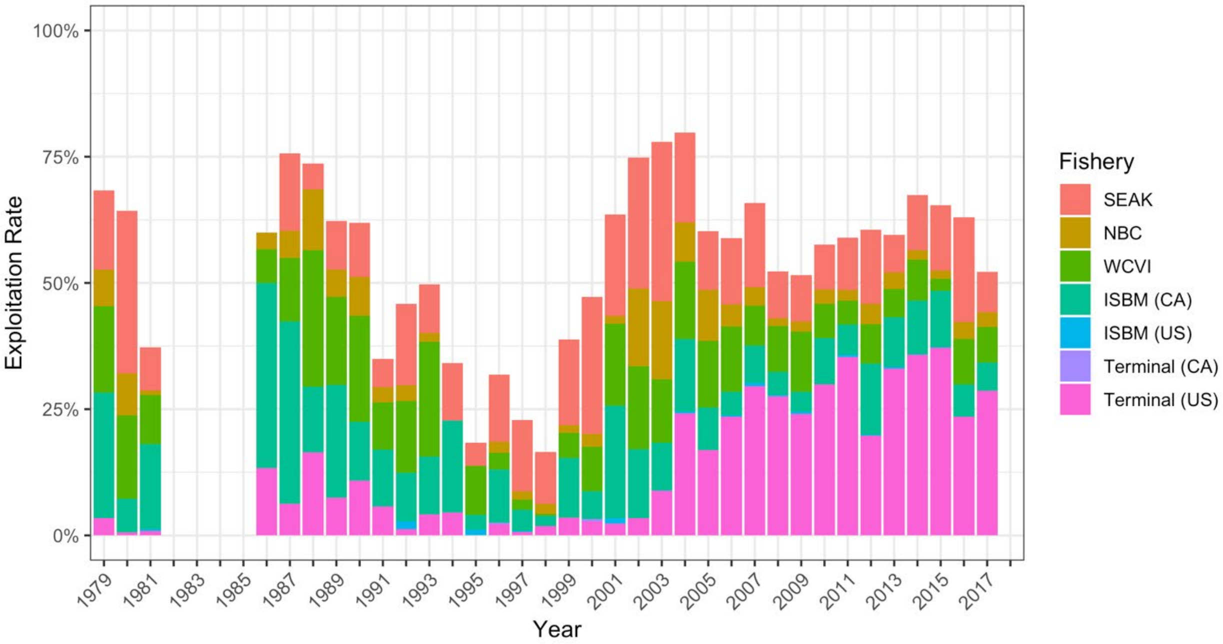

Figure 5. Exploitation rates based on mortality distribution tables for summer Columbia River Chinook indicator stock estimated by the Pacific Salmon Commission Chinook Technical Committee for the following fisheries: Southeast Alaska (SEAK), Northern British Columbia (NBC), West Coast Vancouver Island (WCVI), Individual Stock-Based Management fisheries in Canada (ISBM (CA)) and US (ISBM (US)), and Terminal fisheries in Canada (Terminal (CA)) and US (Terminal (US)).

(SEAK), US Individual Stock-Based Management (ISBM.US), and US Terminal (Terminal.US) fisheries. In general, exploitation rates by U.S. fisheries has trended upwards since the early 2000s. The information from the indicator stock can be an important proxy for use in the assessment of the wild Okanagan Chinook Salmon escapement and exploitation rates (data for the specific stock are lacking). That said, there should be no directed fishing pressure currently on (non-adipose clipped) Okanagan Chinook Salmon, hence exploitation rates for hatchery fish are likely not as relevant as incidental (bycatch) mortality.

Substantial numbers of Chinook Salmon may be intercepted as bycatch in the Pacific Coast groundfish fishery (managed by the Pacific Fishery Management Council), Bering Sea – Aleutian Island and Gulf of Alaska groundfish fishery (managed by the North Pacific Fishery Management Council), and the Pacific Sardine fishery (managed by the Pacific Fishery Management Council). Within these fisheries, adult equivalent Chinook Salmon bycatch can be as high as 75,000 fish (in 2007) in the Alaskan Pollock fishery (Stram et al. 2016). It is reported that 10% of these fish are sourced from B.C. and 7% originate from the West Coast of the U.S. (Washington, Oregon and California). The impact of these fisheries on Upper Columbia River Summer Chinook Salmon is unknown. No summaries exist for Chinook Salmon bycatch in Canadian fisheries (C. Parken, pers. comm., 2017).

Escapement

Data collected from the Wells Hatchery feed into the Pacific Salmon Commission Joint Chinook Technical committee's annual report on catch and escapement. Data from these indicator stocks show that over the last 10 years (since 2007), escapement of Chinook Salmon has well exceeded escapement goals. Over 20,000 spawners have returned each year (Figure 6).

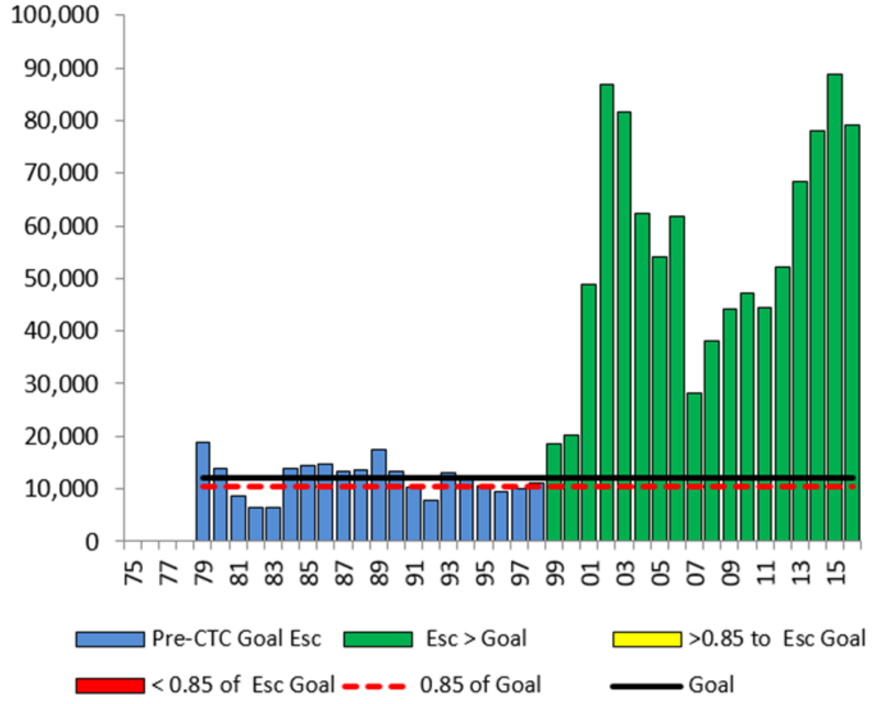

Figure 6. Adult passage (number of fish) of Mid-Columbia Summer Chinook Salmon initially released from hatcheries above Rock Island Dam, 1979-2016. Data includes hatchery and wild fish combined. The horizontal black line represents the escapement goal at Rock Island Dam. Data from CTC (2016).

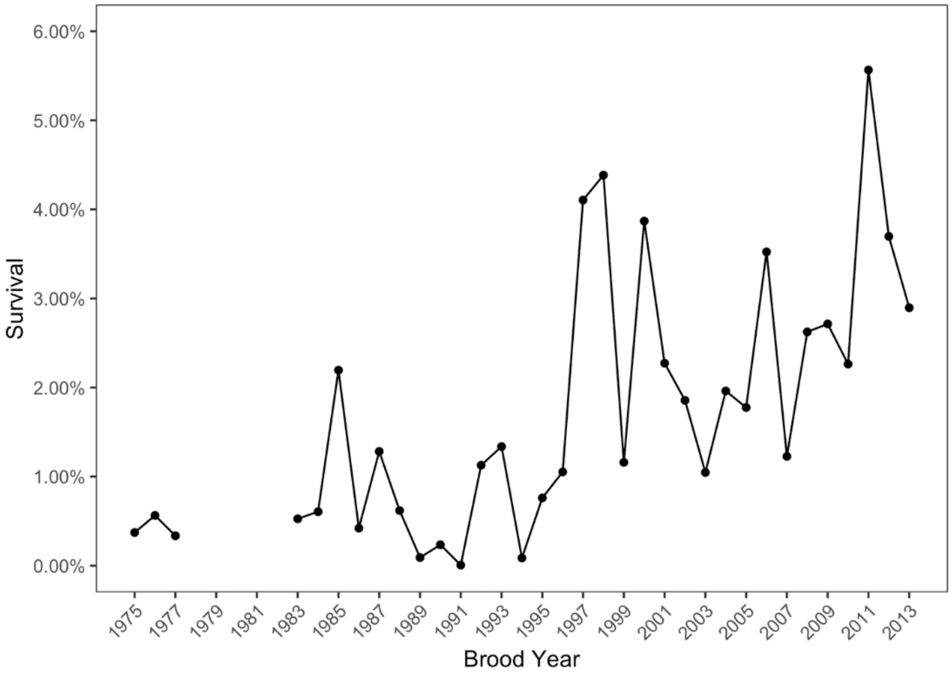

Figure 7. Columbia River Summer age 2 survival rates from Wells Hatchery. Survival rate is determined by CWT Cohort survival. Age 2 cohort size is divided by the total number of fish tagged and released. From CTC (2018).

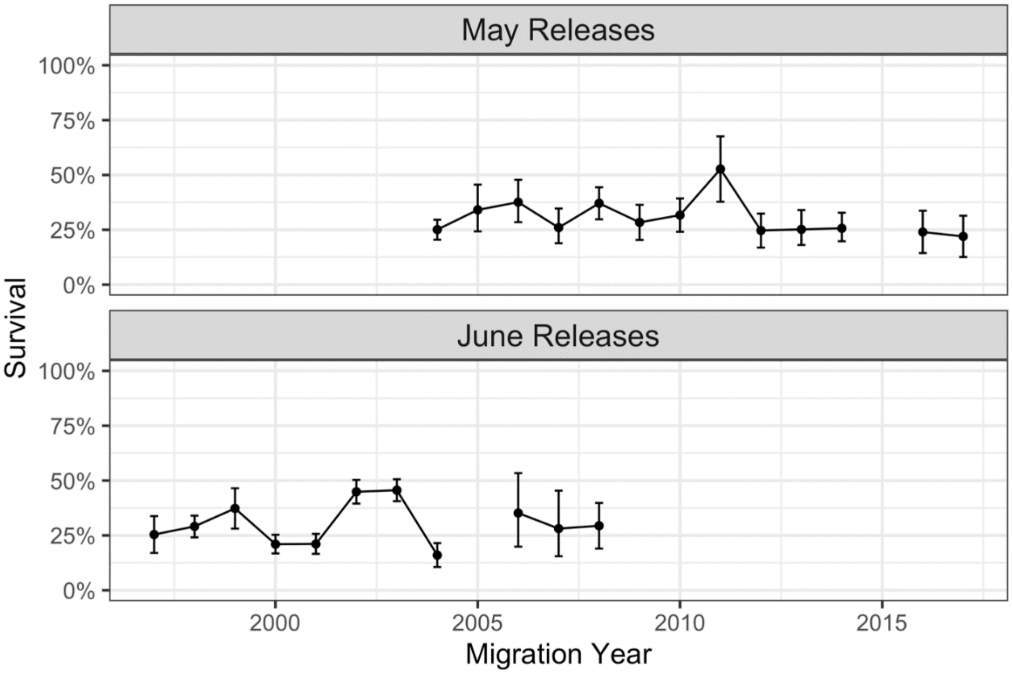

Figure 8. Columbia River Age 1 survival rates for May and June release from Wells Hatchery to McNary Dam. Data from Scheer (2018). Survival was determined by PIT-tag counts. Bars indicate 95% confidence intervals.

These escapement values consider 2-year old juvenile survival rates ranging from ~1 to 4.5% between 1996 and 2010 (calculated based on brood year; Figure 7). Survival rates for 1-year old juvenile Chinook Salmon are considerably higher and range from 45 to 80% (Figure 8). Since these values are lacking for the wild population, the hatchery fish can be used as a proxy for wild fish for predication of outcomes for mitigation scenarios.

Population Modeling Parameters

Other population parameters, such as stock-recruitment, inter-dam survival (juvenile and adult), and harvest rates, are described in Appendix A, where they are used for PVA analysis.

HABITAT AND RESIDENCE REQUIREMENTS

ELEMENT 4: DESCRIBE THE HABITAT PROPERTIES THAT OKANAGAN CHINOOK SALMON NEEDS FOR SUCCESSFUL COMPLETION OF ALL LIFE-HISTORY STAGES

Early freshwater residency

Egg incubation conditions for Summer Chinook Salmon include: (1) water temperatures between 5.0 and 14.4ºC (Bjornn and Reiser 1991); (2) intra-gravel dissolved oxygen > 8 mg/L; and (3) low concentrations (< 20-30%) of fine sediments that can fill interstitial spaces and starve eggs of oxygen (Tappel and Bjornn 1983). Honea et al. (2016) showed that fine sediment in gravels during the incubation period is one of the biggest freshwater habitat predictors of spawner abundance. Restoration of riparian areas has been shown to reduce extreme temperature changes, provide shade, and reduce run off (less erosion; Beschta 1997).

Shelton (1955) found that following hatching, emergence success was dependent on the size of the gravel bed, with >87% emergence in gravel that was 1-3” (2.54 to 7.62 cm) in diameter and <65% emergence in gravel that was <1” (2.54 cm) in diameter.

Spawning

Chinook Salmon spawn in a broad range of water depths, velocities, and substrate sizes (Scott and Crossman 1973, Healey 1991) in transitional areas between pools and riffles (Bjornn and Reiser 1991). Redd distribution is patchy within apparently uniform habitats, suggesting that other factors such as intra-gravel flow may be critical (Vronskiy 1972). Okanagan Chinook Salmon preferences are summarized in Table 3. Low turbidity and substrate between 13 and 102 mm in size are preferred (Bjornn and Reiser 1991). Since 2001, the ONAFD have been recording characteristics of Okanagan Chinook Salmon spawning sites between Oliver, B.C. and McIntyre Dam by identifying redd size and the presence of holding Chinook Salmon. Data collected over the last few years indicate that the water depth and velocity, and substrate size preferred by Okanagan Chinook fall within the outlined ranges (ONA, unpublished data).

Upstream migration of summer Chinook Salmon typically occurs in water temperatures ranging from 14ºC to 20ºC (Bjornn and Reiser 1991). Individuals that experience temperatures > 20ºC delay upstream migration (Hallock et al. 1970, Caudill et al. 2014), seeking refuge in cold-water tributaries of the Columbia River (i.e., behavioural thermoregulation; Goniea et al. 2006) until mainstem temperatures return to thermal optima. Like other anadromous fishes, Chinook Salmon can arrive in natal lakes and streams weeks to months prior to spawning. Early-arriving (early to mid-September) Chinook Salmon experience high water temperatures (> 18ºC) in the Okanagan River.

An examination of redd dewatering events that had low egg-to-pre-smolt survival rates, found that discharge rates of 1600-4638 m^3s^{-1} during the majority of the spawning period (one month in duration) had a negative impact. However, a dewatering event of 8 h where flows averaged 1194 m^3/s and remained <1600 m^3/s resulted in little or no mortality (Harnish et al. 2014).

As presented in Table 3, Chinook Salmon redds in Okanagan River have been observed in water depths as between 0.20 m and 0.75 m and in water velocities ranging from 0.34 m/s to 1.14 m/s (Wright and Long 2005, Davis et al. 2007). Substrates in and around redds are dominated by gravel and small cobbles, although coarse sand is a major component of the substrate in several spawning areas, with median substrate particle sizes ranging between 0.03 m and 0.10 m. The mean redd size for Chinook Salmon in Okanagan River is 6.0 m^2, and ranged from 3.1 to 11.0 m^2 (Davis et al. 2007). Mean Chinook Salmon redd sizes in tributaries of the Columbia River are between 2.5 and 6.5 m^2 (Burner 1951). If the redd sizes in Okanagan River were scaled to account for a difference in measurement method, the mean Okanagan Chinook redd size would be about 4.5 m^2, which translates to a spawning territory of 18 m^2. Chinook redds are typically placed adjacent to instream bars or bar complexes in the natural river sections or where the original (1954) river crossed the existing channel. Nearly all redds are also placed near areas of identified groundwater influence.

Burner (1951) estimated that the area defended by a pair of Chinook Salmon is about four times the average redd size, so the mean size of measured Chinook redds in the Okanagan River is used to estimate the number of spawning pairs that could spawn in the Okanagan River for each of the above habitat availability estimates. Chinook in Okanagan River would be expected to defend territories of about 18 m^2.

While simple metrics like water depth, velocity, and substrate may be useful in predicting Chinook Salmon habitat usage in some situations, often additional factors may be as or more important. Burner (1951) determined that Chinook Salmon were attracted to areas with relatively high levels of intragravel water percolation and a predominance of medium to fine gravel, with little fine silt or clay. Chinook Salmon redds were located at the crest of a riffle (i.e. at the downstream margin of a pool or run) for studies in the Kamchatka River basin (Asian Pacific coast) and in the Columbia River basin (Chapman 1943, Vronskiy 1972). Other important spawning areas, which are likely selected due to high intra-gravel water flow rates, include pools just below log jams and those on the upstream face of lateral dunes, such as are found in the Nechako River (Russell et al. 1983). This preference for spawning sites with high rates of intragravel flow appears to have a physiological basis, since Chinook Salmon eggs are relatively large, and their surface-to-volume ratio makes them sensitive to reductions in oxygen concentrations and water percolation rates (Healey 1991).

Juvenile rearing habitat

Juvenile Chinook Salmon rear in rivers, streams, lakes, estuaries, and/or the ocean (Bjornn and Reiser 1991). Healey (1991) identified suitable rearing habitat as dependent on streamflow, channel morphology, gradient, and riparian/instream cover. The best habitats are those that allow optimal foraging with minimal energy expenditure. Upper Columbia summer stocks emerge primarily in April and May (Evenson and Talbot 2003).

The lake shoreline area may potentially serve as cover, source of food, thermal refuge, or may reflect energy saving strategies associated with low-velocity nearshore habitats (Kemp et al. 2005). Juvenile migrants actively feed before emigrating and throughout the period of migration continue to feed in low velocity habitats created by eddies in constrained segments as they migrate (Stanford et al. 2005). The amount of time that juveniles spend in lakes is unknown, but might range from days (as a migration corridor to the Columbia River) to years (rearing). In Shuswap Lake (Fraser River basin), Chinook Salmon were found rearing along the lake foreshore (Russell et al. 1983). The fish reared and migrated within the littoral zone and seemed to prefer lake delta-type habitats associated with sandy bottoms.

To date, juvenile Chinook Salmon have not been found overwintering within the Canadian portion of the Okanagan drainage. Sampling for juvenile Chinook Salmon has occurred within the Okanagan River during winter months. In December 2007, no fry were found. Habitats that were primarily targeted by the surveys included areas along banks with overhang and deep pools. Chinook that overwinter in larger rivers often move out of tributary streams and into the river mainstem, where they occupy deep pools and interstitial spaces between boulders and rubble during the winter and are strongly nocturnal (Hillman et al. 1987, Healey 1991). Okanagan Chinook Salmon may not exhibit a residual overwintering behaviour, although it is possible that the surveys to date have been conducted in the wrong locations or at the wrong times. Nevertheless, it is likely the fish emigrated downstream into Osoyoos Lake or the mainstem of the Columbia River prior to the onset of winter, although it is possible that a few fish may utilize groundwater sources to rear through the winter, or perhaps migrate downstream to deeper and warmer habitats. Upwelling has been associated with increased survival of Chinook Salmon in British Columbia over winter (Swales et al. 1986).

Estuary usage

Currently, very little information is known regarding the distribution and use of the Columbia River Estuary by Okanagan Chinook Salmon. Some research has suggested that there is differential use of estuaries between wild and hatchery-reared Chinook Salmon. Levings et al. (1986) found that wild fish utilized the transition (area immediately seaward of the estuary) and estuarine (marshy, vegetative areas in the lower reaches of the river) areas equally whereas the hatchery fish were more prone to be found in the transition area of the estuary. Moreover, wild fish were found to reside in the estuary approximately twice as long. Following migration to the ocean, Columbia River Chinook Salmon have been found to be abundant in deep waters in the Columbia River estuary (Harnish et al. 2012, Weitkamp et al. 2012, 2015). Subyearling Chinook appear to be most abundant in the Columbia River Estuary in June of each year (Weitkamp et al. 2012).

Pacific Ocean

Increased survival of Columbia River Chinook Salmon since the mid-1990s has coincided with favorable conditions in the Pacific Ocean. Scheuerell and Williams (2005) found evidence that 3- to 4-fold increases (i.e., < 1% to 3-4%) in smolt-to-adult survival of Chinook Salmon were related to coastal upwelling through bottom-up forcing of the marine food web. Coastal upwelling of cool, nutrient-rich water increased primary and zooplankton production, creating favorable foraging conditions for stream-type Chinook Salmon (Scheuerell and Williams 2005). More recently, the decline in the abundance of the populations that comprise the UCSF ESU has been attributed to unfavourable ocean conditions from 2002 to 2007 (Hess et al. 2014).

ELEMENT 5: PROVIDE INFORMATION ON THE SPATIAL EXTENT OF THE AREAS IN OKANAGAN CHINOOK SALMON'S DISTRIBUTION THAT ARE LIKELY TO HAVE THESE HABITAT PROPERTIES

Okanagan River

The Okanagan River is a Canadian component of the Columbia River Basin. The total watershed area of the Okanagan is approximately 1500 km^2, with 273 km^2 assigned to the designated unit (Table 6; Porter et al. 2013). Very little historical habitat remains for Okanagan Chinook Salmon, which use this portion of the mainstem for spawning. For enumeration purposes, three main sections of the Okanagan River are identified as being distinct (Figure 4). In this report, they are referred to as:

- River Section 1 – Channelized section ranging from the north end of Osoyoos Lake upstream to Vertical Drop Structure (VDS) 13
- River Section 2 – "Semi-natural" and "Natural" sections ranging from VDS 13 upstream to McIntyre Dam
- River Section 3 – Channelized sections upstream of McIntyre Dam including the section between Vaseux and Skaha lakes, and the section between Skaha and Okanagan lakes (Penticton Channel)

Table 6. Physical characteristics of Okanagan Watershed in British Columbia. Data from Porter et al. (2013).

Characteristic	***Description***
Total watershed area	1,502 km^2
CU (DU) area	273 km^2
Watershed in CU (DU)	18.15%
Accessible stream length in watershed	1,878.8 km
Accessible stream length in CU	366.3 km
Spawning length	8.5 km natural or semi-natural state/ spawning platform at Penticton = 480 m^2

River Section 1 is considered poor habitat for spawning Okanagan Chinook Salmon as it contains 13 vertical drop sections (man-made waterfalls; VDS; see Figure 4) and is characterized as being highly modified. This section of the river has been straightened, channelized and heavily developed (many roads and bridges, and removal of vegetation). Observations of spawning Okanagan Chinook in this section have been conduced by the ONA, primarily enumerating salmon by observation from the VDS. However, there is a degree of uncertainty with this enumeration method, as only a small proportion of this region can be viewed from a VDS.

River Section 2 has been documented as the primary spawning area for salmon, especially Okanagan Sockeye Salmon. An 8.5 km non-engineered section remains downstream of McIntyre Dam ('index section') including a 4.5 km "natural" segment immediately below the dam and another 4.0 km dyked but still "semi-natural" segment (Stockwell and Hyatt 2003). Chinook Salmon spawning has been consistently observed in the 'index section', and this can be considered as critical spawning habitat for the Canadian portion of the population (~ 95% of spawners are observed in this segment, annually). Only ~3.5 km is currently utilized for spawning, but the remaining length is required to support a recovering population (Davis et al. 2007). As well, restoration activities have been occurring in the past number of decades to de-channelize reaches and install spawning beds for Okanagan Chinook Salmon. The ONA enumerates the spawning salmon in this section by floating a raft down the river and conducting visual counts.

River Section 3 was only made available to migrating salmon in 2009 with alterations to McIntyre Dam. Habitat access was extended again in 2014 when the fish ladder on the Skaha Lake outlet dam was opened, providing passage to Skaha Lake and the Okanagan River between Skaha Lake and Okanagan Lake (Alex et al. 2018) . Although this reach has been completely straightened, channelized, and dyked, the ONA has been working to enhance spawning habitat since 2013 through the installation of spawning beds designed for Sockeye and Chinook salmon (part of the Okanagan River Restoration Initiative, Davis et al. 2018). ONA has since monitored this reach using snorkel, deadpitch, and redd surveys.

Spawning Habitat

Davis et al. (2007) looked at the availability of spawning habitat to Chinook Salmon in the Okanagan River from Osoyoos Lake to McIntyre Dam (River Sections 1 and 2). This area is composed of channelized habitat (anthropogenic in nature) and natural habitat. Three separate methods have been used to estimate the capacity of both spawning habitats for Okanagan Chinook Salmon: (1) the "cells method" estimated a maximum of 4,340 spawning pairs (Phillips et al. 2005); (2) the "channel intersection method" yielded an estimate of 1,460 spawning pairs (Phillips et al. 2005); and (3) a "watershed-area-based" model calculated a maximum estimate of 1,700 spawning pairs (Parken et al. 2006). These models were developed using average spawning habitat quality from representative Chinook Salmon populations and therefore likely overestimate the capacity of spawning habitat in the Okanagan River (see Davis et al. 2007 for more information regarding the strengths and limitations of these methods).

Method 2 is the most defensible estimate of Chinook Salmon spawning habitat availability provided in this report, and may be a reasonable basis for initial Okanagan Chinook management planning in the Canadian Okanagan River basin (Davis et al. 2007). Regardless of which of the habitat or productive capacity estimates are used, it is clear that neither spawning habitat availability nor productive capacity is the limiting factor for the Canadian Okanagan Chinook population, which currently numbers in the tens, not thousands.

Okanagan River Tributaries

The Okanagan River tributaries can contain habitat accessible to Okanagan Chinook Salmon life history stages. Spawning was observed in Shingle Creek every year since 2012 by Penticton Indian Band fishers and technicians (ONA, unpublished data) and Chinook Salmon presence has been confirmed by eDNA since 2015. As well, Okanagan Chinook Salmon juveniles have been observed utilizing Inkaneep Creek in the late summer (J. Enns, pers. comm., 2019). Whereas summertime mainstem temperatures frequently exceed thresholds for Chinook Salmon juveniles, the only cold-water habitat available may be in the tributaries.

Efforts have been made by ONA in recent years to increase tributary habitat available to Okanagan Chinook. Fish passage projects that have increased tributary habitat access include the removal of the Shingle Creek irrigation dam (2014), re-engineering of the Shuttleworth Creek sediment basin outflow (2015), and re-engineering of the Ellis Creek sediment basin outflow (2018).

ELEMENT 6: QUANTIFY THE PRESENCE AND EXTENT OF SPATIAL CONFIGURATION CONSTRAINTS, IF ANY, SUCH AS CONNECTIVITY, BARRIERS TO ACCESS, ETC.

Habitat quality, quantity and access have been reduced by numerous factors, including water withdrawals, construction of dams (for power generation and water diversion) and degradation of habitat through industrial, agricultural and urban usage. Approximately 91% of the mainstem Okanagan River in Canada has been modified, resulting in a major loss of spawning and rearing habitat (Bull 1999). Much of the habitat alteration occurred between 1910 and the 1950s. The Okanagan River channel then remained unchanged for 50 years (Davis et al. 2007), but recently there has been a trend toward increasing habitat quality, quantity and access as a result of restoration efforts and improved fish passage (see Mitigation Initiatives section).

Habitat modifications have advanced the presence of introduced fish species. Yellow Perch, Smallmouth and Largemouth bass, Pumpkinseed Sunfish (*Lepomis gibbosus*), Carp (*Cyprinus carpio*), and Black Crappie are considered to be alien invasive fish species and these may act as predators and/or competitors to Chinook Salmon (Scott and Crossman 1973, Alexis et al. 2003). These fish present a threat to Chinook Salmon juveniles and may reduce the habitat options available for Chinook rearing.

In addition to loss of access to habitat, there have been direct losses of spawning and rearing habitat in the Okanagan River. Much of the river between Okanagan and Osoyoos lakes (up to 84%, Machin et al. 2015) was channelized, straightened, narrowed, and dyked in the 1950s (Symonds 2000), leaving only 16% of the river (4.9 km) in a natural or semi-natural state. Bull (1999) estimated that there has been a 91% loss of natural accessible river channel, and a 90% reduction in riparian vegetation and wetland habitat (Bull et al. 2000). Little is known as to the amount of summer rearing habitat in the river (i.e., groundwater-fed side channels) that has been lost. It is likely that little usable summer habitat remains in the dyked sections of channel due to the absence of side channels and other areas where groundwater inflow may have a significant temperature-moderating effect. During the summer months, water temperatures may approach the lethal limit for Chinook Salmon (25ºC for stream Chinook in California; Myrick and Cech 1998), except in groundwater-fed side channels (Davis et al. 2007). Juvenile salmonids from the Okanagan River have been observed in river side-channels when temperatures in the mainstem were 24ºC (Alexis and Wright 2004).

Extreme water temperatures in summer months cause significant constraints in adult salmon migrations through migration delays, increased travel time, and reversals in upstream migrations. Studies on Okanagan Sockeye Salmon have observed a thermal barrier to migration where the Okanagan River flows into Wells Reservoir near Brewster, WA. When the relatively warm water temperatures of the Okanagan River rise above 21ºC, salmon will hold in the cooler waters in the Wells Reservoir (Hyatt et al. 2003).

Increased travel time is associated with increased temperature and decreased flows. Observations and model predictions for durations of migratory delays for Okanagan Sockeye salmon from 1924 – 1998 show an average delay entry into the Okanagan River of 29 days per year when Okanagan River temperatures are greater than 21ºC (Hyatt et al. 2003). Regular active migration timing is around 33 days when maintaining an average velocity of 30 km/day (Hyatt et al. 2003). Seasonal arrival timing at Zosel Dam coincides with the rise and fall of temperatures in the Okanagan River. The magnitude of the delays appears to be increasing from the early 1970s to present (Hyatt et al. 2003).

Water temperature variation also causes reversals in spawning migration. Okanagan Sockeye Salmon have been observed on spawning grounds in the Canadian Okanagan River while river temperatures were below 21ºC; however, as temperatures increased above that threshold, the sockeye vacated the spawning grounds electing to hold in downstream lakes (Hyatt et al. 2003).

It is likely that little usable summer habitat remains in the channelized sections of river due to the absence of side channels and other areas where groundwater inflow may have a significant temperature moderating effect. Rearing juvenile Chinook Salmon have been captured in Okanagan River in May and August (Wright and Long 2005). In July 2002, water temperatures in a few side channels were found to be up to 9°C cooler than the main river channel, which was 23°C (Alexis et al. 2003). Areas in the river that had water temperatures more than 3°C warmer than the surrounding river water (Davis et al. 2007). Each of these areas has the potential to provide summer rearing habitat for Chinook Salmon, but whether the effect is significant during higher summer flow conditions (i.e., about 20 m^3/s, compared to about 6 m^3/s when the thermal imaging was taken) and whether salmonids actually use these areas have yet to be determined. In 2006, the water temperature in Okanagan River (Water Survey of Canada station; *Okanagan River near Oliver*) was above 25°C for most of July, peaking at about 28°C in late July. Most of the identified areas of groundwater influence are concentrated along the channel margins and in side channels. Presumably, groundwater flowing into the thalweg (a line connecting the lowest points of successive cross-sections along the course of a valley or river) of the river would be rapidly diluted, and would be much less likely to be observed on the surface of the river; thus there may be temperature refuges near the bed of the river that were not identifiable using thermal imaging.

Okanagan tributaries can often provide cold water refugia for rearing if adequate flows are provided. Juvenile Chinook Salmon have been observed utilizing Inkaneep Creek in late summer. Inkaneep Creek shows a Maximum Weekly Average Temperature (MWAT) inter-quartile range between 19°C to 22°C in summer months (OBMEP 2019). Vaseux Creek shows an MWAT inter-quartile range between 19°C to 22°C, and Shingle Creek between 18°C to 21°C (OBMEP 2019). However, tributaries to the Okanagan River have also undergone extensive impairment in terms of salmon habitat (Lukey and Louie 2015). A long history of water withdrawals for irrigation has drastically reduced available habitat in the summer and fall. Corresponding encroachment has resulted in the decimation of riparian habitat, stream bank armouring, channelization, migration barriers, sedimentation, and ongoing removal of large woody debris (Lukey and Louie 2015).

ELEMENT 7: EVALUATE TO WHAT EXTENT THE CONCEPT OF RESIDENCE APPLIES TO THE SPECIES, AND IF SO, DESCRIBE IT

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

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

Based on the guidelines above, redds most closely match the criteria for a residence by Chinook Salmon because they are constructed, occupied by at least one adult (and by many eggs), and used in consecutive years. Redds have a structural form and function of a nest and the female has invested energy in its creation. Redds are essential for successful incubation and hatching of the eggs, and redds can contain hundreds to a few thousand eggs from a female salmon. Spawning regions have been identified in the Okanagan River, and redds located within these areas could be considered residences.

THREATS AND LIMITING FACTORS TO SURVIVAL AND RECOVERY OF OKANAGAN CHINOOK SALMON

Threats are defined as anthropogenic activities that negatively affect the productivity of Okanagan Chinook Salmon. Limiting Factors are defined as natural (abiotic or biotic) factors that negatively affect their productivity. Threats to the survival and recovery of the population are outlined in Element 8, whereas the potential ecological impacts of these threats (whether to the target species or other co-occurring species) are detailed in Element 11. Activities that threaten habitat are detailed in Element 9. Limiting factors are detailed in Element 10.

Threats and limiting factors were scored based on current and future biological risk as outlined in (DFO 2014b). Information on criteria used to determine threat levels (Table 7) can be found at the Canadian Science Advisory Secretariat. Biological risk is determined from two variables: likelihood of occurrence and level of impact. Current biological risk is based on present day biological risk. Anticipated biological risk is based on conditions anticipated 50 years into the future. The causal certainty (confidence) associated with the current biological risk was also scored.

Cumulative effects are the combination(s) of individual environmental or anthropogenic threats (or limiting factors) in a given area or on a given species. Determining the impact and threat level of cumulative effects are beyond the scope of this report; however, the importance of this issue remains high. Cumulative effects of each threat (or limiting factor) identified in this report remains a significant uncertainty and limitation regarding the interpretation of each threat level.

Table 7. Threats to the survival and recovery of Okanagan Chinook Salmon, and limiting factors. Threats are scored based on risk analysis methods described in DFO (2014b). Threats outline is from Salafsky et al. (2008).

Threat		Likelihood of Occurrence	Level of Impact	Casual Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Mining & quarrying	T3	Remote	Low	Low	Low (4)	Historical	Single	Restricted
Habitat impacts due to transportation and service corridors ▪Roads and railroads ▪Utility and service lines ▪Shipping Lanes	T4	Known	High	Medium	High (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
Population decline due to biological resource use ▪Fishing and harvesting (i.e., Commercial, Recreational, FSC)	T5	Known	High	Very High	High (1)	Historical/ Current/ Anticipatory	Continuous	Extensive
Natural system modification	T6							
▪Fire & fire suppression	T6	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Recurrent	Restricted
▪Dams & water management/use	T6	Known	High	High	High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
▪Other Ecosystem Modifications: e.g. Modifications o Catchment Surfaces, Linear development)	T1	Known	Medium	High	Medium (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
Pollutants ▪Household sewage & urban wastewater ▪Industrial & military effluents ▪Agricultural & forestry effluents	T7	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
Invasive Species & Genes	T9							
▪Invasive non-native/Alien species		Known	Medium-High	Medium	High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
▪Introduced Pathogens and Viruses		Known	Unknown	Very Low	Unknown (5)	Anticipatory	Continuous	Narrow

Threat		Likelihood of Occurrence	Level of Impact	Casual Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Aquaculture - Hatchery Supplementation								
▪Introduced genetic material	T2	Likely	Low	Very Low	Low (5)	Historical/ Current/ Anticipatory	Recurrent	Narrow
Geological Events (i.e., landslides)	T10	Unlikely	Medium-High	High	Medium (2)	Anticipatory	Single	Extensive

Limiting Factors		Likelihood of Occurrence	Level of Impact	Casual Certainty	Risk	Occurrence	Frequency	Extent
Varying Ocean/ Freshwater Conditions	T8	Known	High	High	High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
Competition	LF1	Known	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
Predation	LF1	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
Avalanches/landslides	T10	Likely	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Single	Narrow
Biological & Physiological Limits	LF2	Known	Low	Very High	Low (1)	Historical/ Current/ Anticipatory	Continuous	Extensive
Native Parasites & Pathogens	T9	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

ELEMENT 8: ASSESS AND PRIORITIZE THE THREATS TO THE SURVIVAL AND RECOVERY OF OKANAGAN CHINOOK SALMON

Threats to survival were scored based on current and future biological risk as outlined in (DFO 2014b), and are shown in Table 7, along with a ‘Threat Risk’ score which can be used to prioritize them. The causal certainty associated with the current biological risk was also scored for each threat.

Threats to the survival and recovery of the population include:

- Population decline due to biological resource use (T5)
  This threat was determined to be a **high population-level** risk with very high causal certainty.
- Population decline and habitat impacts due to natural system modification (T6)
  This threat was determined to be a **low to high population-level** risk with medium to high causal certainty.
- Elevated mortality or sub-lethal effects due to aquatic pollutants (T7)
  This threat was determined to be a **medium population-level** risk with medium causal certainty.
- Elevated mortality or sub-lethal effects due to climate change (T8)
  This threat was determined to be a **high population-level** risk with high causal certainty.
- Invasive and other problematic species and genes (T9)
  This threat was determined to be a **high population-level** risk with medium causal certainty.
- Population decline and habitat impacts due to geological events (T10)
  This threat was determined to be a **low population-level** risk with high casual certainty.

The potential ecological impacts of these threats (whether to the target species or other co-occurring species) are detailed as part of Element 11, below.

ELEMENT 9: IDENTIFY THE ACTIVITIES MOST LIKELY TO THREATEN (I.E., DAMAGE OR DESTROY) THE HABITAT PROPERTIES IDENTIFIED IN ELEMENTS 4-5 AND PROVIDE INFORMATION ON THE EXTENT AND CONSEQUENCES OF THESE ACTIVITIES

An overall assessment of habitat quality in the Okanagan River basin was completed in 2013. The wild salmon policy (WSP) report card is a measure of habitat quality associated with conservation units (CUs). The most recent publication of the Okanagan CU (Porter et al. 2013) reports the area as high risk (100%) using methods of cumulative habitat impacts based on a composite risk scoring. Porter et al. (2013) identified urban, agricultural, roads, riparian altered habitat, and wastewater discharges as high-risk pressures in this watershed. Mining activities, total land cover altered, stream crossings (number/km) and water allocation (m^3/ha) were identified as medium-risk pressures facing this watershed. Finally, these researchers identified forest disturbance and mountain pine beetle-disturbed stands as low-risk pressures facing this watershed.

Threats to habitat are shown in Table 7, along with a ‘Threat Risk’ score which can be used to determine the likelihood of having an impact. The causal certainty associated with the current biological risk was also scored for each threat.

Threats to habitat include:

- Habitat impacts due to ecosystem modifications (T1)
  This threat was determined to be a **medium-level** risk with high causal certainty.
- Habitat impacts due to aquaculture – hatchery supplementation (T2)
  This threat was determined to be a **low-level** risk with very low causal certainty.
- Habitat impacts due to mining & quarrying (T3)
  This threat was determined to be a **low-level** risk with low causal certainty.
- Habitat impacts due to transportation and service corridors (T4)
  This threat was determined to be a high-level risk with medium causal certainty.

The potential ecological impacts of these threats are detailed below.

Habitat impacts due to ecosystem modifications (T1)

This threat was determined to be a **medium-level** risk with high causal certainty.

The Okanagan River basin is a popular resident and tourist destination. Recreational and tourist activities such as boating, fishing, and agriculture (wineries, orchards) occur frequently and intensively. The Okanagan Valley is highly populated with several medium-sized cities built along each of the 3 lakes. Kelowna, Vernon, and Penticton are the largest of the towns along this waterway. Kelowna's population was 188 thousand in 2013 and has increased to 198.3 thousand in 2016 (Statistics Canada 2016). These values equate to a ~5% increase in population in only 3 years. In the greater Kelowna area, the number of private dwellings have increased by 8.6% (Statistics Canada 2016). Data grouped by geographic region suggest that all areas of the Okanagan are increasing (Statistics Canada – Focus on geography series based on the 2016 Census). Currently, urban development affects 5.59% of land in the Okanagan River basin (Table 8A; Porter et al., 2013). Increased residential and commercial development will bring in more people, construction, waste products, and water usage. A report documenting habitat quality in the Okanagan River basin reported that most tributaries south of Okanagan Lake as well as those north of Penticton found that almost all creeks, including Shingle Creek, were under high habitat impact and had high significance for habitat restoration (Rae 2005).

Agriculture

The Okanagan River basin has fertile soil and readily-available water sources. It is a popular destination for agriculture operations, including wineries and orchards. Porter et al. (2013) reported that 9.9% of the land in this area is impacted by agricultural and rural development. (Table 8A). Currently, 55% of freshwater usage is by agriculture, followed by 24% by domestic outdoor use (domestic pools, watering etc.; Summit Environmental Consultants 2010, Okanagan Water Board 2017). Water withdrawal from agriculture has been and is currently a concern in the Okanagan Valley, as both surface water and groundwater are withdrawn. The withdrawal of water (and resulting reduction in water levels, increased water temperatures, and lowered oxygen concentrations) can ultimately reduce the amount of fish habitat (National Research Council 2004). The two aquifers within the Okanagan Basin are classified as 1A (predominantly unconfined fluvial or glacio-fluvial sand and gravel aquifers found along major rivers of higher stream order with the potential to be hydraulically influenced by the river; Government of British Columbia 2017). The first is located under the portion of the Okanagan River between Vaseux and Osoyoos lakes. Another is located between Vaseux and Skaha lakes. These regions are located near town centres, have undergone considerable

Table 8. (A) Percent land and (B) specific attributes affected by anthropogenic pressures in the Okanagan basin (based on the area in the conservation unit). Data from Porter et al. (2013). Note that these percentages are for the whole watershed (from the US Border to Vernon), whereas the CU is restricted to an area that is more impacted by Urban Development and Agriculture, thus the values in these tables must be interpreted with caution.

A.

Anthropogenic Pressure	***Percent of Land Affected***
Mining development	0.08 %
Urban development	5.59 %
Agricultural/Rural	9.90 %
Forest disturbance	3.39 %
Riparian disturbance	26.51 %
Mountain Pine Beetle	1.22 %

B.

Anthropogenic Pressure Attribute	***Value***
Road development (km/km^2)	2.60
Stream crossing density (crossings per km of fish accessible streams)	0.93
Permitted wastewater discharges (number of discharge locations within watershed)	346
Water allocation (m^3/ha)	6558.57

development, and are vulnerable to contamination. Thus, both aquifers should have a high priority rating for management purposes.

Water usage is closely regulated to maintain compliance with terms of the Canada-BC Okanagan Basin Agreement (Anonymous 1974, 1982, Hyatt et al. 2015). Locally, the Okanagan Basin Water Board provides a source of expert advice and information relating to the Okanagan Basin. Annual reports are filed containing water usage numbers as well as educational initiatives directed at sustainable water use (www.obwb.ca). Increased development of the agricultural sector results in increased clearing of land and increased water usage and waste production. Removal of natural land cover also increases water evaporation rates which has recently become a significant concern in this area, as it was found that recharging capacity for aquifers surrounding Okanagan lakes and rivers have minimal or limited recharging capacity. From 1996-2006, it is estimated that annual evaporation in Okanagan and Vaseux lakes was 320,000 million litres and 2,800 million litres, respectively (Summit Environmental Consultants 2010). Agricultural water usage over a 10-year span (1996-2006) showed an increasing trend (Summit Environmental Consultants 2010). The B.C. Ministry of Forests, Lands and Natural Resource Operations (FLNRO) has guidelines to protect kokanee and Sockeye Salmon during spawning times. These actions include minimizing the drawdown of Okanagan Lake between the date of peak kokanee shore spawning and 100% hatch and emergence of the kokanee fry. Using the Ministry's fish water management tool (FWMT; described below), efforts are made to limit the drawdown to 15 cm so as not to dewater the shoreline. In 2017, the drawdown was 17 cm. The FLNRO also tries to keep the flow in the Okanagan River (measured at Oliver) below 28.3 m^3/s during Sockeye Salmon egg and alevin incubation (between 1 Nov and 100% emergence, which is usually in early May). These guidelines are overridden if flooding is expected. Although not a target of these efforts, Okanagan Chinook Salmon spawn between October and November and are therefore likely benefit from them.

Knowledge Gaps:

1. What are the current plans for residential and commercial growth around waterways in the Okanagan River basin?
2. What is the distance from lake/river after which development is allowed? What are the different regulations for different development types? There are many different owners/authorities over this habitat distance.

Co-occurring Species: Continued residential and commercial development in this area would also negatively affect Sockeye Salmon and kokanee that also spawn in this area.

Habitat impacts due to aquaculture – hatchery supplementation (T2)

This threat was determined to be a **low-level** risk with very low causal certainty.

Freshwater

Traditional net-pen-based aquaculture does not occur in the Okanagan River basin; however many hatchery operations are located in the U.S. portion of the Okanogan River as well as one newly operational hatchery in Penticton, B.C. Hatchery fish are marked with coded wire tags (CWT), which are used to generate growth and survival data.

Hatchery-reared salmon are considered less fit than wild salmon (Araki et al. 2008, Beamish et al. 2012, Drenner et al. 2012, Eliason and Farrell 2016). Different selection pressures are experienced by hatchery-reared fish relative to their wild counterparts. In a hatchery, temperature, oxygen and feed are all optimally provided under a no-predator environment, and high growth rates are usually prioritized over swim performance (Fleming et al. 2002). Data regarding overall fitness suggests that hatchery fish are ~30% less fit than wild fish (Araki et al. 2008). Negative effects such as lower genetic diversity and reproductive fitness are well documented for many fish species including Chinook Salmon (Shrimpton et al. 1994a,b, Heath et al. 2003, Jonsson et al. 2003, Hill et al. 2006, Araki et al. 2007, 2008, Chittenden et al. 2008, Beamish et al. 2012, Anderson et al. 2014). Recently, DFO has concluded that natural production of Canadian Pacific Chinook Salmon declines with increasing hatchery program size due to genetic impacts on fitness, and lowered reproductive success of hatchery fish in the wild (Withler et al. 2018).

Genetic impacts on wild fish from hatchery fish are more likely to be seen when the wild population is productive. Improved hatchery practices can increase the survival of hatchery-reared salmon and supplement salmon production of a struggling wild population. Hatchery practices are likely an important consideration in the survival of Okanagan Chinook Salmon due to their very low population numbers. Considering that it is unlikely that a distinct group of Okanagan Chinook Salmon remain, there is likely little threat to wild fish establishment by hatchery-reared fish. DFO is currently not involved in the rearing or release of the fish insofar as approving transfer and release permits for monitoring purposes (Monica Walker and Melanie McNabb, pers. comm., 2017).

The Kł cp̓əlk̓ stim̓ hatchery in Penticton, B.C. (operated by the ONA) has recently released Chinook Salmon into Okanagan River. Their fry release program has only begun in 2017 and very little data are thus far available. This hatchery is the first non-Provincial or non-Federal fish hatchery to undertake this work for conservation and commercial fishing purposes. In January 2017, the ONA imported 16,000 Chinook Salmon eggs from the Chief Joseph Hatchery in Bridgeport, Washington. In June 2017, the ONA released 15,000 Chinook Salmon fry into Skaha Lake. In September 2017, a further import of 30,000 Chinook Salmon eggs was approved by the 'Introductions and Transfers Committee' (ITC; DFO), again from the Chief

Joseph Hatchery. In October 2017, the ITC approved the collection of 14 adult Chinook Salmon from the Okanagan River to support their broodstock program. Twelve fish were actually caught (R. Bensen, pers. comm.). Considering there were only 40 spawning Chinook Salmon observed in 2016, the removal of 12 fish represents a considerable proportion (35%) of spawners. The primary goal for this program is rehabilitation of a wild population and a secondary goal is to allow harvest opportunities when escapement is sufficient (Bussanich et al. 2016). Both spring and summer Chinook Salmon are planned for release. These hatchery releases represent fewer fish than what the historical capacities of the Okanagan River has been reported to be. Aboriginal traditional knowledge suggests that upwards of 2.4 million Chinook Salmon were once present in the river during spawning (Armstrong 2015).

Hatchery practices are likely an important consideration in the survival of Okanagan Chinook Salmon. Hatchery salmon represent both a benefit and a potential threat to the wild salmon. Improved hatchery practices can increase the survival of hatchery-reared salmon. However, this can also create competition with the wild fish. Considering that it is unlikely that a distinct group of Okanagan Chinook Salmon remain, there is likely little threat to wild fish establishment by hatchery-reared fish. DFO is currently not involved in the rearing or release of the fish insofar as approving transfer and release permits for monitoring purposes (Monica Walker and Melanie McNabb, pers. comm., 2017).

Marine

Under marine conditions, hatchery fish (especially large enhancement activities) can have adverse effects on both wild salmon abundance and the health of ecosystems (Noakes et al. 2000). Between 1977 and 2000, nearly 500 million salmon have been produced and released in BC annually which constitutes ~40% of the total salmon biomass in the ocean. Chinook Salmon average about 42 million/year. The western states combined released ~ 250 million hatchery Chinook Salmon (~384 million total salmon), and Alaska released ~1.25 billion salmon. These high release numbers affect wild stocks (including Columbia-River sourced Chinook Salmon), especially where the distributions of the many salmon stocks overlap in the ocean, and when returning salmon are jointly harvested in mixed-stock fisheries (both in the US and Canada). Concern for the carrying capacity of the ocean became a concern in the 1980s when hatchery survival of all salmonids released to the Pacific Ocean were in decline (Noakes et al. 2000).

Knowledge Gaps: a better understanding between fitness of hatchery vs. wild fish.

Co-occurring Species: Other species planned for culture in the Penticton hatchery are White Sturgeon and Rainbow Trout, and impact of these fish on other native fish populations is unknown.

Habitat impacts due to mining & quarrying (T3)

This threat was determined to be a **low-level** risk with low causal certainty.

Porter et al. (2013) reported that 0.08% of the land in this area is impacted by mining development (Table 8A). Blue Hawk Mine in Westbank once mined Au, Ag, Pb, Cu and Zn, but has since closed. There is a very low possibly in the long term, >10 yrs, for any mine to be reactivated in the Okanagan or Canadian Columbia regions. As of April 2014, the B.C. Government did not have any record of an active mine in the Okanagan region.

Co-occurring Species: Any mining-related impacts would also negatively affect Sockeye Salmon and kokanee that also spawn in this area.

Habitat impacts due to transportation and service corridors (T4)

This threat was determined to be a **high-level** risk with medium causal certainty.

Terrestrial areas surrounding the Okanagan waterways are highly developed with several cities surrounding the length of the watershed. Roads, railroads and shipping routes are dense in this area. Porter et al. (2013) reports that there are 2.6 km of developed roads in the Okanagan region for every square kilometer (Table 8B). This density is considered high as it is above 0.4 km/km^2 (Stalberg et al. 2009). Road development leads to cleared land and increased run-off of vehicle-related wastes.

A modelling analysis of Wenatchee River spring run Chinook Salmon habitat restoration scenarios found that a reduction in fine sediment (due to human development leading to increased run-off containing the fine sediment) resulted in the greatest increase in mean smolt and spawner abundance (Honea et al. 2009). It is likely that fine sediments have the greatest impact on survival through the egg stage (Honea et al. 2009). Water percolation (maintenance of temperature and oxygen levels) through spawning gravel is critical for egg and alevin survival; a requirement that can be severely compromised by siltation of spawning beds (Healey 1991). One study which used lower Columbia River Chinook Salmon eggs concluded that when percolation rates ranged between 0.4 ft/s (12.2 cm/s) to 2.2 ft/s (67.1 cm/s), almost all eggs hatched (~96%; Shelton 1955). The findings of this study would be relevant to Okanagan Chinook Salmon, as the mainstem river migration route is the same. Increases in fine sediments have previously been correlated with lower forest cover, more anthropogenic impervious surface area (i.e., paved roads), and higher road density (Jorgensen et al. 2009) all of which are present around the Okanagan watershed. The B.C. government has estimated that as a result of land development, only 4% of riparian habitat is left intact in the Okanagan watershed (Government of B.C. 1998). The loss of this habitat impacts Chinook salmon directly in affecting availability of shaded refuge and increasing sun exposure and therefore water temperatures in smaller stream habitats. Moreover, the loss of riparian habitat contributes to changes in insect and plant species composition available to juvenile salmon for food and predator avoidance, respectively.

Knowledge Gaps: What are the plans for increased road development? Is there currently a distance away from a water source such that impacts from the roads aren't as high?

Co-occurring Species: Continued road development in this area would also negatively affect Sockeye Salmon and kokanee that also spawn in this area.

ELEMENT 10: ASSESS ANY NATURAL FACTORS THAT WILL LIMIT THE SURVIVAL AND RECOVERY OF OKANAGAN CHINOOK SALMON

Limiting factors (Table 7) were scored based on current and future biological risk as outlined in (DFO 2014b).

Predation and Competition (LF1)

This threat was determined to be an **unknown-medium-level** risk with very medium causal certainty.

Predator-prey dynamics are highly dependent on environmental variability (Wells et al. 2017). Predation and competition effects on Okanagan Chinook Salmon remain largely unknown. A study of yearling and sub-yearling Chinook Salmon in the Columbia River basin showed that avian predation occurs. Estimates of predation probability ranged from 0.03 and 0.09 for yearling Chinook Salmon and from 0.01 to 0.05 for sub-yearlings (Evans et al. 2016). Predation on smolts by Caspian Terns (*Hydroprogne caspia*) occurred primarily within reservoirs, while predation by gulls (*Larus* spp.) primarily occurred near hydroelectric dams. American White

Pelicans (*Pelecanus erythrorhynchos*) and Double-crested Cormorants (*Phalacrocorax auritus*) did not have a detectable impact. Others studies have found that waterbirds (including the Common Merganser (*Mergus merganser*), California (*Larus californicus*) and Ring-billed (*L. delawarensis*) gulls, Caspian Tern, and Double-crested Cormorant) that reside in the mid-Columbia River were found to consume <1% of the available salmonid smolts (Wiese et al. 2008). This study also found that the waterbirds consumed the fish while they were present in the river; however, when the salmon left the area, the waterbirds switched their prey to a native salmonid predator the Northern Pikeminnow (*Ptychocheilus oregonensis*; discussed below). Models suggest that if these birds were removed from the system, abundance of the pikeminnow would increase and therefore, more predation on Chinook Salmon would take place by the pikeminnow (Wiese et al. 2008). Lastly, turbidity of the water had an effect on the predator avoidance behaviour of juvenile Chinook Salmon by birds. Controlled experiments evaluating the risk associated with both fish and bird predators were conducted where fish were found to not swim as deep within a water column or stay as deep when kept in turbid waters relative to fish kept in clear water conditions (Gregory 1993).

Yellow Perch are established throughout the Okanagan River system (Runciman and Leaf 2009). As evidenced by their broad distribution in North America, Yellow Perch have wide environmental tolerances. Upper thermal limits of 25-30ºC have been proposed, and their presence in the northern parts of the Prairie provinces suggests they can persist in conditions of long winters and relatively short and cool growing seasons (Wydoski and Whitney 2003). Headwater introductions were likely the source of Yellow Perch in Okanagan and Skaha lakes, which are isolated from the Columbia Basin by Okanagan Falls (Bradford et al. 2009). Competition between Yellow Perch and salmon (including Chinook Salmon) is likely; however, this issue remains unknown.

Predation on Chinook Salmon by marine mammals such as pinnipeds and whales is also of concern in the marine environment. Orcas consume the most biomass of Chinook Salmon, while Harbour Seals (*Phoca vitulina*) consume the largest number of individuals (Chasco et al. 2017a). It is estimated that the consumption of Chinook Salmon biomass by pinnipeds in Washington State has increased from 68 to 625 metric tons between 1970 and 2015. This equates to nearly double the number of individuals that resident Orcas consume, and is six times the combined commercial and recreational fishery harvests (Chasco et al. 2017a,b). These interspecific interactions are important when evaluating species recovery.

The Northern Pikeminnow is a predatory freshwater fish native to northwestern North America, including the Columbia River basin. There is growing concern regarding the impacts of Northern Pikeminnow populations on salmon in the Columbia and Snake river systems, and Northern Pikeminnow is likely a limiting factor for Chinook Salmon. Northern Pikeminnows can live at least 11 years, reaching up to 63 cm in total length and 13 kg in weight. A mature female can lay 30,000 eggs annually. Northern Pikeminnow are adept predators, and salmon smolts comprise a large part of their diets in the Columbia and Snake Rivers. Specifically, Zimmerman (1999) found that juvenile salmonids were the primary prey of the Northern Pikeminnow (ranging from 29.3-64.2% of the diet) over 6 years (1990-1996). Northern Pikeminnow populations have flourished with the development of the Columbia River hydropower system, as the reservoirs have provided excellent habitat for pikeminnow, and given them an advantage over depressed salmon and steelhead populations (Mesa 1994). Indeed, it has been found that sustained removal of Northern Pikeminnow increases survival of juvenile salmonids (Ward and Zimmerman 1999).

Studies suggest that dominance of Pink Salmon over other salmon species will occur and will likely be climate-change induced (Ruggerone and Goetz 2004). Pink Salmon have been found to significantly alter prey abundance of other salmon species, leading to altered diets, reduced prey consumption, delayed maturation, and reduced survival. Reduced survival was evident in Chinook and Chum salmon from Puget Sound where this out-competition was a result of more successful exploitation of resources rather than interference with the other salmon species (Ruggerone and Goetz 2004). Additionally, Puget Sound Chinook and Pink salmon survival rates were compared on an even vs odd-year basis (Pink Salmon have a 2-year migratory pattern, being more abundant in even years and less abundant in odd years). It was found that during 1984–1997, juvenile Chinook Salmon released during even-numbered years experienced 59% lower survival than those released during odd-numbered years, a trend consistent among 13 Chinook Salmon stocks (Ruggerone and Goetz 2004). In contrast, Chinook Salmon released into coastal streams, where few Pink Salmon occur, did not exhibit an alternating-year pattern of survival, suggesting that the interaction occurred within Puget Sound and the lower Strait of Georgia.

Co-occurring Species: Sockeye Salmon and kokanee are fished for recreational, ceremonial, and commercial purposes and may have similar limiting factors.

Biological and Physiological Limits (LF2)

This threat was determined to be a **low-level** risk with very high causal certainty.

The primary factor limiting physiology and biological processes for Chinook salmon include high water temperatures that exceed thermal tolerance limits.

1. direct losses of juveniles and adults to injury, predation and migration mortality through the network of Columbia River dams and their impoundments; and
2. unknown ecological effects of invasive species, including several competitive and predatory fish species.

The causes of this limiting factor are described in more detail below (T8). Impacts of changing water temperatures on Okanagan Chinook salmon specifically is unknown; however while in the Columbia river, other Chinook salmon populations have been found to have an upper thermal tolerance limit of ~20-22ºC (Tohver et al. 2014; Keefer et al. 2018). In 1939, Okanagan Lake rarely exceeded 20°C during July and August (Clemens et al. 1939). However, more recently, peak summer water temperatures continue to exceed 20ºC in several reaches of the Columbia River (Keefer et al. 2018; Richer et al. 2006). These temperatures are higher than the B.C. aquatic life guideline of 18°C (Dessouki 2009).

Spawning salmon are also at increased risk of exceeding thermal tolerance limits. Temperature and oxygen saturation are inextricably linked through solubility chemistries and thresholds. Higher thermal performance in fish is predicted to be due to sufficient oxygen delivery to the heart that enables an increase in heart rate above resting values (Eliason and Farrell 2016). Okanagan River Chinook returning to spawn must either tolerate sub-optimal in-river temperatures in September (16-22°C), or hold downstream of the Okanagan River until water temperatures decrease to approximately 16ºC in early October (COSEWIC 2017).

Cooler water temperatures of <13ºC are required for spawning Chinook salmon (Becker 1973; Reiser and Bjornn 1979). Temperatures greater than 13 ºC have been found to increase mortality to females prior to spawning (Raleigh et al. 1986). Additionally, mature females subjected to prolonged exposure to water temperatures above 15.6°C (or below 3.3°C) results in poor adult survival and egg viability (U.S.Fish and Wildlife Service 1995). Studies on mid-Columbia Chinook and Coho salmon show that the egg, juvenile and fry stages were the most vulnerable to temperature fluctuations (Hatten et al. 2014). Egg fertilization, hatch and emergence has been documented as >84% when exposed to temperatures between 13 and 16.5°C (Geist et al. 2006). The same study also found that incubation temperature of 17°C yielded high fertilization to eyed egg development rates, but poor (<2.5%) hatch, and emergence survival rates. Exposure to heat can increase disease susceptibility, impair ovulation and increase stress hormone levels in salmonids (Young et al. 2006, Jonsson and Jonsson 2009, Bradford et al. 2010a). Reliance on thermal refuges and shifts in migration timing and phenology are expected responses (Keefer et al. 2018). Declining thermal refuge options combined with increased frequency of exposure to >20ºC temperatures will have a significant effect on the energetic cost of migration and mortality rates in Chinook salmon (Plumb et al. 2018).

Human-caused Landslides (T10)

This threat was determined to be a **low-level** risk with medium causal certainty.

The impacts of human-caused landslides on Okanagan Chinook Salmon have not been studied, but it stands to reason that effects would be similar to those of geologic events (earthquakes or natural landslides). Further information can be found in Element 11 under the treatment of Geological threats.

Parasites & Pathogens (T9)

This threat was determined to be an **unknown-level risk** with low causal certainty.

The impacts of parasites and pathogens are discussed in Element 11 under the treatment of problematic species and genes.

ELEMENT 11: DISCUSS THE POTENTIAL ECOLOGICAL IMPACTS OF THE THREATS IDENTIFIED IN ELEMENT 8 TO THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES

Threats to survival were identified and scored in Element 8 (see Table 7). Here, we discuss the potential ecological impacts of the identified threats, whether to the target species or other co-occurring species.

Population decline due to biological resource use (T5)

This threat was determined to be a **high population-level** risk with very high causal certainty.

Historical fishing impacts on Okanagan Chinook have been substantial. Although there is currently no directed fishery for wild Chinook Salmon in the Okanagan River, the population is part of a complex of populations that is fished from southeast Alaska to the mouth of the Columbia River, and as they migrate up the Columbia River (C. Parken, pers. comm). Exploitation rates for the likely co-migrating Wells Hatchery stock has been as high as 80% (Figure 5) where average ocean harvest rates based on coded wire tag data are estimated at 41% (Appendix A; Table A3). Additionally, the average annual catch from above Wells Hatchery collected from 2000-2017 is 2,589 (range 442-10,410; T. Garrison, pers. comm.). Moreover, substantial numbers of Chinook Salmon may be intercepted as bycatch in the Pacific Coast groundfish fishery, the Bering Sea - Aleutian Island and Gulf of Alaska groundfish fishery, and the Pacific sardine fishery, with unknown overall impacts on Upper Columbia River Summer Chinook Salmon stocks (C. Parken, pers. comm. 2016). Mixed-stock fisheries can lead to higher fishing pressure on smaller wild stocks when harvest rates are determined based on the hatchery production levels. Also, the pre-season estimates are used prior to knowing in-season environmental conditions (Noakes et al. 2000). It is for these reasons that this threat was categorized as high despite the absence of a directed fishery. Re-establishment of any Okanagan Chinook wild population will be subjected to these high fishing pressures.

Knowledge Gaps: Uncertainty in U.S. future harvest planning (e.g., unknown magnitude of fishing impacts outside of the Pacific Salmon treaty area, including as bycatch in groundfish fisheries).

Co-occurring Species: Sockeye Salmon and kokanee are fished for recreational, ceremonial and commercial purposes.

Population decline and habitat impacts due to natural system modification (T6)

This threat was determined to be a **low to high population-level** risk with medium to high causal certainty.

Fires

Fires cause vast destruction of riparian areas. The frequency and intensity of fires in this region is expected to increase (Crozier 2015). This change can lead to raising stream temperatures and cause bursts in nutrient loading through erosion (Crozier 2015). Globally, wildfires are expected to grow in frequency and net declines in fish biomass have been observed following wildfires near stream (Beakes et al. 2014, Crozier 2015). Recent research has suggested that wildfires can generate thermal heterogeneity in aquatic ecosystems and increase stream temperature (Amaranthus et al. 1989, Isaak et al. 2010), resulting in environmental conditions that can stress the bioenergetics of salmonids (Beakes et al. 2014). In addition, the use of fire-retardant chemicals and suppressant foams can pose a risk to the health of aquatic ecosystems (Backer et al. 2004). No research has been conducted to date on the impacts of wildfires and fire suppression practices on Okanagan Chinook.

Dams

Dams present a significant challenge to migrating juvenile and adult salmonids. Dams alter the water quality and habitat of a river environment. Some characteristics, such as water quantity, flow rates, timing, frequency, and magnitude of release can be controlled and modified in favour of improved conditions for freshwater fishes. Rapid changes in water discharge rates during spawning or migration periods have led to dramatic declines in successful spawning events or the dewatering of redds (Geist et al. 2008, Harnish et al. 2014). Short term effects of water flow fluctuations during juvenile rearing stages can strand fish in isolated water pools. Long term effects include altering the density, availability, and diversity of their food supply (Cushman 1985, Gislason 1985, Bunn and Arthington 2002, Harnish et al. 2014). Lower water flows mean less dilution of runoff from agriculture and industry, and concentration effects for pollutants and contaminants. Access to diverse habitat conditions is an important buffer to the response of salmon to climate change (Schindler et al. 2008). Dams block access to certain habitat types, limiting the availability of these more diverse regions (in geography and conditions such as temperature; Anderson et al. 2014).

Dams also alter the selection pressures on salmon within the Columbia River. Dams impose a substantial loss of fitness and strong selection of phenotypes (Angilletta et al. 2008). Spawning dates are highly heritable and thus, the evolutionary response to these pressures should be rapid. Dams have an effect on: temperature; historical date of spawning; and the relationship between emergence and survivorship. Reservoirs increase water residence time and solar gain (Hamblin and McAdam 2003), creating significant thermal stratification upstream of dams. Such stratification has created temperature gradients within fishways, causing slowed and failed upstream migrations of Chinook Salmon (Caudill et al. 2014). Elevated water temperatures in the Columbia River have also influenced predation on out-migrating juvenile salmon (Petersen and Kitchell 2001), and the behaviour and rate of migration of adult Chinook Salmon (Goniea et al. 2006). Juveniles must survive downstream passage and adults must locate fishways and navigate slack water in reservoirs (Waples et al. 2008b). Dams prolong ocean migration timing, and reduce water flows and create new habitats for potential predators and competitors (Schaller et al. 2013).

A number of modifications have been made to Okanagan River dams in recent years. In 2014, the fish ladder was opened on the Skaha Lake outlet dam allowing Chinook Salmon to access Skaha Lake and the Okanagan River between Skaha Lake and Okanagan Lake (Alex et al. 2018). Prior to that, in 2009, the Vaseux Lake outlet dam (McIntyre Dam) was re-engineered to create ‘over-shot’ gates, allowing Chinook Salmon to jump the dam (Rivard-Sirois et al. 2013). This provided access to Vaseux Lake and the Okanagan River between Vaseux Lake and Skaha Lake. In general, salmon need a depth over 1 m to leap a maximum of 1.8-3 m (Evans and Johnston 1980). Another study noted that Chinook Salmon have a maximum jumping height of 2.4 m and a maximum darting speed of 3.29-6.83 m/s (Bjornn and Reiser 1991). Since installation, Chinook Salmon have been observed leaping over the gates (ONA, unpublished data).

Knowledge Gaps: separating out in-ladder temperatures with overall river temperature responses is highlighted by Caudill et al. (2014) as being nearly impossible.

Co-occurring Species: Sockeye Salmon and kokanee habitat will also be significantly affected by wildfires and dams.

Elevated mortality or sub-lethal effects due to aquatic pollutants (T7)

This threat was determined to be a **medium population-level** risk with medium causal certainty.

The Okanagan River basin is highly monitored for water quality. Total phosphorous, mean chloroform, water clarity, and total nitrogen are regularly monitored by the B.C. Government. Overall, these water quality parameters have remained stable over ~30 years or are improving (B.C. Ministry of Environment, unpublished data). Data collected by the B.C. Ministry of Environment and by Environment Canada, spanning 1990-2007, also suggest that overall water quality is improving. Many parameters had statistically significant increasing trends including dissolved chloride, fecal coliforms, hardness, extractable magnesium, molybdenum, strontium and turbidity. Other trends displayed statistically significant decreasing trends, including aluminum, chromium, colour, copper, flow, iron, lithium, manganese, pH, phosphorus, potassium and zinc. The Canadian council of Ministers of the Environment (CCME) water quality guidelines for the protection of aquatic life currently do not report threshold concentrations for copper or aluminum and are being updated.

Two concerning metals are copper and aluminum, as both can both have detrimental effects on all stages of salmonid life, but the early stages are most susceptible (Beckman and Zaugg 1988, Hansen et al. 1999b, Jezierska et al. 2009) and can inhibit Na^+/K^+ ATPase activity, a critical enzyme expressed in the parr-smolt transformation stage (Beckman and Zaugg 1988). Chinook Salmon where found to avoid low concentrations (<25 µg/L) of copper, and failed to avoid higher concentrations (>25 µg/L), correlating to a greater detriment to fish health (Hansen et al. 1999a). One study demonstrated that the LD50 for Atlantic Salmon could be >1.9 µM (51.3 µg/L) when exposed for ~120 hours (Roy and Campbell 1995). Moreover, Roy and Campbell (1995) also showed increased toxicity when co-exposures with other metals were performed (toxicity observed to be < 0.18 µM (4.86 µg/L)) when aluminum exposure was coupled with zinc exposure. Heavy metal exposure (e.g., lead or copper) can cause a wide array of effects in during embryonic development including malformations, reduced hatching, reduced developmental rates and reduced survival rates including in Chinook Salmon (Hazel and Meith 1970, Jezierska et al. 2009). Average aluminum concentrations in the Okanagan River, measured at Oliver by Environment Canada from 2003-2016 were 60.4 µg/L (range of 6-970 µg/L). Average copper concentration was 0.77 µg/L (range of 0.46-2.7 µg/L) during the same time period. These data contain several anomalous readings and therefore would have to be further investigated. Lead has been negligible in the water until 2016 when several readings averaged 6.5 µg/L.

The migrating life history of Chinook Salmon means that they encounter a suite of chemical contaminants. These migration route pass through waters that are located near agricultural and industrial-developed land. Organochlorine (OC) chemicals are residues from pesticides and industrial compounds such as polychlorinated biphenyls (PCBs) first detected in the 1960s. OC compounds can bioaccumulate and are persistent and toxic (Miller 1994). OCs include DDT, hexachlorobenzene, chlordanes, and dieldrin. Reproduction effects have been detected in both fish and birds in the Great Lakes (Fitchko 1986). Maximum levels of PCBs in food including fish products sold in Canada is currently under review (https://www.canada.ca/en/services/health.html). Levels within fish are difficult to determine, as measured chemical loads represent lifetime loads and can't be correlated to when and where the fish were caught.

A study of several contaminants including OCs found that hatchery-reared juvenile fall Chinook Salmon from the lower Columbia River had mean concentrations of summed PCBs, summed DDTs, and summed PAHs that were 17, 9.0, and 30 ng/g wet weight, respectively. These contaminant exposure levels were below those associated with adverse effects on salmon health (Johnson et al. 2010). Wild fall juvenile Chinook Salmon from the lower Columbia River were found to also contain similar types of contaminants, where PCBs and DDTs were found at the highest concentrations and possibly at levels that were at the threshold for adverse health effects in juvenile salmonids of 2,400 ng/g lipid (Johnson et al. 2007).

Rae and Jensen (2007) produced a report for the Okanagan River basin that described the presence of other contaminants such as PCBs (poly chlorinated biphenyls) and DDT (dichloro diphenyl trichloroethane). PCBs are hydrophobic, easily penetrate skin, and do not break down easily. DDT was a common pesticide and can still be found in some modern products. Information is only available at the fish tissue level, but can be used as a proxy for environmental contamination exposure. Between 2000 and 2006, Lake Trout and kokanee (not a migrating species) were assessed. Arsenic, PCBs, and total dioxin levels were found to be below the Health Canada consumption thresholds for concern; however, DDT was found in Lake Trout to be equal to or greater than the Health Canada guidelines (Rae and Jensen 2007).

The impacts of plastic pollution in the marine environment on fish is an emerging concern (Wilcox et al. 2016). Recent studies have shown impacts of plastics (at 10,000 – 80,000 particles/m^3) on egg survival and juvenile behaviour in fish (Lönnstedt and Eklöv 2016). However, exposure and impacts of plastics in the marine environment on Chinook Salmon have not been studied.

Knowledge Gaps: updated testing of pollutants in the system is needed; including information on microplastics.

Co-occurring Species: Heavy metal/contaminants exposure for Sockeye Salmon and kokanee are likely to be similar to Chinook Salmon; however, their tolerance levels may differ.

Elevated mortality or sub-lethal effects due to varying ocean/freshwater conditions (T8)

This threat was determined to be a **high population-level** risk with high causal certainty.

Salmon will likely experience many impacts as a result of varying ocean/freshwater conditions (i.e. due to climate change), as their habitat range is vast and therefore will be susceptible to environmental change occurring in any part of their range. In 2015, NOAA compiled a comprehensive report (over 600 papers were reviewed) that assessed the impacts of climate change on salmon in the Pacific Northwest (Crozier, 2015). These and other large-scale responses are summarized in Table 9. Among the many limiting or threatening factors, water temperature and habitat loss are likely the most critical for Pacific salmon, and are likely not different in importance for Okanagan Chinook Salmon. Predictions of a 2.1°C average temperature increase between 2070 and 2098 have been made for the Columbia River (Payne et al. 2004).

Table 9. Large scale climate change processes and potential adaptive responses of Chinook Salmon.

Large-scale climate-change process	***Potential large-scale impacts***	***Potential salmonid adaptations***	***Relevance to Okanagan Chinook survival***
Increased temperature	Predator/prey interactions[5] Physiology (osmoregulation, cardiorespiratory etc.)[10] Metabolic rate/swimming Decreased diversity, reproduction, Growth/survival[5]	Increases in egg size[4] Delayed migration[9]	Maximum thermal temperature of >21˚C ; lethality at 25˚C[11]
Increased precipitation	Less cool-water input during spring/summer [5]	Behavioral response to seek out deeper waters/cool water refuges.	Delayed terminal migration[9]
More diverse/intense pathogens	More intense and prevalent infections. Exposure to new invasive pathogens.	Rapid response of major histocompatibility complexes or heat shock proteins[8]	Unknown
Increased ocean acidification	Physiology (osmoregulation, cardiorespiratory etc.), Metabolic rate and swimming[10], Reproduction, Growth/survival, Calcification and Acid-base balance[5,7]	Unknown	Unknown
Hypoxia[10]	'Dead' zones in estuary/coastal areas Altered species distribution and predator/prey interactions	Species dispersion to seek out more oxygen-rich waters	Unknown
Invasive species	Invasion and expansion of more heat-tolerant fishes Increased competition for resources	Cool water refuges would deter more heat-tolerant fishes	Bass have overlapping territories with Chinook Salmon[6]
More intense upwelling patterns[5]	Influence on rate of ocean acidification and primary productivity[8]	Unknown	Unknown
Interactions with toxic chemicals	Increase in toxicity of pesticides to salmon – including neurotoxicity[1,2,3]	Unknown	Unknown

Data are from 1-Laetz et al. (2014); 2-Dietrich et al. (2014); 3-Counihan et al. (2014); 4-Muñoz et al. (2014); 5-Harley et al. (2006); 6-Lawrence et al. (2014); 7-Heuer and Grosell (2014); 8-Crozier (2015); 9-Goniea et al. (2006); 10-Pörtner and Farrell (2008); 11-Richter and Kolmes (2005).

Globally, rising air and water temperatures are rapidly rising with warm-ocean anomalies (‘the blob’; North Pacific Gyre Oscillation) occurring (Miller et al. 2014, 2015a, Bond et al. 2015). This oscillation is now recognized as being a more dominant system over the Pacific Decadal Oscillation in predicting survival of Columbia River juvenile Chinook Salmon (Miller et al. 2014). Large-scale basin-wide transitions will be made from snow-dominated basins to rain-dominated basins (Payne et al. 2004, Sawaske and Freyberg 2014). This will likely be the trend for the Columbia basin which will impact recovery efforts of Okanagan Chinook Salmon. Predictive modelling for the Columbia basin found many climate change-related risks for this region. These risks include increased probability of 20 and 100- year floods, decreases in summer low flows – with the exception of the headwaters of the Columbia basin, reduced summer precipitation and higher evapotranspiration from warmer summer temperatures (Tohver et al. 2014). Sea water rise will also bring saltwater further upstream impacting the estuaries. The degree of impact of this rise are unknown for Columbia River salmon, but is likely to be significant. Large-scale conditions that are predicted to change in the Pacific Ocean include wind patterns, hypoxic water, upwelling patterns and water acidification all of which will have a large impact on all salmon in the Columbia river (Crozier 2015).

An assessment of mid-Columbia Basin salmonid responses found that juvenile and fry stages of Chinook and Coho salmon were the most vulnerable (Hatten et al. 2014). Eggs have lower heat tolerances than adults (10°C lower) and rely completely on adults for placement in suitable areas to avoid heat stress, hypoxia and scouring. Estuary usage is expected to be of increasing importance for juvenile salmon in response to climate change. Predictions made from observations in the Columbia River suggest that Coho Salmon will spend longer periods of time in estuarine environments, and even overwinter there (Crozier 2015). Estuary usage (timing or distribution) in the Columbia River basin by Okanagan Chinook Salmon is currently unknown, but likely will be altered as a result of varying ocean and freshwater conditions.

Effects of diseases and pathogen will likely intensify as a response to climate change. Research into this area is only in its infancy, but early studies suggest salmon have some capacity for a rapid evolutionary response to pathogens, either through major histocompatibility complexes or heat shock protein responses (Anttila et al. 2014, Larson et al. 2014, Crozier 2015). Chinook salmon responses to cumulative pathogen infections as a result of changing ocean and freshwater conditions is also not known, but is likely to be a significant stressor.

In 1939, Okanagan Lake rarely exceeded 20°C during July and August (Clemens et al. 1939). During this year, average temperatures were ~7°C and oxygen concentrations ranged from 5.0-6.0 cm^3/L, whereas surface water pH was measured at 8.0-8.2. Increase in snowmelt runoff and reduced summer and fall flows will necessitate the trade-off between reservoir releases and instream flow targets for fish (Payne et al. 2004). Although water temperature is seasonally decreasing, peak summer water temperatures continue to exceed the B.C. aquatic life guideline of 18°C (Dessouki 2009). Porter et al. (2013) predicted air temperatures to increase in the Okanagan CU regions (during spawning and migration periods; September to October) from a current calculated baseline (2000-2009) of 22.0°C to 23.4°C in 2020, 24.3°C in 2050 and 26.4°C in 2080. Additionally, during rearing periods (i.e., year-long), modeled air temperatures were predicted to increase in the Okanagan CU regions from a current calculated baseline (2000-2009) of 31.0°C in 2050 and 32.9°C in 2080. Table 10 describes some observed climate change-induced ecological effects on salmon.

Maximum thermal tolerance values for spawning Chinook Salmon exposure is 14.5°C; for adult migration is 21°C; and temperatures above 25°C are lethal for Chinook Salmon (Richter and Kolmes 2005). Variability in responses between salmon populations is high; however, these values serve as good benchmarks for Okanagan Chinook Salmon temperature exposures.

Table 10. Observed climate change-induced ecological effects on Chinook Salmon and other species of salmon.

Impact	***Relative change***	***Qualification***	***Location / Salmon species***	***Reference***
Spawning date	With an increase of 2°C, spawning occurs one week later since 1950	Observed	Columbia River/Chinook	Hayes et al. (2014)
Migration range	Northward shift	Observed	Norway/Atlantic Salmon	Jensen et al. (2014)
Smolt timing	2.5 days earlier/decade relative to 50 years ago	Observed	Atlantic Salmon	Otero et al. (2014)
Spawner numbers	Decrease by 4-7% with a corresponding temperature of >17°C	Predicted	Wenatchee/Spring Chinook Salmon	Honea et al. (2016)

Knowledge Gaps: What is the usage of Chinook Salmon in the Columbia River estuary? What are the proposed changes to dam operations from a water storage/energy needs perspective by the U.S. government or U.S. energy firms? What is the U.S. plan for climate change mitigation in the Columbia River basin? What are the thresholds of cumulative temperature exposures where Okanagan Chinook can still reproduce successfully?

Uncertainties: How do changes in air temperatures translate into changes in stream temperatures? Most models fail at addressing this issue despite multiple attempts (Hague and Patterson 2014).

Co-occurring Species: Sockeye salmon and kokanee are similarly impacted by the broad effects of climate change.

Invasive and other problematic species and genes (T9)

This threat was determined to be a **high population-level** risk with medium causal certainty.

Exotic Species

In 2003, an assessment was conducted to evaluate the species composition and risk associated with any exotic species that were found (Alexis et al. 2003). Both findings are summarized in Table 11. Walleye (*Sander vitreus*) was found in the mainstem of the Columbia River and was rated as the highest risk for direct interaction with native salmonids in the U.S. (Alexis et al. 2003). Other invasive fishes present in the area (e.g., Carp, Smallmouth Bass, Pumpkinseed) may act as predators and/or competitors to Chinook Salmon (Scott and Crossman 1973, Alexis et al. 2003). These fish present a threat to Chinook Salmon juveniles and may reduce the habitat options available for Chinook rearing.

The walleye is a freshwater perciform fish native to most of Canada and to the Northern United States including the Columbia River Basin. Walleyes show a fair amount of variation across watersheds (Wiese et al. 2008). Studies have shown that an estimated ~13% of salmonids were consumed by Walleye in the John Day Reservoir (Beamesderfer and Rieman 1991).

Table 11. Exotic species identified in the Okanagan basin between 2001 and 2003. Data from Alexis et al. (2003).

Exotic species of concern	***Geographical range***	***Habitat preferences and species interactions***	***Areas thought to be colonized***	***Exotic fish risk assessment***
Black Crappie	Osoyoos Lake oxbows; not above McIntyre Dam	Lake littoral zone. Adults feed on very small fish.	Skaha Lake littoral zone	Little interaction with salmonids
Largemouth Bass	Vaseux and Osoyoos lakes	Warm, shallow, weedy areas. Piscivorous but predation would be minimized on pelagic species except during emergence and smolts.	Skaha Lake littoral zone	Would feed on salmonids passing through the littoral zones
Smallmouth Bass	Throughout Okanagan River	River margins	-	Potentially a very high risk; active during summer Chinook Salmon emigration
Bluegill	Osoyoos Lake	Littoral zone; adults move into limnetic open-water; feed predominantly on limnetic zooplankton and rarely eat fish	Skaha Lake littoral zone as juveniles, then limnetic open water as adults	Occupy different habitat and feed on zooplankton. Likely little interaction with pelagic species such as salmon.
Walleye	Established population in the Columbia River mainstem. Absent in Osoyoos, Skaha and Okanagan lakes so far	Littoral and pelagic areas of lakes. Seasonally inhabit the same areas and are known to prey on juvenile salmonids.	Suitable habitat in Skaha and Osoyoos lakes	Would have an impact on resident salmonids if they established in the Okanagan River basin
Tench (*Tinca tinca*)	Vaseux and Osoyoos lakes	Littoral areas of lakes, or swamps, particularly where organic material is substantial.	Skaha Lake littoral and oxbow areas. Rare in Osoyoos Lake	Little interaction with salmonids
Zebra and Quagga mussels	Not detected so far	Establish on rock surfaces. If established would physically impact spawning areas for salmon as well as alter food availability for young salmonids	NA	Potentially a very high risk
Didymo	-	-	Middle Columbia River near Revelstoke	Potentially a very high risk
New Zealand Mud Snails	-	Underside of rocks in shallow waters	Columbia River estuary	Potentially a very high risk

Northern Pike (*Esox lucius*) are widely distributed freshwater fish in North America. In the Canadian portion of the Columbia River, large pike (up to 1 m) have been observed (Doutaz 2019). Additionally, juvenile pike have been observed near Castlegar, BC, suggesting that spawning is occurring. This study found that 50% of the pike diet was made up of salmonids. Acoustic tracking found the pike to be mostly sedentary; however capable of migrating in excess of 100 km (Doutaz 2019). Analysis of pike consumption in Alaskan rivers suggest that pike can consume up to 1.1 metric tons of salmon in one summer and that pike aged 3-4 could consume the most fish (Sepulveda et al. 2015).

Indirect interactions by Zebra (*Dreissena polymorpha*) and Quagga mussels (*D. bugensis*) were found to be potential threats to salmonids in the Okanagan Lake, including Chinook Salmon (Self and Larratt 2013). The risk of the spread of these mussels is assessed to be high (Mackie 2010, Self and Larratt 2013). Invasive mussels would have a huge impact on the Okanagan Lake ecosystem by concentrating pollutants in their wastes, inducing bird and fish kills, and altering food webs by removal of phytoplankton and zooplankton (Self and Larratt 2013), which for salmon feed on as juveniles. The Okanagan Water Board has established education programs to prevent the spread of mussels to this region.

New Zealand Mud Snails (*Potamopyrgus antipodarum*) and Didymo (*Didymosphenia geminata*) have also been identified as high risk of environmental impact on salmonids if these species successfully establish in the Okanagan River basin (Self and Larratt 2013, Benson et al. 2017). New Zealand Mud Snails are known to compete with native macroinvertebrate fauna for food and habitat, and are thought to be a poor food source for fish because they provide little energy and can pass through the gut of fish undigested (Bruce and Moffitt 2010). The New Zealand Mud Snail, typically a freshwater snail, has been recently been detected in the Columbia River estuary, and has been found to be sea water tolerant up to 34 ppt at 24 days (Hoy et al. 2012). Didymo has been found in the Middle Columbia River near Revelstoke, B.C. (Schleppe and Larratt 2016).

Human activity (boating, water sports, and fishing) can lead to the increased rate of spread of aquatic invasive species if adequate control measures (disinfecting of boats or equipment) are not undertaken (Johnson et al. 2001, Bax et al. 2003, Vander Zanden and Olden 2008). B.C. Lake Stewardship Society, the Invasive Species Council of BC, the South Okanagan-Similkameen Invasive Plant Society, and the Okanagan Basin Water Board have all launched educational programs to inform boaters that they need to clean, drain, and dry their boats and gear to prevent the spread of aquatic invasive species (Self and Larratt 2013). Established invasive mussels and Didymo are extremely difficult if not impossible to eradicate. New Zealand Mud Snails have been found to survive transport on the hulls of vessels and even fishing boots and mud attached to birds (Hoy et al. 2012).

Competition between Chinook Salmon and species of bass is predicted to increase, as bass habitat expands in response to climate change. Increasing habitat overlap was observed in Columbia River Chinook Salmon (Lawrence et al. 2014). Smallmouth Bass is native to Southeastern U.S. and has now been introduced to many lakes in the Columbia River basin, and is currently present in the Okanagan River and Osoyoos Lake (Brown et al. 2009).

Smallmouth Bass is a prevalent nonnative recreational fish species in the Columbia River Basin and has been highlighted in the U.S. as a critical management priority to achieve salmon recovery goals (Rubenson and Olden 2020). Smallmouth Bass are located in many of the major tributaries and some of the smaller streams of the Columbia River Basin including in the Okanagan region (Brown et al. 2009). Predicted changes to future (i.e., 2080) flows and temperatures resulted in dramatic increases to Smallmouth Bass distribution throughout most of the Columbia River system (Beamesderfer and Rieman 1991, Rubenson and Olden 2020).

Predation by Smallmouth Bass has been found to be most intense on subyearling Chinook Salmon (Naughton et al. 2004). Studies looking at the diets of Smallmouth Bass in the Columbia River showed juvenile Chinook Salmon comprised 16% (1996) and 59% (1997) of all salmonids ingested (salmonids were 5-11% of diet), and varied depending on where the fish were caught (Naughton et al. 2004, Carey et al. 2011). Another study estimated that Smallmouth Bass were responsible for 9% mortality of salmon in the Columbia River Basin (Rieman et al. 1991). Size of the Smallmouth Bass also appears to be an important contributor to salmon consumption rates. It has been found that fish were not an important prey category for > 100 mm Smallmouth Bass in the Columbia River. It was estimated that a 100 mm Smallmouth Bass could potentially consume a fish in the 30-35 mm size range, which is the size of newly emerged fall Chinook Salmon (Fritts and Pearsons 2006). In addition to interacting as predators, Smallmouth Bass may also compete with salmon. In the Willamette River (part of the Columbia River system in Oregon), diet similarities between juvenile Chinook Salmon and juvenile Smallmouth Bass suggested that competition could result from resource limitations (Carey et al. 2011).

Other problematic species include Invasive freshwater shrimp (*Mysis relicta*), Eurasian milfoil (*Myriophyllum spicatum*, known to provide cover for Yellow Perch), and cyanobacteria. Cyanobacteria can be a problematic native species for salmonids in the Okanagan River watershed (Andrusak et al. 2005). Low N:P (nitrogen to phosphorous) ratios tend to support the dominance of this group of plankton (Cumming et al. 2015). The dominance of cyanobacteria in the phytoplankton community can limit the growth of zooplankton which can lead to reduced food availability for young salmon (Stockner and Shortreed 1989). The effects of a cyanobacteria-dominated phytoplankton community on juvenile Chinook Salmon have not been assessed.

Taken together, the impact on Okanagan Chinook salmon by non-native species is high and is compounded by the invading species competing or preying on the Chinook salmon during different freshwater phases of their lifecycle. As identified above, bass, walleye and pike species, which have all been detected in the Columbia river, are likely to have the greatest impact on both Chinook salmon and their habitat. Established populations of pike and walleye in the Okanagan River will be nearly impossible to control and eradicate.

Pathogens

This threat was determined to be an unknown **population-level** risk with a very low causal certainty.

Aquaculture

Amplification of disease on from fish farms remains a concern. Salmon from the Columbia River likely pass farms located on the coast of B.C.as they migrate through the Pacific Ocean (Fisher et al. 2014). However, data associating potential effects from aquaculture to Columbia River salmon, and more specifically to Okanagan Chinook Salmon, are not known. To date, all diseases reported in farmed fish on the west coast of B.C. and the U.S. have been endemic to B.C. – i.e. no non-native pathogens. Studies of farmed and wild salmon have shown the prevalence of *Renibacterium salmoninarum*, the cause of bacterial kidney disease (BKD), is similar in ocean-caught Pacific salmon as in healthy farmed salmon. Furthermore, *Loma salmonae*, a serious microsporidian pathogen of pen-reared Chinook Salmon was found in all species of ocean-caught Pacific salmon in British Columbia (Kent et al. 1998). Antibiotic and vaccine use have dramatically improved the health of farmed salmon. Alternatively, there have also been incidences of disease outbreak in wild fish in locations where fish farming activities are absent (Noakes et al. 2000). Studies to date have shown a low risk of effects on wild salmon from aquaculture (Noakes et al. 2000).

Wild fish

Data on disease prevalence on Okanagan Summer Chinook Salmon are lacking primarily due to the low numbers available for sampling. However, some studies on out-migrating spring Chinook Salmon from the Columbia River were surveyed for a number of pathogens (Van Gaest et al. 2011). The most commonly detected pathogens were *R. salmoninarum* (26.5%) and *Saprolegniaceae* (5.6%). Infectious hematopoietic necrosis virus was detected in 1.7% of samples, while less-detected bacterial and viral pathogens (0.0–1.0%) included *Aeromonas hydrophila*, *A. salmonicida*, *Flavobacterium psychrophilum*, IPNV (infectious pancreatic necrosis virus), *Listonella anguillarum*, and *Yersinia ruckeri*.

Knowledge Gaps: Updated exotic species survey is needed especially to re-inform on the spread of these organisms (with special attention to Walleye) in the Columbia River basin. Additional information will be required to inform a threat risk category for introduced pathogens and viruses.

Co-occurring Species: Sockeye Salmon may have interactions with these exotic species that are similar to Chinook Salmon.

Population decline and habitat impacts due to geological events (T10)

This threat was determined to be a **medium population-level** risk with high causal certainty.

The impacts of earthquakes or landslides on Okanagan Chinook Salmon have not been studied. It stands to reason that geological events that block fish from critical habitat could have profound population-level impacts (Waples et al. 2008a). Landslides would deposit large amounts of fines into the river, and could have the effect of blocking fish from spawning habitat, or of siltation of spawning gravels (Cedarholm and Salo 1979). Okanagan Chinook Salmon would be particularly vulnerable to geological events since their spawning area is concentrated in one small location.

Knowledge Gaps: Frequency of earthquakes or landslides in area.

Co-occurring Species: Sockeye Salmon would respond to habitat blockages in a manner similar to Chinook Salmon.

RECOVERY TARGETS FOR OKANAGAN CHINOOK SALMON

ELEMENT 12: PROPOSE CANDIDATE ABUNDANCE AND DISTRIBUTION TARGETS FOR RECOVERY

The current spawning population of Okanagan Chinook Salmon is <65 salmon (Figure 2). ONA suggested an abundance target of 1,000 spawners, based on a previous PVA that determined the effective breeding size of more than 300 females from 1,000 individuals (Richard Bussanich, pers. comm., 2017; Chuck Parken, pers. comm. 2019). Since the Canadian Okanagan Chinook Salmon population is not isolated from other Upper Columbia fish, and its productivity may in part be dependent upon U.S. strays, then recovery goals could include considerable augmentation from U.S. populations through a hatchery program.

Distribution targets are likely not relevant here, considering the current spawning habitat accessibility and availability for 1000+ adult spawners in the ‘index’ area of the Okanagan River, and the spawning platform at Penticton. Monitoring of spawning Chinook Salmon in these and other areas should be maintained.

ELEMENT 13: PROJECT EXPECTED POPULATION TRAJECTORIES OVER A SCIENTIFICALLY REASONABLE TIME FRAME (MINIMUM OF 10 YEARS), AND TRAJECTORIES OVER TIME TO THE POTENTIAL RECOVERY TARGETS, GIVEN CURRENT POPULATION DYNAMICS PARAMETERS

Under the current population dynamic parameters (i.e., baseline conditions) the PVA (Appendix A) indicated that the population is expected to continue to decline in both the short-term (i.e., 12 years) and in the long-term (i.e., 30 years); and that the probability of reaching potential recovery targets of 1,000 spawners is very unlikely on either time scale (Table 12).

Table 12. Results from a Population Viability Analysis (PVA) assessing the likelihood of meeting the recovery target of 1,000 spawners within 12 years and positive population growth.

	Recovery Target [1]		**Population Trend [2]**		
Mitigation Scenario	**Short-term (12 yr)**	**Long-term (30 yr)**	**Short-term (12 yr)**	**Long-term (30 yr)**	**Description**
Baseline Conditions	Very Unlikely	Very Unlikely	Negative	Negative	No action taken (i.e., status quo)
Postulated Habitat Improvements					
10% Mort Reduction	Very Unlikely	Very Unlikely	Negative	Negative	Habitat improvements were assumed to reduced juvenile mortality rates. See Table 13 for proposed approaches.
30% Mort Reduction	Very Unlikely	Very Unlikely	Positive	Positive	
50% Mort Reduction	Very Unlikely	Very Unlikely	Positive	Positive	
Hatchery Supplementation					
50,000 per year	Very Unlikely	Very Unlikely	Positive	Positive	Number of full-fitness hatchery releases per year over the duration of the simulation period
100,000 per year	Very Unlikely	Very Unlikely	Positive	Positive	
150,000 per year	Unlikely	Likely	Positive	Positive	
250,000 per year	Very Likely	Very Likely	Positive	Positive	
500,000 per year	Very Likely	Very Likely	Positive	Positive	
Additional Scenarios					
No Harvest	About as likely as not	Very Likely	Positive	Positive	Complete fishery cessation [3]
Productivity 2x	Very Unlikely	Very Unlikely	Positive	Positive	Doubling of spawner to juvenile recruitment [4]
Hatchery 150K + 30% Mort Reduction	Very Likely	Very Likely	Positive	Positive	150,000 full-fitness hatchery releases combined with a 30% reduced juvenile mortality
Hatchery 150K + No Harvest	Very Likely	Very Likely	Positive	Positive	150,000 full-fitness hatchery releases combined with complete fishery cessation
No Harvest + 30% Mort Reduction	Very Likely	Very Likely	Positive	Positive	Fishery cessation with a 30% reduced juvenile mortality

[1] The International Panel of Climate Change adopted several risk/certainty categories that are now widely used to categorically describe probabilities of scenarios occurring. Very likely ≥ 0.90, Likely ≥ 0.66, About as likely as not 33-66 %, Unlikely ≤ 0.33, Very Unlikely ≤ 0.10 (Mastrandrea et al. 2010).
[2] Trends were estimated as the log linear trend on the 4-year geometric mean rolling averages.
[3] No Canadian or international fishery mortality
[4] Reflects per spawner fecundity (alpha parameter in the Ricker's curve)

ELEMENT 14: PROVIDE ADVICE ON THE DEGREE TO WHICH SUPPLY OF SUITABLE HABITAT MEETS THE DEMANDS OF THE SPECIES, BOTH AT PRESENT AND WHEN THE SPECIES REACHES THE POTENTIAL RECOVERY TARGET(S) IDENTIFIED IN ELEMENT 12

There is no indication that the current availability of spawning habitat would limit the recovery of Okanagan Chinook Salmon at any stage, given the current abundance of observed salmon. Assessments of habitat quantity and quality will have to be revisited if abundance numbers increase and are stable over several generations (e.g., 8-10 years).

The release of 15,000 Summer Chinook Salmon from the Penticton Hatchery will likely have an impact, as a result of competition between the current native salmon and the returning hatchery fish. For example, it is predicted that a release of 15,000 Chinook Salmon could result in a return of roughly 194 spawners over a 5 year period (using the survival parameters identified from other Chinook Salmon populations, e.g., Wells Hatchery, including an early ocean survival rate of 1%, fishery mortality rates of 28% annually in the ocean and 44% in-river, and an inter-dam survival rate of 94%; see Appendix A). This means, in any given year, that the number of hatchery-derived adults in the spawning area could be similar to the number of naturally-produced spawners (given the number of natural spawners that have been observed in the four most recent years).

ELEMENT 15: ASSESS THE PROBABILITY THAT THE POTENTIAL RECOVERY TARGET(S) CAN BE ACHIEVED UNDER CURRENT RATES OF POPULATION DYNAMICS PARAMETERS, AND HOW THAT PROBABILITY WOULD VARY WITH DIFFERENT MORTALITY (ESPECIALLY LOWER) AND PRODUCTIVITY (ESPECIALLY HIGHER) PARAMETERS

The likelihood of reaching the recovery target over 12 years (i.e., 3 generations) and 30 years was assessed (Table 12) and uses certainty categories adopted by the IPCC as descriptive and understandable language (Mastrandrea et al. 2010). The recovery target of 1,000 spawners was assessed by based on a 4-year geometric mean. The geometric mean was used instead of the arithmetic mean so that neither large nor small returns over influenced the averages, as has been recommended for Pacific Salmon species given their log-normally distributed abundance data (Grant et al. 2011). A four year time span was chosen to reflect the fact that the majority of the returns will have occur by age 4. The probability of reaching the recovery target (i.e., at least one year with a 4-year geometric mean at or above 1,000 spawners) was assessed over two time periods: 12 years (i.e., 3 generations) and 30 years. Population trajectories over these time periods were also assessed based on fitting log-linear trends to a 4-year geometric mean of total adult abundance.

Under the current population dynamic parameters (i.e., baseline conditions) it is very unlikely that the current recovery targets can be met. Rather, the population will likely persist at low levels due to strays from the U.S. Reductions of mortality rates (e.g., fishery activity) will not be enough to reach recovery targets given the current depleted state of the natural population. Even if there was a complete cessation of all fishery-related mortality, the population would still require aggressive management interventions to meet recovery targets. These could come in the form of either habitat improvements (e.g., the “No Harvest + 30% Mort Reduction” scenario; Table 12) or a hatchery supplementation program (e.g., the “Hatchery 150K + No Harvest” scenario; Table 12).

Currently, very few spawners are observed (see HABITAT AND RESIDENCE REQUIREMENTS), and even if natural productivity doubled current recovery targets will not be met (i.e., the “Productivity 2x” scenario; Table 12). Productivity improvement through hatchery supplementation were also considered (i.e., Hatchery Supplementation scenarios; Table 12). If no other management actions were implemented, a supplementation program of 250,000 full fitness smolts released per year (or greater) would be required to meet recovery targets with high likelihood. If hatchery-raised smolts are expected to have lower fitness than wild fish, then larger numbers would need to be released to compensate. Hatchery supplementation programs could be reduced (e.g., 150,000 full fitness smolts per year) if combined with other management actions, either by reducing natural juvenile mortality (i.e., “Hatchery 150K + 30% Mort Reduction” scenario; Table 12), or adult mortality (i.e., the “Hatchery 150K + No Harvest” scenario; Table 12). Hatchery production levels would likely vary in relation to recovery targets of the recovery potential assessment. With the implementation of a successful recovery strategy, hatchery production levels may be reduced over time.

Finally, if hatchery programs cannot be implemented in Canada, then aggressive management actions will be required to restore habitat and eliminate fishing mortalities in order to meet some of the recovery targets (i.e., “No Harvest + 30% Mort Reduction” scenario; Table 12). Compared to other approaches using hatchery supplementation, this scenario exhibited minimums of spawners and adults that were below recovery targets, which is often associated with a higher overall extinction risk (Connell and Sousa 1983, Grimm and Wissel 1997). Habitat improvements on their own will likely not translate to population improvements to meet recovery gargets within 12 years and will likely require a greater timeframe.

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

The following sections discuss feasible mitigation measures (Element 16), activities that could increase the productivity or survivorship (Element 17), feasibility of restoring the habitat (Element 18), and expected reductions in mortality rates that may result from each mitigation measure (Element 19).

ELEMENT 16: DEVELOP AN INVENTORY OF FEASIBLE MITIGATION MEASURES AND REASONABLE ALTERNATIVES TO THE ACTIVITIES THAT ARE THREATS TO THE SPECIES AND ITS HABITAT

Current and Ongoing Mitigation Initiatives

The following is an inventory of seven current and ongoing mitigation initiatives. These initiatives are not directly considered in the PVA modelling.

Initiative 1

The Aquatic Resources, Research, and Assessment Division at DFO produced the most recent Southern Chinook Salmon habitat indicator report (Porter et al. 2013), which outlines proposals and current habitat improvement projects:

1. Obtaining improved spawning location information; and
2. Development of Chinook-specific modeling to better estimate the total length of accessible habitat.

The status of these projects is currently unknown.

Initiative 2

Since 2000, restoration efforts in the Okanagan River have aimed to enhance the quantity and quality of spawning and rearing habitat for salmonids. This project is led by the Okanagan

Nation Alliance. The Okanagan River Restoration Initiative (ORRI) was initiated in 2000 to return channelized portions of the river to a more natural state. ORRI conducted five restoration projects in the mainstem Okanagan River from 2008 to 2013 to:

1. reconnect floodplain habitat,
2. re-meander the river,
3. connect side channels and oxbows,
4. modify in-river structures (vertical drops) to enhance fish habitat, and
5. create wetland.

Details of this program can be found in Machin et al. (2015). This work is now complete and monitoring for salmon productivity improvements is ongoing. In 2014, ORRI created a 480 m^2 (20 x 24 m) Chinook Salmon spawning platform in the Penticton Channel between Skaha and Okanagan lakes. Gravel ranging in size from 50 to 100 mm was used for this platform (Rivard-Sirois 2014), conforming to the gravel size range (40 to 90 mm) that Okanagan Chinook appear to prefer.

In 2015, an additional spawning bed was created in Penticton channel (5,900 m^2), and in 2018 one more bed was created (10,120 m^2) with the addition of boulder clusters for cover (Davis et al. 2018). Beds created in 2015 and 2018 used substrates that were designed for Sockeye Salmon and kokanee (Davis et al. 2018). To date, Chinook Salmon have not been observed using this spawning platform (Rivard-Sirois, pers. comm. 2017). ORRI has conducted six years (2013-2018) of post-restoration aquatic monitoring to date with a focused effort on monitoring Sockeye Salmon colonization of spawning platforms. Continued monitoring is required to determine the effectiveness of these restoration efforts specifically for Okanagan Chinook.

Initiative 3

There is a Recovery Plan for Chinook Salmon in the Okanagan River. This project is led by the Okanagan Nation Alliance (more details in Bussanich et al. 2016). The goals of the project include:

1. Improve fish passage to Skaha Dam, including building new acclimation ponds adjacent to the mainstem to target summer Chinook Salmon.
2. Improve fish habitat, in addition to the ORRI described above. This project would include restoring tributaries to Osoyoos, Skaha, and Okanagan lakes (2016-2018).
3. Integrate and improve protection of salmonid habitat (2016-2018).
4. Improve Chinook Salmon monitoring for conservation and harvest (2016-2018).
5. Establish instream water flow demands to balance both human and fish needs (2016-2018).
6. Establish artificial propagation, genetic monitoring, and health programs for hatchery released fish (2016-2018 and monitor to 2032).

Uncertainties outlined by the ONA include:

1. Risks of disease spread when using US-sourced broodstock.
2. Unknown information regarding the current and historical trends for natural vs. hatchery returns to Canada.
3. Unknown information regarding the survival of summer Chinook Salmon yearlings released upstream of Osoyoos Lake.

4. Unknown information regarding the abundance, run timing, and fate of adult Chinook Salmon at Zosel Dam.

Initiative 4

Development of a Chinook Salmon production and release program in the Okanagan River basin is underway. The ONA released 15,000 Chinook Salmon into the river in June 2017, and developed a comprehensive program to improve salmon abundance monitoring, health monitoring, and habitat restoration (details in Bussanich et al. 2016). A recovery target of 1,000 natural origin spawning Chinook Salmon has been set based on obtaining 300 mature females.

Initiative 5

A fifth initiative is underway, having two subcomponents: 1) the Okanagan Basin Monitoring and Evaluation Program; and 2) the Chief Joseph Hatchery Chinook Salmon Release Program.

The Okanagan Basin Monitoring and Evaluation Program was and continues to be conducted by the Colville Confederated Tribes Fish and Wildlife Department, including Canadian-based Chinook Salmon habitat. The goals of this program are to: 1) assess the status and trend of natural and hatchery origin abundance of fish populations for various life stages; 2) assess the status and trend of juvenile abundance and productivity of natural origin fish populations; 3) assess the status and trend of spatial distribution of fish populations; 4) monitor and evaluate tributary habitat conditions that may be limiting achievement of biological performance objectives (Miller et al. 2015b); and 5) assess the status and trend of diversity of natural and hatchery origin fish populations (OBMEP 2019). This project monitored status and trends to evaluate habitat in the Okanogan River sub-basin, particularly habitat used by ESA-listed Upper Columbia River steelhead and summer/fall Chinook Salmon.

The Chief Joseph Hatchery (CJH) Program began operations in 2013 and consists of four different Chinook Salmon programs releasing up to 2.9 million smolts to meet conservation and harvest objectives for the Colville Tribes, and to partially fulfill Federal and Public Utility District mitigation obligations for Columbia River Dam impacts to anadromous salmonids.

- An integrated summer/fall Chinook program uses a high proportion of natural-origin broodstock and management actions to maintain a low proportion of hatchery-origin spawners to achieve population objectives for conservation that ensure that the natural environment has maximal influence on local adaptation. The smolt release targets at full program for the integrated program are 800,000 yearling smolts from the Omak and Similkameen acclimation ponds and 300,000 subyearlings from the Omak acclimation pond. The integrated program is 100% adipose fin clipped and coded-wire tagged with 10,000 PIT tags.

- A segregated summer/fall Chinook program is intended for harvest and uses primarily first generation returns from the integrated program to minimize multi-generation hatchery affects. The segregated program smolt release goals are 500,000 yearlings and 400,000 subyearlings from the Chief Joseph Hatchery on the Columbia River (upstream of the confluence with the Okanogan River). The segregated program is 100% adipose fin clipped and includes 200,000 coded-wire tags.

- A segregated Spring Chinook program began with a non-local brood from the Leavenworth National Fish Hatchery (Carson stock) and is a harvest program that releases fish into the Columbia River at the Chief Joseph Hatchery. The smolt release target for the segregated Spring Chinook program is 700,000 yearlings that are 100% adipose fin clipped with 200,000 coded-wire tags.

- A Spring Chinook reintroduction program in the Okanogan utilizes ESA-listed eggs from the Winthrop National Fish Hatchery that are designated as a non-essential experimental population when released into the Okanogan River. The Okanogan reintroduction program target is 200,000 yearling smolts released from the Riverside acclimation pond that are adipose-fin present with 100% coded-wired tags.

Number of spawners and the outmigrating juveniles will be monitored for spawning success. Canadian tributaries, including Shingle and Vaseux creeks, will be monitored and will potentially include reporting of Chinook Salmon. An eDNA (environmental DNA) program has also recently begun under this program (water samples will be taken from target tributaries in order to correlate observations of salmon present in the area; Andrea Pearl, Colville Confederated Tribes Fish and Wildlife Department, pers. comm., Nov. 2017). and may also confirm the presence of Chinook Salmon. It should be noted, however, that eDNA cannot resolve between spring and summer runs, or between adult and juvenile fish (e.g., Shingle Creek is unlikely to host the more typically mainstem-spawning summer run Chinook Salmon; whereas summer run juveniles could indeed move into the creek, and spring-run adults could use it for spawning), thus evidence of Chinook Salmon presence would not necessarily mean that Summer-run adults are present in the tributary.

Initiative 6

The Okanagan Basin Implementation Agreement was initially developed in 1975 and implemented a ‘fish-friendly’ fish and water management tool (FWMT) to improve fish habitat in the Okanagan River through water discharge management. Although primarily developed for the restoration of Sockeye Salmon populations, Chinook Salmon also likely benefited. For example, days of non-compliance of water discharge rates measured at the town of Oliver (at the south end of the ‘index’ area) have dramatically declined since 2003 relative to time periods characterized by the absence of a FWMT (Hyatt et al. 2015).

Initiative 7

The National Marine Fisheries Service in the U.S. has put together an extensive recovery program for salmon including lower Columbia River Chinook Salmon (National Marine Fisheries Service 2013). These strategies should improve habitat quantity and quality through mitigations to ecological interactions (predation), hatchery releases, harvest rates, hydropower, and estuary and tributary habitats. Specific mitigations that will likely have benefit to Okanagan River Chinook Salmon include:

1. Reducing pinniped predation on salmon;
2. Shifting hatchery programs downstream and establishing more integrated hatchery practices;
3. Maintaining adequate water flows in the Bonneville Dam trailrace, and in downstream habitats throughout salmon migration periods;
4. Improving fish (juvenile and adult) passage at Bonneville Dam; and
5. Improving estuary conditions:
    a. Protecting intact riparian areas in the estuary and restore riparian areas that are degraded;
    b. Protecting remaining high-quality off-channel habitat from degradation, and restoring degraded areas with high intrinsic potential for high-quality habitat;
    c. Breaching, lowering, or relocating dikes and levees to establish or improve access to off-channel habitats;

d. Reducing the export of sand and gravels via dredge operations by using dredged materials beneficially;

e. Reducing entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary;

f. Operating the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures;

g. Protecting or enhancing estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals;

h. Adjusting the timing, magnitude, and frequency of flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume;

i. Studying and mitigating the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume;

j. Reducing the square footage of over-water structures in the estuary;

k. Reducing the effects of vessel wake stranding in the estuary;

l. Implementing pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary;

m. Identifying and reducing terrestrially and marine-based industrial, commercial, and public sources of pollutants;

n. Restoring or mitigating contaminated sites; and

o. Implementing storm-water best management practices in cities and towns.

Mitigation Advice Details (Threats to Productivity and Survivorship)

In the following section, we discuss mitigation advice details that pertain to the threats to productivity or survivorship (see Elements 8 and 11). See Element 17 for mitigation advice details that pertain to the threats to habitat.

See Table 13 for links between suggested mitigations for Okanagan Chinook Salmon and the Mitigation Guide for the Protection of Fishes and Fish Habitat to Accompany Species at Risk Recovery Potential Assessments conducted by Fisheries and Oceans Canada in Central and Arctic Region (Coker et al. 2010).

Population decline due to biological resource use (T5)

1. Continued enforcement of no directed commercial or recreational fishery.
2. Pressure governments to curtail bycatch of Okanagan Chinook Salmon in ocean and lower-river fisheries. Consider selective gears in mixed stock areas in the ocean, or time/area restrictions.
3. In light of potential hatchery enhancement, consider how limited incidental harvest could be allowed while protecting wild stocks.

Population decline and habitat impact due to natural system modification (T6)

1. Continued implementation of the FWMT for purposes of water flow moderation: a study in the Skagit River, U.S.A., found that a program by the U.S. Federal Energy Regulatory Commission to decrease maximum spawning flows and minimize flows during incubation

had a measurable effect on Chinook Salmon. Chinook Salmon from this watershed had an improved freshwater survival if water flow events were kept to a moderate magnitude (Connor and Pflug 2004, Zimmerman et al. 2015).

2. Measures can be implemented to modify the temperature regimes imposed by the McIntyre Dam. Construction of a siphon would draw cooler water from lower depths of Vaseux Lake and discharge it at the base of the dam. A hypolimnetic siphon has been proposed for Skaha and Vaseux Lakes (Bull 1999) and has not be constructed yet. Water from lower levels of Skaha Lake would reduce temperatures in the Okanagan River upstream of Vaseux Lake by two degrees (Davis et al. 2007).
3. Modifications of the dam at Okanagan Lake are required (similar to those undertaken at McIntyre and Skaha dams) to allow fish passage. This will open up large unused areas upriver of Okanagan Lake to Chinook spawning.
4. The FLNRO attempts to keep the flow in the Okanagan River at Oliver below 28.3 m^3/s during Sockeye Salmon egg and alevin incubation (between 1 Nov and 100% emergence – usually early May): Although not a target of these efforts, Okanagan Chinook Salmon spawn between October and November of each year and likely benefit from them. For Chinook Salmon to benefit to the maximum extent, the timing of the flow-attempts could be adjusted to include Chinook Salmon rearing.
5. Changes in fish ladder parameters may benefit migrating Chinook Salmon, a temperature-sensitive species (Caudill et al. 2014), especially if implemented at all nine of the mainstem Columbia River dams through with Okanagan Chinook Salmon must pass. Within fish ladders, increases in temperatures experienced during migration were correlated migration delays for adult salmon in the Snake River. Some fish were observed holding for longer, while others reversed their movements in search of alternative routes. Studies have involved the release of cool water into ladder systems during spawning migration periods with some success (Tiffan et al. 2009). Water was released below the surface at the top of ladder exit pools, as spawning Chinook Salmon appeared to select for cooler water temperatures during migration (Goniea et al. 2006). In addition, other groups have suggested providing a corridor of cool water from the ladder exit through the immediate forebay using suspended water diffusers or some mechanism to create upwelling that would allow adults to exit to deeper, cooler water. These measures were under consideration at the Lower Granite Dam in Washington (Caudill et al. 2014).
6. Changes to the physical properties of fish ladder may improve fish passage efficiency. For example, Noonan (2012) found that pool and weir, pool and slot, and natural fishways all had the highest fish passage efficiencies, whereas Denil and fish locks/elevators had the lowest. Upstream passage efficiency decreased significantly with fishway slope, but increased with fishway length and water velocity. A detailed report of fish passage facilities and their effectiveness should be produced for all dams applicable to Okanagan-migrating Chinook Salmon.

Table 13. Risk mitigations for the Okanagan Chinook Salmon population.

Threat / Limiting Factor	***Life History Stage***	***Mitigation***	***Likelihood of increased survival and recovery***
Habitat impacts due to ecosystem modifications (T1)	Freshwater: terminal migration, spawning, and juvenile rearing	Collaborate with municipalities within the Okanagan River basin on present and future development surrounding spawning areas; install fish screens, reconnect oxbows, create winter habitats	Unknown
Habitat impacts due to aquaculture (T2)	Freshwater: terminal migration, spawning, and juvenile rearing	Aquaculture: 1) develop fitness indices of hatchery fish that are for release into the Okanagan River; 2) minimize the size of the hatchery program; 3) manipulate the composition of the broodstock; 4) decrease the returns of hatchery-origin fish to the river by selective harvest or the use of a weir or similar device.	Unknown
Habitat impacts due to mining & quarrying (T3)	Freshwater: terminal migration, spawning, and juvenile rearing	More frequent water quality monitoring for mining waste materials (heavy metals) by Environment Canada.	Unknown
Habitat impacts due to transportation and service corridors (T4)	Freshwater: terminal migration, spawning, and juvenile rearing	Identify roads or transportation corridors that are near sensitive migration or spawning habitat (near the 'index' area of the river) and consider their removal; engineer solutions to prevent fines from washing into river. Re-establish connections between historical meandering portions of the river that are now stranded.	Unknown
Population decline due to biological resource use (T5)	Freshwater: terminal migration, spawning, and juvenile rearing	Continued enforcement of no directed commercial or recreational fishery; reduce bycatch of Okanagan Chinook in ocean and lower-river fisheries through selective gear, and spatial/temporal closures	High
Population decline and habitat impact due to natural system modification (T6)	Freshwater: terminal migration, spawning, and juvenile rearing	1) Continued implementation of the FWMT; 2) modifications to McIntyre Dam to compensate for the higher temperature regimes imposed by the dam.	High
Elevated mortality or sub-lethal effects due to aquatic pollutants (T7)	Freshwater: terminal migration, spawning, and juvenile rearing	More frequent (annual) and continued water quality monitoring than is currently being conducted (5 years) by Environment Canada.	Unknown

Threat / Limiting Factor	***Life History Stage***	***Mitigation***	***Likelihood of increased survival and recovery***
Elevated mortality or sub-lethal effects due to climate change (T8)	Freshwater: terminal migration, spawning, and juvenile rearing	1) Reassess cold water input into the Okanagan River.	High
Invasive and other problematic species and genes (T9)	Freshwater: terminal migration, spawning, and juvenile rearing	1) Continued education programs to prevent the spread of invasive species; 2) introduction of fishery targeting invasive species	Unknown
Geological events (T10)	Freshwater: terminal migration, spawning, and juvenile rearing	Considered low risk at this time.	-

Elevated mortality or sub-lethal effects due to aquatic pollutants (T7)

1. More frequent (annually) and continued water quality monitoring should help identify changes in aquatic pollutant concentrations.

Elevated mortality or sub-lethal effects due to climate change (T8)

1. A temperature reduction of 5°C would keep temperatures below the lethal level for salmonids throughout the year. Redirection of spring water sources into the river may mitigate this threat. In-river cumulative temperature is an indicator of climate change effects that is measurable. Cumulative temperatures experienced by migrating adults are known to have a large correlation to survival (Crozier 2015). Record and report cumulative (degree day) exposures during Okanagan Chinook Salmon upstream and downstream migrations.
2. Reassess cool water refuges and aquifer water input into the Okanagan River basin. Determine where these areas are in relation to spawning habitat (i.e., index area) and document the surrounding development and impacts. Consider establishing ‘cool water’ sensitive regions. Cold streams may be less sensitive to changes in air temperatures (Luce et al. 2014). Increasing riparian shade is critical to lowering stream temperatures (Booth et al. 2014). A comprehensive outline for creating and maintaining thermal refuges has been developed for the Miramichi River in New Brunswick, Canada (Kurylyk et al. 2015). Similar efforts should be developed in conjunction with the Okanagan Nation Alliance for the Okanagan River.
3. Continuous monitoring of conditions (i.e. temperature, dissolved oxygen, water flow, etc.) both in river and ocean.

Invasive and other problematic species and genes (T9)

1. Current education initiatives are ongoing to prevent the spread of invasive species are numerous and appear to be effective (Okanagan Basin Water Board). These programs should be continued and supported by DFO.
2. Create or increase incentives that target invasive species for commercial and recreational fishery (e.g., Davis et al. 2007). Potential targets for a Canadian recreational freshwater fishery include bass and Yellow Perch. There is considerable potential for Carp to be harvested in the Okanagan River and sold to ethnic fish markets in Vancouver.

Population decline and habitat impacts due to Geological events (T10)

1. Currently no direct mitigation is being proposed.

ELEMENT 17: DEVELOP AN INVENTORY OF ACTIVITIES THAT COULD INCREASE THE PRODUCTIVITY OR SURVIVORSHIP PARAMETERS

Mitigation Advice Details (Threats to Habitat)

In this section, we discuss mitigation advice details that pertain to the threats to habitat (see Element 9). Mitigation advice details that pertain to the threats to productivity or survivorship were discussed as part of Element 16.

See Table 13 for links between suggested mitigations for Okanagan Chinook Salmon and the Mitigation Guide for the Protection of Fishes and Fish Habitat to Accompany Species at Risk Recovery Potential Assessments conducted by Fisheries and Oceans Canada in Central and Arctic Region (Coker et al. 2010).

Habitat impacts due to ecosystem modifications (T1)

1. Obtain and collaborate with municipalities within the Okanagan River basin on present and future development surrounding spawning areas; first concentrating on the ‘index’ area north of Oliver where currently the majority of Okanagan Chinook Salmon are spawning.
2. Addition of fish screens to many water intakes on the river and the experimental addition of rock riffles (to increase habitat diversity and improve fish passage) in the channelled section of river (outlined in Davis et al. 2007).
3. Explore the feasibility of re-connecting oxbows with the main channel. This action would drastically lengthen the available habitat. The oxbows currently show significant groundwater input, thus re-connecting these oxbows to the main river will allow increased access to thermal refuge areas and to new spawning locations (Davis et al. 2007). Considerable restoration efforts have been completed in the ‘index’ area between Oliver, B.C. and Vaseux Lake (Machin et al. 2015). These changes should be applied as much as possible to the channelized portion of the river north of Osoyoos Lake, where there are several stranded stretches (previously river meanders) that could be reconnected to the channel via tunnels without drastic moderation to the channel infrastructure itself. Restoration of freshwater habitat, specifically restoration of backwater areas, natural banks, and off-channel areas, has been important in improving freshwater productivity (Zimmerman et al. 2015). Efforts by the ONA have been undertaken to this end, and action are underway (C. Parken, pers. comm., December 2017; Kari Alex Long, pers. comm. 2019). Examples of river sections that could be explored for re-connection include:
    a. the region of the river immediately across the Okanagan River from Tuc-El-Nuit Lake (north of Oliver, B.C.), as it may be able to provide increased Chinook Salmon spawning habitat, as well as increase the input of cool water into the system;
    b. the areas of the river located immediately north of Osoyoos Lake; and
    c. the region along the Penticton Channel.
4. Creation of winter habitat may be necessary if Chinook Salmon are found to overwinter as juveniles within the Okanagan River in Canada. Implementation of some of the proposed measures identified for set-back dyke restoration has been completed in the ‘index’ area of the river (Davis 2010, Machin et al. 2015). However, this approach should also be applied to regions north of McIntyre Dam.

Habitat impacts due to aquaculture – hatchery supplementation (T2)

1. Develop a hatchery or salmon enhancement program. If hatchery supplementation is the only management action taken, roughly 250,000 full-fitness smolts released annually (Table 12) will be required to reach the recovery target; however, other considerations should be noted before determining the scale of production. It has been demonstrated that hatchery production can yield significant survival advantages in the early life stages relative to wild production. This survival advantage may translate into a significant increase in adult abundance (Rinne et al. 1986, Johnson and Jensen 1991). Ultimately, it is unknown whether supplementation will provide positive (increase in the abundance of fish) or negative (genetic and fitness impacts) effects on Okanagan Chinook.
2. Develop fitness indices of hatchery fish that are destined for release into the Okanagan River. The most widely-applied metric to assess the genetic risks of hatchery production on natural populations is an index of gene flow called the ‘proportionate natural influence’ (PNI). See Hatchery Scientific Review Group (2009) and Withler et al. (2018) for details of the method. Currently, the DFO Salmon Enhancement Program (SEP) does not have any

operational programs in the Okanagan River basin. However, hatchery management programs are undertaking measures described above to achieve proposed PNI targets (Withler et al. 2018). These targets should be considered for management by the Kł cp̓əlk̓ stim̓ hatchery in Penticton.

Habitat impacts due to mining & quarrying (T3)

1. More frequent water quality monitoring for mining waste materials (heavy metals) by Environment Canada, which currently reviews data every 5 years. Annual assessments should be considered.

Habitat impacts due to transportation and service corridors (T4)

1. Identify roads or transportation corridors that are near sensitive migration or spawning habitat (near the 'index' area of the river). Restore stream-side habitat that is identified and is under-utilized by Okanagan area residents. The 'Forest Plan' developed in Washington, U.S., aims to decommission roads, eliminate clear-cuts, promote frequent low-intensity fires (instead of catastrophic ones), and maintain fine sediment conditions that are favourable to Chinook Salmon production (Hayman and Bond 2006, Honea et al. 2009). Decreasing nearby road density may also assist in moderating water temperatures through an unknown causal process (Bartz et al. 2006, Jorgensen et al. 2009).
2. Step should be taken to use engineered solutions to reduce fine sediments from entering nearby rivers.

ELEMENT 18: IF CURRENT HABITAT SUPPLY MAY BE INSUFFICIENT TO ACHIEVE RECOVERY TARGETS , PROVIDE ADVICE ON THE FEASIBILITY OF RESTORING THE HABITAT TO HIGHER VALUES. ADVICE MUST BE PROVIDED IN THE CONTEXT OF ALL AVAILABLE OPTIONS FOR ACHIEVING ABUNDANCE AND DISTRIBUTION TARGETS

Currently, there is enough spawning habitat in the Okanagan River to accommodate a minimum of 1,460 spawning pairs (Davis et al. 2007). Considering the numbers of returning Okanagan Chinook Salmon are in the 10's of fish, it is unlikely that physical habitat availability will be a constraint in the near future. However, this does not include physiological habitat such as optimal temperature and oxygen conditions (see 'Physiology' Section above) or the effect of returning hatchery released fish (expected to return starting in 2021, as described in Initiative 4, above). Given that 15,000 fish were released into the Okanagan River and there is an estimated 1% or less marine survival rate, after accounting for ocean and river harvest and inter-dam mortality, it would be expected that roughly 194 of these fish would return to spawn. After a few generations of successful returns by hatchery fish, habitat may become limiting. Currently, the only area where spawning salmon are consistently observed is the 'index' area.

ELEMENT 19: ESTIMATE THE REDUCTION IN MORTALITY RATE EXPECTED BY EACH OF THE MITIGATION MEASURES OR ALTERNATIVES IN ELEMENT 16 AND THE INCREASE IN PRODUCTIVITY OR SURVIVORSHIP ASSOCIATED WITH EACH MEASURE IN ELEMENT 17

Several potential mitigations measures for the reduction of mortality are outlined in Table 13. But due to the nature of the mitigation or the lack of scientific information, there was no case in which the magnitude of the potential effects could be reliably quantified.

ELEMENT 20: PROJECT EXPECTED POPULATION TRAJECTORY (AND UNCERTAINTIES) OVER A SCIENTIFICALLY REASONABLE TIME FRAME AND TO THE TIME OF REACHING RECOVERY TARGETS, GIVEN MORTALITY RATES AND PRODUCTIVITIES ASSOCIATED WITH THE SPECIFIC MEASURES IDENTIFIED FOR EXPLORATION IN ELEMENT 19. INCLUDE THOSE THAT PROVIDE AS HIGH A PROBABILITY OF SURVIVORSHIP AND RECOVERY AS POSSIBLE FOR BIOLOGICALLY REALISTIC PARAMETER VALUES.

In Element 16, several mortality-reduction pathways were identified, including fishery reductions, and mitigations related to aquaculture, transportation and service corridors, natural system modifications, and invasive/problematic species (Table 13). No attempts were made to specifically quantify these potential mortality reductions (see Element 19), and the PVA was modelled only in general terms. To investigate the general effects of reductions in mortality (regardless of which specific restorative action or set of actions was the cause), the PVA used three place holder amounts of 10%, 30%, and 50%. The likelihood of reaching the recovery target was assessed over a 12-year (i.e., 3 generations) and 30-year time horizon using a PVA (Table 12; see Appendix A for methods). In all cases, it was very unlikely any of the three placeholder effects will result in reaching the recovery target on the short- or long-term. The PVA did however indicate that combining these proposed measures with a hatchery supplementation program (e.g., “Hatchery 150K + 30% Mort Reduction” in Table 12) could result in a high likelihood of reaching the recovery target on both the short- and long-term.

The curtailing of ocean and in-river fisheries could potentially have an impact on Okanagan River Chinook Salmon (Table 13) via reduction in incidental take and en-route losses. This was considered in the PVA model as fishery effects (i.e., “No Harvest”; Table 12). Based on these analyses, even a cessation of fishing may not result in reaching the recovery target in the short-term without other additional actions such as a hatchery supplementation program or improvements to juvenile freshwater habitat. If these types of management actions are not feasible, then a large hatchery supplementation program (i.e., ≥ 250,000 full-fitness smolts per year) will be required to ensure the recovery goals are met (Table 12).

ELEMENT 21: RECOMMEND PARAMETER VALUES FOR POPULATION PRODUCTIVITY AND STARTING MORTALITY RATES AND, WHERE NECESSARY, SPECIALIZED FEATURES OF POPULATION MODELS THAT WOULD BE REQUIRED TO ALLOW EXPLORATION OF ADDITIONAL SCENARIOS AS PART OF THE ASSESSMENT OF ECONOMIC, SOCIAL, AND CULTURAL IMPACTS IN SUPPORT OF THE LISTING PROCESS

Given that the population is considered to be genetically and ecologically exchangeable with U.S. Upper Columbia River fish, then considerable augmentation from U.S. populations through a hatchery program should be acceptable, and recovery time could be accelerated. The current PVA analysis concluded that to meet the necessary escapement maximum based on spawning ground estimates, 250,000 full-fitness hatchery-reared smolts will need to be released annually, or 150,000 annually in conjunction with a suite of habitat restoration actions (“Hatchery 150K + 30% Mort Reduction” in Table 12) or in conjunction with total elimination of fishing mortality (“Hatchery 150K + No Harvest” in Table 12) in order to meet recovery targets with a high probability.

The target, if achieved, should secure the long-term viability of Chinook Salmon within the Canadian portion of the Okanagan River basin. The long term objective would be to maintain a run of naturally-spawning Chinook Salmon in the Canadian portion of the Okanagan River. The short term objectives will include the increase in run numbers through hatchery supplementation.

A large emphasis should be placed on planning for the impact of climate change by increasing buffers for recovery targets. Emphasis should be placed on providing thermal refuges and natural habitat areas (including the estuary) for Okanagan Chinook Salmon recovery.

ALLOWABLE HARM ASSESSMENT

ELEMENT 22: EVALUATE MAXIMUM HUMAN-INDUCED MORTALITY AND HABITAT DESTRUCTION THAT THE SPECIES CAN SUSTAIN WITHOUT JEOPARDIZING ITS SURVIVAL OR RECOVERY

The Okanagan Chinook Salmon population is likely currently maintained with strays from neighbouring U.S. Columbia river stocks. With current life history survival rates, low marine survival, and without the enhancement program, the population would likely be extirpated.

Although spawning habitat is currently not limiting Okanagan Chinook Salmon productivity to the same degree that marine survival is, every measure should be taken to protect and to maintain the quality and quantity of spawning habitat. Additionally, all freshwater rearing habitats should not be further harmed.

Until population levels return to a minimum viable population level, no fishery-related mortality is currently sustainable in Canadian waters. All sources of harm should be minimized below 2019 levels, and only activities in support of the survival and recovery of the species can be permitted. Information regarding the newly-implemented ONA Chinook Salmon hatchery release program should be monitored, and returns documented. If these fish return at appreciable numbers, allowable harm numbers could be revisited.

KNOWLEDGE GAPS AND SOURCES OF UNCERTAINTY

KNOWLEDGE GAPS

Biology

- What are the thermal physiological maxima for Okanagan Chinook Salmon?
- What are the energetic costs associated with Chinook Salmon during key transition points in their life (maturation and smoltification)?
- Are there adequate data available to estimate the physiological limits of Okanagan Chinook Salmon and other salmon populations using mathematical models?
- How much are the physiological requirements of Chinook Salmon factored in during management decisions?
- What is the individual stress response in fish after each subsequent dam passage?
- Are acclimation responses to increases in rearing temperatures heritable? If so, is the heritability of thermal tolerance and associated adaptation rates of Chinook Salmon faster than the current predicated warming trends?
- Are the observed adaptations in other Chinook Salmon populations applicable to Okanagan Chinook Salmon?

- What is the degree of competition for food among co-habiting species of salmon rearing in Osoyoos and Okanagan lakes? Will there be increased pressure or overlap of food sources with increasing water temperatures? What will the changes (species type and distribution) to these food sources look like?
- What species are significant predators to Okanagan Chinook Salmon and at what point during their lifecycle is this most prominent?

Habitat

- There are a limited number of habitat indicators for which defensible, science-based, empirical benchmarks can be identified. Most are relative in nature rather than expressed in absolutes (Porter et al. 2013). If physiological-based habitat indicators are better predictors, which ones should be explored?
- The impact and influence of invasive species on juvenile rearing and habitat quality.
- As temperature is playing an increasingly important role for the development of salmonids, a field program will need to be conducted to identify significant thermal refuges in the river and to determine whether salmonids rear in these areas. This will aid in management decisions regarding which areas of the Okanagan basin to protect.
- Habitat usage and timing during ocean migration and juvenile rearing (i.e., groundwater-fed side channels) needs to be assessed specifically for salmon rearing in the Okanagan River. This information will aid in determining the extent of habitat capacity for these life stages.
- Further understanding of the current life history of Chinook Salmon spawning in the Canadian Okanagan will enable the evaluation of the current water management in the Okanagan River or if any modifications are required to the FWMT.
- Aboriginal Traditional Knowledge (ATK) suggests that redd/juvenile/adult surveys may not be as thorough as needed in tributary areas, as access to private property to properly assess stream areas may be an issue (Armstrong 2015).
- Are fish ladders operational at low water levels?

SOURCES OF UNCERTAINTY

Biology

- With respect to physiological responses, research suggests that predictive models conducted on one species of fish are not shown to be appropriate predictors for other species. Models will have to be run on a per species basis. It is unknown if local populations will have similar limitations.
- There are no data on natural fry-to-smolt survival for Okanagan Chinook Salmon. The number of natural smolts produced each year was estimated based on scientific literature looking at other Chinook Salmon populations, and based on information from Wells Hatchery.
- There is uncertainty in the exploitation rate and survival estimates provided by the Wells Hatchery. There is uncertainty as to the level of biological and life history overlap between these two populations.

Habitat

Aquaculture (T2)

- The genetic risks from the hatchery broodstock model show that while the relation between management actions and the genetic risk index, PNI, appear robust, with current knowledge it is not possible to estimate the magnitude of the genetic risk in terms of the loss of fitness or productivity of wild populations as a consequence of hatchery influence (Withler et al. 2018). Further, the model contains a simplistic consideration of the effects of both the hatchery program, and hatchery measures such as selective removal or regional fishery management planning. Operationally, the genetic risk management should be conducted within the context of both watershed and fishery management planning (DFO 2018).
- There is uncertainty in the amount of intermingling with American stocks in the Columbia River. The Canadian population of Okanagan Chinook is related to many other stocks within the Columbia River. Increased enhancement or production in Canadian waters must be supported by the U.S., or any efforts implemented will likely not be effective.

Other

- What is the overlap between all of initiatives listed under Elements 16 How do all of these projects interact and how do they affect one another?
- What are the remaining research gaps?
- What is the degree of communication between local conservation groups? What is a mechanism to share data regarding spring vs summer/fall run numbers for out-migrating salmon (Armstrong 2015)?

Future Research

Ecosystem Modifications

- The Okanagan Basin Water Resource Information Database (www.obwb.ca/obwrid) contains research and reports relating to Okanagan water use. This site appears to be in disuse and contains only older reports. Efforts should be made to add to this database and increase the user base for more effective communication and sharing of water-related resources and information.
- Ground water surveys need to updated (latest was from Davies et al. 2007), and should cover the newly accessible spawning areas upstream of McIntyre Dam, and the creeks where Chinook Salmon have been recently observed (e.g., Shingle Creek). Moreover, these surveys should be extended into stranded river fragments to determine if their reconnection should be prioritized.

Pollutants

- There should be more frequent (annually) and continued water quality monitoring than is currently being conducted (5 years) by Environment Canada.
- Scientific management relating to coastal and ocean water quality monitoring should be considered as outlined in Strong et al. (2014).
- Emerging issues such as pharmaceuticals and other organic chemicals need to be examined to determine the potential risks of these compounds to the Okanagan Basin water supply and aquatic ecosystems.

Climate Change

- Increased use of estuaries by salmonids in response to climate change will necessitate the need for more knowledge of the timing and distribution of Okanagan Chinook Salmon.
- Explore the current status and possibility of increased protection in estuary regions.
- Sensitivity analysis for Chinook Salmon in response to climate change should be completed. Other fish species have been assessed (Hunter et al. 2014).
- Consider the concept of 'physiological habitat' (thermal, flow, and oxygen optima) as a guidance mechanism for determining appropriate habitat conditions.

Problematic Species

- Establish more thorough recording and monitoring of Chinook Salmon at spawning grounds. Samples from each observed salmon spawning in the river should be taken for a comprehensive DNA analysis of stock origin and relatedness of each spawner.
- Penticton Hatchery fish were released for the first time in the Okanagan River in 2017 with an expected return in 2021. This presents an opportunity to fully track the distribution and timing of return of these fish. Careful monitoring of the hatchery spawners should be made to determine the level of mixing with the wild population. See further hatchery considerations discussed above under the 'aquaculture' subheading.

CONCLUSIONS AND ADVICE

Issues concerning the Okanagan Chinook Salmon are similar to those outlined in the RPA produced in 2008. Concerns are:

1. the Population Viability Analysis indicates that because of the current low population abundance, recovery of Okanagan Chinook is unlikely without large-scale hatchery intervention. As suggested in 2008, hatchery supplementation with U.S. and Canadian fish will be required to off-set low spawning abundance. Numbers will also have to offset the increasing effects that climate change will have on this temperature-sensitive species. Hatchery supplementation would compromise any remaining genetic uniqueness that may remain in the current Canadian population.
2. there still remain a number of gaps in the understanding of basic life history characteristics for Okanagan Chinook. In particular, studies to assess the importance of juvenile rearing habitat for the survival or recovery of a Canadian population including the impact of invasive species. A comprehensive habitat update should be undertaken to assess the location and importance of groundwater input and estuary use. Moreover, limitations from temperature and oxygen regimes should be investigated as part of a habitat and dam passage assessment.

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AUTHORITIES CONTACTED

- Dean Allan – B.C. Interior Area Resource Manager, DFO, Kamloops, B.C.
- Richard Bailey – Program head, DFO (retired) Chinook/Coho program, Kamloops, B.C.
- Chuck Parken – B.C. Interior Area Biologist, DFO, Kamloops, B.C.
- Antonio Velez-Espino – DFO stock assessment biologist, Nanaimo, B.C.
- Jeanette Armstrong, Canadian Research Chair in Okanagan Indigenous Knowledge and Philosophy, UBC, Kelowna, B.C.
- Kari Alex, Fisheries Biologist, Okanagan Nations Alliance, Westbank, B.C.
- Dawn Machin, Fisheries Biologist, Okanagan Nations Alliance, Westbank, B.C.
- Ryan Benson, Fisheries Biologist, Okanagan Nations Alliance, Westbank, B.C.
- Kim Hyatt – Research Scientist, DFO Ecosystems and Ocean Science, Nanaimo, B.C.
- John Candy – Research Scientist, DFO genetics, Nanaimo, B.C.
- Mary Thiess – Research Biologist, DFO (formerly), Nanaimo, B.C.
- Ruth Withler – Research Scientist, DFO genetics (retired), Nanaimo, B.C.
- Carrie Holt – Research Scientist, DFO Ecosystems and Ocean Science, Nanaimo, B.C.
- Joanne Groot – Supervisor, DFO Aging lab, Nanaimo, B.C.
- Christie Whelan – DFO Strategic Planner (formerly), Nanaimo, B.C.
- Monica Walker – DFO Aquaculture Management Coordinator, Nanaimo, B.C.
- Melanie McNabb – DFO governance coordinator, Vancouver, B.C.
- Andrea Pearl, Senior Fisheries Biologist, Colville Tribes, Washington, U.S.A.
- Casey Baldwin, Senior Research Scientist, Colville Tribes, Washington, U.S.A.

REFERENCES

Adams, J., I.C. Kaplan, B. Chasco, K.N. Marshall, A. Acevedo-Gutiérrez, and E.J. Ward. 2016. A century of Chinook Salmon consumption by marine mammal predators in the Northeast Pacific Ocean. Ecological Informatics 34: 44-51.

Alderdice, D., and F. Velsen. 1978. Relation between temperature and incubation time for eggs of Chinook Salmon (*Oncorhynchus tshawytscha*). Journal of the Fisheries Research Board of Canada 35: 69-75.

Alex, K., C. Louie, C. Mathieu and S. Folks. 2018. Skaha Dam 2017 salmon passage monitoring. Report by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Alexis, F., and R. Wright. 2004. Okanagan River Sockeye spawner enumeration and biological sampling 2003. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Alexis, F., H. Alex, and S. Lawrence. 2003. Exotic species risk assessment. *In* Trevor, E., S. Lawrence, F. Alexis, H. Alex, K. Long, C. Fisher, R. Newbury, H. Wright, A. Vedan, C. Peters, D. Marmorek, I. Parnell, and H. Smith. An evaluation of an experimental re-introduction of Sockeye Salmon into Skaha Lake: year 3 of 3. Technical report for Bonneville Power Administration.

Amaranthus, M., H. Jubas, and D. Arthur. 1989. Stream shading, summer streamflow and maximum water temperature following intense wildfire in headwater streams. USDA Forest Service General Technical Report (GTR)-PSW-109.

Anderson, J.H., G.R. Pess, R.W. Carmichael, M.J. Ford, T.D. Cooney, C.M. Baldwin, and M.M. McClure. 2014. Planning Pacific salmon and steelhead reintroductions aimed at long-term viability and recovery. North American Journal of Fisheries Management 34: 72-93.

Andrusak, H., S. Matthews, I. McGregor, K. Ashley, and others. 2005. Okanagan Lake action plan year 9 (2004) report, Fisheries project report. Province of British Columbia 111:2005.

Angilletta, M.J., E.A. Steel, K.K. Bartz, J.G. Kingsolver, M.D. Scheuerell, B.R. Beckman, and L.G. Crozier. 2008. Big dams and salmon evolution: changes in thermal regimes and their potential evolutionary consequences. Evolutionary Applications 1: 286-299.

Anonymous. 1974. Main report of the Consultative Board including the Comprehensive Framework Plan. Prepared under the Canada–British Columbia Okanagan Basin Agreement.

Anonymous. 1982. Report on the Okanagan Basin Implementation Agreement (OBIA). Okanagan Basin Implementation Board Canada.

Anttila, K., E.J. Eliason, K.H. Kaukinen, K.M. Miller, and A.P. Farrell. 2014. Facing warm temperatures during migration: cardiac mRNA responses of two adult *Oncorhynchus nerka* populations to warming and swimming challenges. Journal of Fish Biology 84: 1439-1456.

Araki, H., B. Cooper, and M.S. Blouin. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science 318: 100-103.

Araki, H., B.A. Berejikian, M.J. Ford, and M.S. Blouin. 2008. Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications 1: 342-355.

Armstrong, J.C. 2015. ATK Gathering report on (Chinook Salmon) *Oncorhynchus tshawytscha* in Canada. Report for Aboriginal Traditional Knowledge Sub-Committee on the Status of Endangered Wildlife in Canada.

Backer, D.M., S.E. Jensen, and G. McPherson. 2004. Impacts of fire-suppression activities on natural communities. Conservation Biology 18: 937-946.

Bartz, K.K., K.M. Lagueux, M.D. Scheuerell, T. Beechie, A.D. Haas, and M.H. Ruckelshaus. 2006. Translating restoration scenarios into habitat conditions: an initial step in evaluating recovery strategies for Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 63: 1578-1595.

Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy 27: 313-323.

Beacham, T.D., and C.B. Murray. 1993. Fecundity and egg size variation in North American Pacific salmon (*Oncorhynchus*). Journal of Fish Biology 42: 485-508.

Beacham, T.D., J.R. Candy, K.L. Jonsen, J. Supernault, and others. 2006. Estimation of stock composition and individual identification of Chinook Salmon across the Pacific Rim by use of microsatellite variation. Transactions of the American Fisheries Society 135: 861-888.

Beakes, M.P., J.W. Moore, S.A. Hayes, and S.M. Sogard. 2014. Wildfire and the effects of shifting stream temperature on salmonids. Ecosphere 5: 1-14.

Beamesderfer, R.C., and B.E. Rieman. 1991. Abundance and distribution of Northern Squawfish, Walleyes, and Smallmouth Bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:439-447.

Beamish, R.J., R.M. Sweeting, C.M. Neville, K.L. Lange, T.D. Beacham, and D. Preikshot. 2012. Wild Chinook Salmon survive better than hatchery salmon in a period of poor production. Environmental Biology of Fishes 94: 135-148.

Beckman, B.R., and W.S. Zaugg. 1988. Copper intoxication in Chinook Salmon (*Oncorhynchus tshawytscha*) induced by natural springwater: effects on gill Na+, K+-ATPase, hematocrit, and plasma glucose. Canadian Journal of Fisheries and Aquatic Sciences 45: 1430-1435.

Becker, C.D., 1973. Food and growth parameters of juvenile Chinook salmon, Oncorhynchus tshawytscha, in central Columbia River. Fishery Bulletin 71: 387-400.

Benson, A.J., R.M. Kipp, J. Larson, and A. Fusaro. 2017. *Potamopyrgus antipodarum* (J.E. Gray, 1853): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL.

Beschta, R.L. 1997. Riparian shade and stream temperature: an alternative perspective. Rangelands 19: 25-28.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 138.

Bond, N.A., M.F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters 42: 3414-3420.

Booth, D.B., K.A. Kraseski, and C. Rhett Jackson. 2014. Local-scale and watershed-scale determinants of summertime urban stream temperatures. Hydrological Processes 28: 2427-2438.

Bradford, M.J. 1995. Comparative review of Pacific salmon survival rates. Canadian Journal of Fisheries and Aquatic Sciences 52: 1327-1338.

Bradford, M.J., C.P. Tovey, and L-M. Herborg. 2009. Biological risk assessment for Yellow Perch (*Perca flavescens*) in British Columbia. Can. Sci. Advis. Sec. Res. Doc. 2008/073. v + 21.

Bradford, M.J., J. Lovy, and D. Patterson. 2010a. Infection of gill and kidney of Fraser River Sockeye Salmon, *Oncorhynchus nerka* (Walbaum), by *Parvicapsula minibicornis* and its effect on host physiology. Journal of Fish Diseases 33: 769-779.

Bradford, M.J., J. Lovy, D.A. Patterson, D.J. Speare, W.R. Bennett, A.R. Stobbart, and C.P. Tovey. 2010b. *Parvicapsula minibicornis* infections in gill and kidney and the premature mortality of adult Sockeye Salmon (*Oncorhynchus nerka*) from Cultus Lake, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 67: 673-683.

Braun, D.C., J.W. Moore, J. Candy, and R.E. Bailey. 2016. Population diversity in salmon: linkages among response, genetic and life history diversity. Ecography 39: 317-328.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. State of California Department of Fish and Game, Marine Fisheries Branch, Fish Bulletin No. 94.

Brown, T.G., B. Runciman, S. Pollard, A.D.A. Grant, and M.J. Bradford. 2009. Biological Synopsis of Smallmouth Bass (*Micropterus dolomieu*). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2887.

Bruce, R.L., and C.M. Moffitt. 2010. Quantifying risks of volitional consumption of New Zealand Mudsnails by Steelhead and Rainbow Trout. Aquaculture Research 41: 552-558.

Bull, C. 1999. Fisheries habitat in the Okanagan River, phase 2: investigation of selected options. unpublished report prepared for Douglas County Public Utility, District.

Bull, C., M. Gaboury, and R. Newbury. 2000. Okanagan River habitat restoration feasibility. Prepared for Ministry of Environment, Lands and Parks, Kamloops, BC.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental management 30: 492-507.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. Fishery Bulletin 61: 97-110.

Bussanich, R., H. Wright, E. McGrath, J. Enns, R. Benson, and N. Johnson. 2016. Recovery action plan for Chinook Salmon (*Oncorhynchus tshawytscha*, ntytyix, sk'lwis), in the Okanagan River (q̓awsitkʷ), Canada. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Carey, M.P., B.L. Sanderson, T.A. Friesen, K.A. Barnas, and J.D. Olden. 2011. Smallmouth Bass in the Pacific Northwest: a threat to native species; a benefit for anglers. Reviews in Fisheries Science 19: 305-315.

Caudill, C.C., M.L. Keefer, T.S. Clabough, G.P. Naughton, B.J. Burke, and C.A. Peery. 2014. Indirect effects of impoundment on migrating fish: temperature gradients in fish ladders slow dam passage by adult Chinook Salmon and Steelhead. PLOS ONE 8: e85586.

Cederholm, C.J., and E.O. Salo. 1979. The effects of logging road landslide siltation on the salmon and trout spawning gravels of Stequaleho Creek and the Clearwater River Basin, Jefferson County, Washington, 1972-1978. Fisheries Research Institute, University of Washington, Seattle. Report FRI-UW-7915.

Chapman, W.M. 1943. The spawning of Chinook Salmon in the main Columbia River. Copeia 1943: 168-170.

Chasco, B., I.C. Kaplan, A. Thomas, A. Acevedo-Gutiérrez, D. Noren, M.J. Ford, M.B. Hanson, J. Scordino, S. Jeffries, S. Pearson, K.N. Marshall, and E.J. Ward. 2017a. Estimates of Chinook Salmon consumption in Washington State inland waters by four marine mammal predators from 1970 to 2015. Canadian Journal of Fisheries and Aquatic Sciences 74: 1173-1194.

Chasco, B.E., I.C. Kaplan, A.C. Thomas, A. Acevedo-Gutiérrez, D.P. Noren, M.J. Ford, M.B. Hanson, J.J. Scordino, S.J. Jeffries, K.N. Marshall, A.O. Shelton, C. Matkin, BJ, Burkem and E.J. Ward. 2017b. Competing tradeoffs between increasing marine mammal predation and fisheries harvest of Chinook Salmon. Scientific Reports 7: 15439.

Chen, Z., M. Snow, C.S. Lawrence, A.R. Church, S.R. Narum, R.H. Devlin, and A.P Farrell. 2015) Selection for upper thermal tolerance in rainbow trout (*Oncorhynchus mykiss* Walbaum). Journal of Experimental Biology 218: 803-812.

Chittenden, C.M., S. Sura, K. Butterworth, K.F. Cubitt, and others. 2008. Riverine, estuarine and marine migratory behavior and physiology of wild and hatchery-reared Coho Salmon *Oncorhynchus kisutch* (Walbaum) smolts descending the Campbell River, BC, Canada. Journal of Fish Biology 72: 614-628.

Clarke, W.C., and J.E. Shelbourn. 1985. Growth and development of seawater adaptability by juvenile fall Chinook Salmon (*Oncorhynchus tshawytscha*) in relation to temperature. Aquaculture 45: 21-31.

Clemens, W.A. 1939. The fishes of Okanagan Lake and nearby waters. Bulletin of the Fisheries Research Board of Canada 56: 27-38.

Clemens, W.A., D.S. Rawson, and J.L. McHugh. 1939. Eds. A biological survey of Okanagan Lake, British Columbia. Bulletin of the Fisheries Research Board of Canada, Vol 56.

Coker, G.A., D.L. Ming, and N.E. Mandrak. 2010. Mitigation guide for the protection of fishes and fish habitat to accompany Species at Risk Recovery Potential Assessments conducted by Fisheries and Oceans Canada in Central and Arctic Region. Version 1.0. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2904.

Collings, M.R., R.W. Smith, and G.T. Higgins. 1972. The hydrology of four streams in western Washington as related to several Pacific salmon species, Geological Survey Water-Supply Paper 1968.

Connell, J.H., and W.P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. American Naturalist 121: 789-823.

Connor, E.J., and D.E. Pflug. 2004. Changes in the distribution and density of Pink, Chum, and Chinook salmon spawning in the upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24: 835-852.

COSEWIC. 2006. COSEWIC assessment and status report on the Chinook Salmon *Oncorhynchus tshawytscha* (Okanagan population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

COSEWIC. 2018. COSEWIC guidelines for recognizing designatable units.

COSEWIC. 2017. COSEWIC assessment and status report on the Chinook Salmon *Oncorhynchus tshawytscha*, Okanagan population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

Counihan, T.D., I.R. Waite, E.B. Nilsen, J.M. Hardiman, E. Elias, G. Gelfenbaum, and S.D. Zaugg. 2014. A survey of benthic sediment contaminants in reaches of the Columbia River Estuary based on channel sedimentation characteristics. Science of the Total Environment 484: 331-343.

Crête-Lafrenière A., L.K. Weir, and L. Bernatchez. 2012. Framing the Salmonidae family phylogenetic portrait: a more complete picture from increased taxon sampling. PLOS ONE 7:e46662.

Crozier, L. 2015. Impacts of climate change on salmon of the Pacific Northwest: a review of the scientific literature published in 2014. Report for National Marine Fisheries Service, NOAA, Seattle, WA.

CTC. 2016. Pacific Salmon Commission Joint Chinook Technical Committee annual report of catch and escapement for 2015. Report TCCHINOOK (16)-3. Vancouver, BC.

CTC. 2018. 2017 exploitation rate analysis and model calibration. Pacific Salmon Commission Joint Chinook Technical Committee Report TCCHINOOK (18)-1. Vancouver, BC.

Cumming, B.F., K.R. Laird, I. Gregory-Eaves, K.G. Simpson, M.A. Sokal, R. Nordin, and I.R. Walker. 2015. Tracking past changes in lake-water phosphorus with a 251-lake calibration dataset in British Columbia: tool development and application in a multiproxy assessment of eutrophication and recovery in Osoyoos Lake, a transboundary lake in Western North America. Frontiers in Ecology and Evolution 3: 84.

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5: 330-339.

Davis, C. 2010. Okanagan River Chinook Salmon (*Oncorhynchus tshawytscha*) compilation report 2006-2010. Report for Okanagan Nation Alliance, Westbank, B.C.

Davis, C., H. Wright, T. Brown, B. Phillips, R. Sharma, and C. Parken. 2007. Scientific information in support of recovery potential analysis for Chinook Salmon Okanagan population, *Oncorhynchus tshawytscha*. Can. Sci. Advis. Sec. Res. Doc. 2007/065. ix + 88.

Davis, S., K. Alex, C. Rivard-Sirois, and N. Lukey. 2018. Aquatic Monitoring 2018 - Penticton Channel salmon spawning restoration work. Report for the Habitat Conservation Committee.

Dessouki, T.C.E. 2009. Water quality assessment of the Okanagan River near Oliver, British Columbia (1990-2007), Report for B.C. Ministry of Environment and Environment Canada.

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

DFO. 2008. Recovery Potential Assessment for the Okanagan population of Chinook Salmon (*Oncorhynchus tshawytscha*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/021.

DFO. 2014a. Guidance for the completion of Recovery Potential Assessments (RPA) for Aquatic Species at Risk. Fisheries and Oceans Canada.

DFO. 2014b. Guidance on assessing threats, ecological risk and ecological impacts for Species at Risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013.

DFO. 2015. Directive on the Application of Species at Risk Act Section 33 (Residence) to Aquatic Species at Risk. Fisheries and Oceans Species at Risk Act.

DFO. 2018. Review of genetically based targets for enhanced contributions to Canadian Pacific Chinook Salmon populations. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/001.

Dietrich, J.P., A.L. Van Gaest, S.A. Strickland, and M.R. Arkoosh. 2014. The impact of temperature stress and pesticide exposure on mortality and disease susceptibility of endangered Pacific salmon. Chemosphere 108: 353-359.

Doutaz, D.J. 2019. Columbia River Northern Pike -- investigating the ecology of British Columbia's new apex invasive freshwater predator. M.Sc. Thesis. Thompson Rivers University.

Drenner, S.M., T.D. Clark, C.K. Whitney, E.G. Martins, S.J. Cooke, and S.G. Hinch. 2012. A synthesis of tagging studies examining the behaviour and survival of anadromous salmonids in marine environments. PLoS One 7: e31311.

Dunn, M. and S. Folks. 2015. Brood Year 2014: Skaha Dam 2015 fish passage monitoring. Report for Colville Confederated Tribes, Ministry of Forests, Lands and Natural Resource Operations, and Department of Fisheries and Oceans Canada.

Einum S., I.A. Fleming, I.M. Côté, and J.D. Reynolds. 2003. Population stability in salmon species: effects of population size and female reproductive allocation. Journal of Animal Ecology 72: 811-821.

Eliason E.J., and A.P. Farrell. 2016. Oxygen uptake in Pacific salmon *Oncorhynchus* spp.: when ecology and physiology meet. Journal of Fish Biology 88: 359-388.

Eliason, E.J., T.D. Clark, M.J. Hague, L.M. Hanson, and others. 2011. Differences in thermal tolerance among Sockeye Salmon populations. Science 332: 109-112.

Enns, J. 2015. Fish Passage at akłxʷminaʔ (Shingle Creek) Dam Construction Report 2014. Report for the Penticton Indian Band, Rocky Reach Habitat Conservation Plan Tributary Committee, and Wells Habitat Conservation Plan Tributary Committee.

Ernst, A, and A. Vedan. 2000. Aboriginal fisheries information within the Okanagan Basin. Prepared for the Okanagan Nation Fisheries Commission, Westbank, BC

Evans, W.A., and F.B. Johnston. 1980. Fish migration and fish passage: a practical guide to solving fish passage problems. USDA Forest Service, Washington, D.C.

Evans, A.F., Q. Payton, A. Turecek, B. Cramer, K. Collins, D.D. Roby, P.J. Loschl, L. Sullivan, J. Skalski, M. Weiland, and C. Dotson. 2016. Avian predation on juvenile salmonids: spatial and temporal analysis based on acoustic and Passive Integrated Transponder tags. Transactions of the American Fisheries Society 145: 860-877.

Evenson, D.F., and A.J. Talbot. 2003. Development of a stock assessment and research plan for mid-Columbia River Summer Chinook Salmon, Technical Report 03-03. Columbia River Inter-Tribal Commission. Portland, OR.

Farrell, A., S. Hinch, S. Cooke, D. Patterson, G.T. Crossin, M. Lapointe, and M. Mathes. 2008. Pacific salmon in hot water: applying aerobic scope models and biotelemetry to predict the success of spawning migrations. Physiological and Biochemical Zoology 81: 697-708.

Fisher, J.P., L.A. Weitkamp, D.J. Teel, S.A.Hinton, J.A. Orsi, E.V. Farley Jr., J.F.T. Morris, M.E. Thiess, R.M. Sweeting, and M. Trudel. 2014. Early ocean dispersal patterns of Columbia River Chinook and Coho salmon. Transactions of the American Fisheries Society 143: 252-272.

Fitchko, Y. 1986. Literature review of the effects of persistent toxic substances on Great Lakes biota. Report to the Great Lakes Science Advisory Board, Windsor, ON.

Fleming, I.A., T. Agustsson, B. Finstad, J.I. Johnsson, and B.T. Björnsson. 2002. Effects of domestication on growth physiology and endocrinology of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 59: 1323-1330.

Ford, J.K., and G.M. Ellis. 2006. Selective foraging by fish-eating Killer Whales *Orcinus orca* in British Columbia. Marine Ecology Progress Series 316: 185-199.

Fritts A.L., and T.N. Pearsons. 2006. Effects of predation by nonnative Smallmouth Bass on native salmonid prey: the role of predator and prey size. Transactions of the American Fisheries Society 135: 853-860.

Geen, G.H., J.D. Neilson, M. Bradford. 1985. Effects of pH on the early development and growth and otolith microstructure of Chinook Salmon, *Oncorhynchus tshawytscha*. Canadian Journal of Zoology 63: 22-27.

Geist, D.R., and D.D. Dauble. 1998. Redd site selection and spawning habitat use by fall Chinook Salmon: the importance of geomorphic features in large rivers. Environmental Management 22: 655-669.

Geist, D.R., C.S. Abernethy, K.D. Hand, V.I. Cullinan, J.A. Chandler, and P.A. Groves. 2006. Survival, development, and growth of fall Chinook Salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. Transactions of the American Fisheries Society 135: 1462-1477.

Geist, D.R., E.V. Arntzen, C.J. Murray, K.E. McGrath, Y-J. Bott, and T.P. Hanrahan. 2008. Influence of river level on temperature and hydraulic gradients in Chum and fall Chinook salmon spawning areas downstream of Bonneville Dam, Columbia River. North American Journal of Fisheries Management 28: 30-41.

Gislason, J.C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. North American Journal of Fisheries Management 5: 39-46.

Goniea, T.M., M.L. Keefer, T.C. Bjornn, C.A. Peery, D.H. Bennett, and L.C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook Salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society 135: 408-419.

Government of British Columbia. 2017. B.C. Water Resources Atlas.

Government of Canada. 2010. Canada Gazette Part II. Order Giving Notice of Decisions not to add Certain Species to the List of Endangered Species SOR/2010-32 to 51 and SI/2010-14 to 18.

Grant A., D. Higgs, C. Brauner, and P. Schulte. 2010. Dietary lipid composition affects the gene expression of gill Na+/K+-ATPase α1b but not the α1a isoform in juvenile fall Chinook Salmon (*Oncorhynchus tshawytscha*). Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology 180: 141-149.

Grant, S.C.H., B.L. MacDonald, T.E. Cone, C.A. Holt, A. Cass, E.J. Porszt, J.M.B. Hume, and L. Pon. 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.

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behaviour of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50: 241-246.

Grimm, V., and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. Oecologia 109: 323-334.

Hague, M.J., and D.A. Patterson. 2014. Evaluation of statistical river temperature forecast models for fisheries management. North American Journal of Fisheries Management 34: 132-146.

Hague, M.J., M. Ferrari, J. Miller, D. Patterson, G. Russell, A. Farrell, and S. Hinch. 2011. Modelling the future hydroclimatology of the lower Fraser River and its impacts on the spawning migration survival of Sockeye Salmon. Global Change Biology 17: 87-98.

Hallock, R.J., R.F. Elwell, and D.H. Fry. 1970. Migrations of adult king salmon *Oncorhynchus tshawytscha* in the San Joaquin Delta as demonstrated by the use of sonic tags. State of California Department of Fish and Game Fish Bulletin 151.

Hamblin, P., and S. McAdam. 2003. Impoundment effects on the thermal regimes of Kootenay Lake, the Arrow Lakes Reservoir and Upper Columbia River. Hydrobiologia 504: 3-19.

Hansen, J.A., J.C.A. Marr, J. Lipton, D. Cacela, and H.L. Bergman. 1999a. Differences in neurobehavioral responses of Chinook Salmon (*Oncorhynchus tshawytscha*) and Rainbow Trout (*Oncorhynchus mykiss*) exposed to copper and cobalt: behavioral avoidance. Environmental Toxicology and Chemistry 18: 1972-1978.

Hansen, J.A., J.D. Rose, R.A. Jenkins, K.G. Gerow, and H.L. Bergman. 1999b. Chinook Salmon (*Oncorhynchus tshawytscha*) and Rainbow Trout (*Oncorhynchus mykiss*) exposed to copper: neurophysiological and histological effects on the olfactory system. Environmental Toxicology and Chemistry 18: 1979-1991.

Harley, C.D., A. Randall Hughes, K.M. Hultgren, B.G. Miner, and others. 2006. The impacts of climate change in coastal marine systems. Ecology Letters 9: 228-241.

Harnish, R.A., G.E. Johnson, G.A. McMichael, M.S. Hughes, and B.D. Ebberts. 2012. Effect of migration pathway on travel time and survival of acoustic-tagged juvenile salmonids in the Columbia River Estuary. Transactions of the American Fisheries Society 141: 507-519.

Harnish R.A., R. Sharma, G.A. McMichael, R.B. Langshaw, and T.N. Pearsons. 2014. Effect of hydroelectric dam operations on the freshwater productivity of a Columbia River fall Chinook Salmon population. Canadian Journal of Fisheries and Aquatic Sciences 71: 602-615.

Hatchery Scientific Review Group. 2009. Columbia River Hatchery Reform System-Wide Report.

Hatten, J.R., T.R. Batt, P.J. Connolly, and A.G. Maule. 2014. Modeling effects of climate change on Yakima River salmonid habitats. Climatic Change 124: 427-439.

Hayes, D.B., B.J. Bellgraph, B.M. Roth, D.D. Dauble, and R.P. Mueller. 2014. Timing of redd construction by fall Chinook Salmon in the Hanford Reach of the Columbia River. River Research and Applications 30: 1110-1119.

Hayman, S., and K. Bond. 2006. A work in progress: Eastern Washington Cascades and Yakima Provincial Advisory Committees Collaborative Process for Forest Plan revision Okanogan-Wenatchee National Forests. USDA Forest Service and Eastern Washington Cascades and Yakima Provincial Advisory Committees.

Hazel, C.R., and S.J .Meith. 1970. Bioassay of king salmon eggs and sac fry in copper solutions. California Fish and Game 56: 121-124.

Healey, M.C. 1991. Life history of Chinook Salmon. UBC Press. Vancouver, B.C.

Healey, M.C., and W.R. Heard. 1984. Inter- and intra-population variation in the fecundity of Chinook Salmon (*Oncorhynchus tshawytscha*) and its relevance to life history theory. Canadian Journal of Fisheries and Aquatic Sciences 41: 476-483.

Heath, D.D., J.W. Heath, C.A. Bryden, R.M. Johnson, and C.W. Fox. 2003. Rapid evolution of egg size in captive salmon. Science 299: 1738-1740.

Hess, J.E., J.M. Whiteaker, J.K. Fryer, and S.R. Narum. 2014. Monitoring stock-specific abundance, run timing, and straying of Chinook Salmon in the Columbia River using genetic stock identification (GSI). North American Journal of Fisheries Management 34: 184-201.

Heuer, R.M., and M. Grosell. 2014. Physiological impacts of elevated carbon dioxide and ocean acidification on fish. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology: DOI: 10.1152/ajpregu.00064.2014.

Hill, M.S., G.B. Zydlewski, and W.L. Gale. 2006. Comparisons between hatchery and wild steelhead trout (*Oncorhynchus mykiss*) smolts: physiology and habitat use. Canadian Journal of Fisheries and Aquatic Sciences 63: 1627-1638.

Hillman, T.W., J. Griffith, and W. Platts. 1987. Summer and winter habitat selection by juvenile Chinook Salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116: 185-195.

Hillman, T., M. Miller, M. Johnson, C. Moran, J. Williams, M. Tonseth, C. Willard, S. Hopkins, B. Ishida, C. Kamphaus, T. Pearsons, and P. Graf. 2017. Monitoring and evaluation of the Chelan and Grant County PUDs hatchery programs: 2016 annual report. Report for the Habitat Conservation Plans Hatchery Committees, Wenatchee and Ephrata, WA.

Honea, J.M., J.C. Jorgensen, M.M. McClure, T.D. Cooney, K. Engie, D.M. Holzer, and R. Hilborn. 2009. Evaluating habitat effects on population status: influence of habitat restoration on spring-run Chinook Salmon. Freshwater Biology 54: 1576-1592.

Honea, J.M., M.M. McClure, J.C. Jorgensen, and M.D. Scheuerell. 2016. Assessing freshwater life-stage vulnerability of an endangered Chinook Salmon population to climate change influences on stream habitat. Climate Research 71: 127-137.

Hoy, M., B.L. Boese, L. Taylor, D. Reusser, and R. Rodriguez. 2012. Salinity adaptation of the invasive New Zealand Mud Snail (*Potamopyrgus antipodarum*) in the Columbia River estuary (Pacific Northwest, USA): physiological and molecular studies. Aquatic Ecology 46: 249-260.

Hunter, K.L., K.M. Gillespie, T.M. Brydges, J. Irvine. 2014. Preliminary assessment of the sensitivity of West Coast Vancouver Island marine species to climate change. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3036.

Hyatt K., and D. Rankin. 1999. A habitat-based evaluation of Okanagan Sockeye Salmon escapement objectives. Canadian Stock Assessment Secretariat Research Document 99/191.

Hyatt, K.D., M.M. Stockwell, and D.P. Rankin. 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: 689-711.

Hyatt, K.D., C.A.D. Alexander, and M.M. Stockwell. 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.

Isaak, D.J., C.H. Luce, B.E. Rieman, D.E. Nagel, and others. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20: 1350-1371.

Ito, J., and R. Parker. 1971. A record of Pacific Herring (*Clupea harengus pallasi*) feeding on juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in a British Columbia estuary. Journal of the Fisheries Research Board of Canada 28: 1921.

Jensen, A.J., S. Karlsson, P. Fiske, L.P. Hansen, G.M. Ostborg, and K. Hindar. 2014. Origin and life history of Atlantic Salmon (*Salmo salar*) near their northernmost oceanic limit. Canadian Journal of Fisheries and Aquatic Sciences 71: 1740-1746.

Jezierska, B., K. Ługowska, and M. Witeska. 2009. The effects of heavy metals on embryonic development of fish (a review). Fish Physiology and Biochemistry 35: 625-640.

Johnson, J.E., and B.L. Jensen. 1991. Hatcheries for endangered freshwater fishes. *In* Minckley, W.L., and J.E. Deacon, eds. Battle Against Extinction: Native Fish Management in the American West. University of Arizona Press, Tucson, AZ. pp. 199-218.

Johnson, L.E., A. Ricciardi, and J.T. Carlton. 2001. Overland dispersal of aquatic invasive species: a risk assessment of transient recreational boating. Ecological Applications 11: 1789-1799.

Johnson, L.L., G.M. Ylitalo, C.A. Sloan, B.F. Anulacion, A.N. Kagley, M.R. Arkoosh, T.A. Lundrigan, K. Larson, M. Siipola, and T.K. Collier. 2007. Persistent organic pollutants in outmigrant juvenile Chinook Salmon from the Lower Columbia Estuary, USA. Science of the Total Environment 374: 342-366.

Johnson, L.L., M.L. Willis, O.P. Olson, R.W. Pearce, C.A. Sloan, and G.M. Ylitalo. 2010. Contaminant concentrations in juvenile fall Chinook Salmon from Columbia River Hatcheries. North American Journal of Aquaculture 72: 73-92.

Jonsson, B., and N. Jonsson. 2009. A review of the likely effects of climate change on anadromous Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*, with particular reference to water temperature and flow. Journal of Fish Biology 75: 2381-2447.

Jonsson, N., B. Jonsson, and L.P. Hansen. 2003. The marine survival and growth of wild and hatchery-reared Atlantic salmon. Journal of Applied Ecology 40: 900-911.

Jorgensen, J.C., J.M. Honea, M.M. McClure, T.D. Cooney, K. Engie, and D.M. Holzer. 2009. Linking landscape-level change to habitat quality: an evaluation of restoration actions on the freshwater habitat of spring-run Chinook Salmon. Freshwater Biology 54: 1560-1575.

Keefer, M.L., C.A. Peery, T.C. Bjornn, M.A. Jepson, and L.C. Stuehrenberg. 2004. Hydrosystem, dam, and reservoir passage rates of adult Chinook Salmon and Steelhead in the Columbia and Snake rivers. Transactions of the American Fisheries Society 133: 1413-1439.

Keefer, M.L., G.A. Taylor, D.F. Garletts, C.K. Helms, G.A. Gauthier, T.M. Pierce, and C.C. Caudill. 2012. Reservoir entrapment and dam passage mortality of juvenile Chinook Salmon in the Middle Fork Willamette River. Ecology of Freshwater Fish 21: 222-234.

Keefer M.L., T.S. Clabough, M.A. Jepson, E.L. Johnson, C.A. Peery, and C.C. Caudill. 2018. Thermal exposure of adult Chinook salmon and steelhead: Diverse behavioral strategies in a large and warming river system. PLoS ONE 13(9).

Kemp, P.S., J.D. Armstrong, and D.J. Gilvear. 2005. Behavioural responses of juvenile Atlantic salmon (*Salmo salar*) to presence of boulders. River Research and Applications 21: 1053-1060.

Kent, M.L., G.S. Traxler, D. Kieser, J. Richard, S.C. Dawe, R.W. Shaw, G. Prosperi-Porta, J. Ketcheson, and T.P.T. Evelyn. 1998. Survey of salmonid pathogens in ocean-caught fishes in British Columbia, Canada. Journal of Aquatic Animal Health 10: 211-219.

Kondolf, G.M., and M.G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2275-2285.

Kurylyk, B.L. K.T. MacQuarrie, T. Linnansaari, R.A. Cunjak, R.A. Curry. 2015. Preserving, augmenting, and creating cold-water thermal refugia in rivers: concepts derived from research on the Miramichi River, New Brunswick (Canada). Ecohydrology 8: 1095-1108.

Laetz, C.A., D.H. Baldwin, V.R. Hebert, J.D. Stark, and N.L. Scholz. 2014. Elevated temperatures increase the toxicity of pesticide mixtures to juvenile Coho Salmon. Aquatic Toxicology 146: 38-44.

Laramie, M.B., Pilliod, D.S. and C.S. Goldberg. 2015. Characterizing the distribution of an endangered salmonid using environmental DNA analysis. Journal of Biological Conservation 183: 29-37.

Larson, W.A., J.E. Seeb, T.H. Dann, D.E. Schindler, and L.W. Seeb. 2014. Signals of heterogeneous selection at an MHC locus in geographically proximate ecotypes of Sockeye Salmon. Molecular Ecology 23: 5448-5461.

Lawrence, D.J., B. Stewart-Koster, J.D. Olden, A.S. Ruesch, and others. 2014. The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications 24: 895-912.

Levings, C., C. McAllister, and B. Chang. 1986. Differential use of the Campbell River estuary, British Columbia by wild and hatchery-reared juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 43: 1386-1397.

Lönnstedt, O.M., and P. Eklöv. 2016. Environmentally relevant concentrations of microplastic particles influence larval fish ecology. Science 352: 1213-1216.

Luce, C.H., V. Lopez-Burgos, Z. Holden. 2014. Sensitivity of snowpack storage to precipitation and temperature using spatial and temporal analog models. Water Resources Research 50: 9447-9462.

Lukey, N., and C. Louie. 2015. Okanagan Subbasin Habitat Improvement Program (OSHIP): 2013-15. Tributary Prioritization. Report by Okanagan Nation Alliance Fisheries Department. Westbank, BC.

Lund, S.G., D. Caissie, R.A. Cunjak, M.M. Vijayan, and B.L. Tufts. 2002. The effects of environmental heat stress on heat-shock mRNA and protein expression in Miramichi Atlantic salmon (*Salmo salar*) parr. Canadian Journal of Fisheries and Aquatic Sciences 59: 1553-1562.

Machin D., K. Alex, C. Louie, C. Mathieu, and C. Rivard-Sirois. 2015. Aquatic monitoring of the Okanagan River Restoration Initiative post-construction 2014. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Mackie, G. 2010. Risk assessment of water quality in Okanagan Lake, British Columbia, to zebra/quagga mussel infestations. Prepared for Mollusc Species Subcommittee, The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), Ottawa, ON.

Maier, G. 2017. Upper Columbia Integrated Recovery Hatchery Background Summary. Report for the Upper Columbia Salmon Recovery Board, Wenatchee, WA.

Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L.Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.K. Plattner, G.W. Yohe, and F.W. Zwier. 2010. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. Intergovernmental Panel on Climate Change (IPCC).

McClure, M.M., P. Spruell, F. Utter, R. Carmichael, and others. 2003a. Independent populations of listed Chinook Salmon, Sockeye Salmon and Steelhead Evolutionarily Significant Units in the Interior Columbia Basin. Draft Technical Recovery Team document released for co-manager review. Draft Technical Recovery Team Document Released for Co-Manager Review.

McClure, M.M., E.E. Holmes, B.L. Sanderson, and C.E. Jordan. 2003b. A large-scale, multispecies status assessment: anadromous salmonids in the Columbia River basin. Ecological Applications 13: 964-989.

McCormick ,S.D. 1994. Ontogeny and evolution of salinity tolerance in anadromous salmonids: hormones and heterochrony. Estuaries 17: 26-33.

McCormick, S.D., and R.L. Saunders. 1987. Preparatory physiological adaptations for marine life in salmonids: osmoregulation, growth and metabolism. American Fisheries Society Symposium 1: 211-229.

Mesa, M.G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile Chinook Salmon. Transactions of the American Fisheries Society 123: 786-793.

Miller, A.J., H. Song, and A.C. Subramanian. 2015a. The physical oceanographic environment during the CCE-LTER years: changes in climate and concepts. Deep Sea Research Part II: Topical Studies in Oceanography 112: 6-17.

Miller, B., J. Enns, J. Miller, S. Schaller, D. Hathaway, L. George, and J. Arterburn. 2015b. Okanogan Basin Monitoring and Evaluation Program 2014 - Annual Progress Report. Report for Colville Confederated Tribes, Omak, WA.

Miller, J.A., D.J. Teel, W.T. Peterson, and A.M. Baptista. 2014. Assessing the relative importance of local and regional processes on the survival of a threatened salmon population. PLOS ONE 9: e99814.

Miller, M.A. 1994. Organochlorine concentration dynamics in Lake Michigan Chinook Salmon (*Oncorhynchus tshawytscha*). Archives of Environmental Contamination and Toxicology 27: 367-374.

Molony, B.W., A.R. Church, and G.B. Maguire. 2004. A comparison of the heat tolerance and growth of a selected and non-selected line of rainbow trout, *Oncorhynchus mykiss*, in Western Australia. Aquaculture 241: 655-665.

Moran, P., Teel, D., Banks, M., Beacham, T., Bellinger, M. R., Blankenship, S., Candy, J., Garza, J., Hess, J., Narum, S., Seeb, L., Templin, W., Wallace, C., Smith, C. 2013. Divergent life-history races do not represent Chinook salmon coast-wide: The importance of scale in Quaternary biogeography. Canadian Journal of Fisheries and Aquatic Sciences 70. 415-435. 10.1139/cjfas-2012-0135.

Morgan, J.D., and G.K. Iwama. 1991. Effects of salinity on growth, metabolism, and ion regulation in juvenile Rainbow and Steelhead Trout (*Oncorhynchus mykiss*) and fall Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 48: 2083-2094.

Mullan J.W. 1987. Status and propagation of Chinook Salmon in the Mid-Columbia River through 1985, Vol 2. US Dept. of the Interior, Fish and Wildlife Service, Research and Development.

Muñoz, N.J., K. Anttila, Z. Chen, J.W. Heath, A.P. Farrell, and B.D. Neff. 2014. Indirect genetic effects underlie oxygen-limited thermal tolerance within a coastal population of Chinook Salmon. Proceedings of the Royal Society B: Biological Sciences 281: 20141082.

Muñoz N.J., A.P. Farrell, J.W. Heath, and B.D. Neff. 2015. Adaptive potential of a Pacific salmon challenged by climate change. Nature Climate Change 5: 163-166.

Myers J.M., R.G. Kope, G.J. Bryant, D. Teel, and others. 1998. Status review of Chinook Salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC 35: 443.

Myrick, C., and J. Cech Jr. 1998. Temperature effects on Chinook Salmon and Steelhead: a review focusing on California's Central Valley populations. Technical Publication produced by the Bay-Delta Modeling Forum.

Nagasawa, K. 1998. Predation by Salmon Sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean. North Pacific Anadromous Fish Commission Bulletin 1: 419-433.

National Marine Fisheries Service. 2013. ESA Recovery Plan for Lower Columbia River Coho Salmon, Lower Columbia River Chinook Salmon, Columbia River Chum Steelhead, Lower Columbia River Steelhead. Prepared by the National Marine Fisheries Service, Northwest Region.

National Research Council. 2004. Managing the Columbia River: instream flows, water withdrawals, and salmon survival. National Academies Press, Washington, D.C.

Naughton, G.P., D.H. Bennett, and K.B. Newman. 2004. Predation on juvenile salmonids by Smallmouth Bass in the Lower Granite Reservoir System, Snake River. North American Journal of Fisheries Management 24: 534-544.

Neilson, J.D., and G.H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Transactions of the American Fisheries Society 110: 554-556. et al. 2008.

Noakes, D.J., R.J. Beamish, and M.L. Kent. 2000. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia. Aquaculture 183: 363-386.

Noonan, M.J., J.W.A. Grant, and C.D. Jackson. 2012. A quantitative assessment of fish passage efficiency. Fish and Fisheries 13: 450-464.

OBMEP. 2019. Okanogan Basin Monitoring and Evaluation Program. 2018 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

Okanagan Basin Water Board. Okanagan waterwise. Accessed November 20, 2017.

Otero, J., J.H. L'Abee-Lund, T. Castro-Santos, K. Leonardsson, and others. 2014. Basin-scale phenology and effects of climate variability on global timing of initial seaward migration of Atlantic Salmon (*Salmo salar*). Global Change Biology 20: 61-75.

Parken, C., R. McNicol, and J. Irvine. 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.

Payne, J.T., A.W. Wood, A.F. Hamlet, R.N. Palmer, and D.P. Lettenmaier. 2004. Mitigating the effects of climate change on the water resources of the Columbia River Basin. Climatic Change 62: 233-256.

Pearl, A.M., M.B. Laramie, C.M. Baldwin, J.P Rohrback, and P.E. Phillips. 2017. The Chief Joseph Hatchery Program 2015 Annual Report. BPA Project No. 2003-023-00.

Perry, S.F. 1997. The chloride cell: structure and function in the gills of freshwater fishes. Annual Review of Physiology 59: 325-347.

Petersen, J.H., and J.F. Kitchell. 2001. Climate regimes and water temperature changes in the Columbia River: bioenergetic implications for predators of juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 58: 1831-1841.

Phillips, B., H. Wright, and K. Long. 2005. Okanagan River Chinook habitat usage and availability. Report for Okanagan Nation Alliance, Westbank, B.C.

Plumb, J.M. 2018. A bioenergetics evaluation of temperature-dependent selection for the spawning phenology by Snake River fall Chinook salmon. Ecology and Evolution 8: 9633-9645.

Porter, M., S. Casley, D. Pickard, M. Nelitz, and N. Ochoski. 2013. Southern Chinook Conservation Units: Habitat indicators report cards. Prepared by ESSA Technologies Ltd for Fisheries and Oceans Canada.

Pörtner, H.O., and A.P. Farrell. 2008. Physiology and climate change. Science 322: 690-692.

Rae, R. 2005. The state of fish and fish habitat in the Okanagan and Similkameen Basins. Report for the Canadian Okanagan Basin Technical Working Group, Westbank, B.C.

Rae, R., and V. Jensen. 2007. Contaminants in Okanagan fish: recent analysis and review of historic data. Report for Okanagan Nation Alliance Fisheries Department, Westbank B.C.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook salmon. National Ecology Center.

Rand, P., S. Hinch, J. Morrison, M. Foreman, and others. 2006. Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River Sockeye Salmon. Transactions of the American Fisheries Society 135: 655-667.

Rechisky, E.L., D.W. Welch, A.D. Porter, M.C. Jacobs-Scott, and P.M. Winchell. 2013. Influence of multiple dam passage on survival of juvenile Chinook Salmon in the Columbia River estuary and coastal ocean. Proceedings of the National Academy of Sciences 110: 6883-6888.

Reiser, D.W. and T.C. Bjornn. 1979. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in the Western United States and Canada: Habitat Requirements of Anadromous Salmonids. Pacific Northwest Forest and Range Experiment Station, Forest Service, US Department of Agriculture.

Richter, A., and S.A. Kolmes. 2005. Maximum temperature limits for Chinook, Coho, and Chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13: 23-49.

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

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by Northern Squawfish, Walleyes, and Smallmouth Bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 448-458.

Rinne, J.N., J.E. Johnson, B.L. Jensen, A.W. Ruger, and R. Sorenson. 1986. The role of hatcheries in the management and recovery of threatened and endangered fishes. pp. 271-285 *in* Stroud, R.H (ed.). Fish Culture in Fisheries Management. American Fisheries Society, Bethesda, MD.

Rivard-Sirois, C. 2014. Okanagan River Restoration Initiative (ORRI) spawning platforms no.1 & no.2 in the Penticton Channel - construction works. 2013-2014. Report for the ORRI Steering Committee and PRCC Committees, Westbank, BC.

Rivard-Sirois, C., K. Alex, S. Folks, and N. Audy. 2013. Providing fish passage at McIntyre Dam - Okanagan Sockeye adult monitoring (2009-2012). Prepared by Okanagan Nation Alliance – Fisheries Department, Westbank, BC.

Roni, P., C. Johnson, T. De Boer, G. Pess, A. Dittman, and D. Sear. 2015. Interannual variability in the effects of physical habitat and parentage on Chinook Salmon egg-to-fry survival. Canadian Journal of Fisheries and Aquatic Sciences 73: 1047-1059.

Roy, R., and P.G.C. Campbell. 1995. Survival time modeling of exposure of juvenile Atlantic Salmon (*Salmo salar*) to mixtures of aluminum and zinc in soft water at low pH. Aquatic Toxicology 33: 155-176.

Rubenson, E.S., and J.D. Olden. 2020. An invader in salmonid rearing habitat: current and future distributions of Smallmouth Bass (*Micropterus dolomieu*) in the Columbia River Basin. Canadian Journal of Fisheries and Aquatic Sciences 77: 314-325.

Ruggerone, G.T., and F.A. Goetz. 2004. Survival of Puget Sound Chinook Salmon (*Oncorhynchus tshawytscha*) in response to climate-induced competition with Pink Salmon (*Oncorhynchus gorbuscha*). Canadian Journal of Fisheries and Aquatic Sciences 61: 1756-1770.

Runciman, J.B., and B.R. Leaf. 2009. A Review of Yellow Perch (*Perca flavascens*), Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), Pumpkinseed (*Lepomis gibbosus*), Walleye (*Sander vitreus*) and Northern Pike (*Esox lucius*) distributions in British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2882.

Russell, L., K. Conlin, O. Johansen, and U. Orr. 1983. Chinook Salmon studies in the Nechako River: 1980, 1981, 1982. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1728.

Sabal, M., S. Hayes, J. Merz, and J. Setka. 2016. Habitat alterations and a nonnative predator, the Striped Bass, increase native Chinook Salmon mortality in the Central Valley, California. North American Journal of Fisheries Management 36: 309-320.

Salafsky, N., D. Salzer, A.J. Stattersfield, C. Hilton-Taylor, and others. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conservation Biology 22: 897-911.

Sawaske, S.R., and D.L. Freyberg. 2014. An analysis of trends in baseflow recession and low-flows in rain-dominated coastal streams of the pacific coast. Journal of Hydrology 519: 599-610.

Schaller. H.A., C.E. Petrosky, and E.S. Tinus. 2013. Evaluating river management during seaward migration to recover Columbia River stream-type Chinook Salmon considering the variation in marine conditions. Canadian Journal of Fisheries and Aquatic Sciences 71: 259-271.

Scheer, G. 2018. Memorandum re: 2017 Wells Hatchery Report. Accessed October 2019.

Scheuerell, M.D., and J.G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook Salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography 14: 448-457.

Schindler, D.E, X. Augerot, E. Fleishman, N.J. Mantua, and others. 2008. Climate change, ecosystem impacts, and management for Pacific salmon. Fisheries 33: 502-506.

Schleppe J., and H. Larratt. 2016. CLBMON-15b Middle Columbia River Ecological Productivity Monitoring, Annual Report 2015. Report for BC Hydro, Vancouver, B.C.

Scott, W., and E. Crossman. 1973. Freshwater fishes of Canada: Fisheries Research Board of Canada Bulletin, Vol. 184. Fisheries Research Board of Canada, Ottawa

Self, J., and H. Larratt. 2013. Limiting the spread of aquatic invasive species into the Okanagan. Report for Okanagan Basin Water Board and Glenmore-Ellison Improvement District, West Kelowna, B.C.

Sepulveda, A.J., D.S. Rutz, A.W. Dupuis, P.A. Shields, and K.J. Dunker. 2015. Introduced Northern Pike consumption of salmonids in Southcentral Alaska. Ecology of Freshwater Fish 24: 519-531.

Sharma, R., and T.P. Quinn. 2012. Linkages between life history type and migration pathways in freshwater and marine environments for Chinook salmon, *Oncorhynchus tshawytscha*. Acta Oecologica 41: 1-13.

Shelton, J.M. 1955. The hatching of Chinook Salmon eggs under simulated stream conditions. The Progressive Fish-Culturist 17: 20-35.

Shepherd P., J. Tansey, and H. Dowlatabadi. 2006. Context matters: what shapes adaptation to water stress in the Okanagan? Climatic Change 78: 31-62.

Shrimpton, J.M., N.J. Bernier, G.K. Iwama, and D.J. Randall. 1994a. Differences in measurements of smolt development between wild and hatchery-reared juvenile Coho Salmon (*Oncorhynchus kisutch*) before and after saltwater exposure. Canadian Journal of Fisheries and Aquatic Sciences 51: 2170-2178.

Shrimpton, J.M., N.J. Bernier, and D.J. Randall. 1994b. Changes in cortisol dynamics in wild and hatchery-reared juvenile Coho Salmon (*Oncorhynchus kisutch*) during smoltification. Canadian Journal of Fisheries and Aquatic Sciences 51: 2179-2187.

Snow, C, C. Frady, A. Repp, B. Goodman, and A. Murdoch. 2014. Monitoring and evaluation of the Wells hatchery and Methow hatchery programs: 2013 annual report. Report for Douglas PUD, Grant PUD, and the Wells HCP Hatchery Committee, East Wenatchee, WA.

Sopinka, N.M., S.G. Hinch, C.T. Middleton, J.A. Hills, and D.A. Patterson. 2014. Mother knows best, even when stressed? Effects of maternal exposure to a stressor on offspring performance at different life stages in a wild semelparous fish. Oecologia 175: 493-500.

Stalberg, H., R. Lauzier, E. MacIsaac, M. Porter, and C. Murray. 2009. Canada's policy for conservation of wild pacific salmon: stream, lake, and estuarine habitat indicators. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2859.

Stanford, J.A., C.A. Frissell, and C.C. Coutant. 2005. The status of freshwater habitats. pp. 173-248 *in* Williams, R.N., Ed. Return to the River: Restoring Salmon Back to the Columbia River. Elsevier Academic Press, Burlington, MA.

Statistics Canada. 2016. Statistics Canada 2016 Census. Accessed November 20, 2017.

Stockner, J., and K. Shortreed. 1989. Algal picoplankton production and contribution to food-webs in oligotrophic British Columbia lakes. Hydrobiologia 173: 151-166.

Stockwell, M.M., and K.D. Hyatt. 2003. A summary of Okanagan Sockeye Salmon (*Oncorhynchus nerka*) escapement survey observations by date and river segment from 1947 to 2001. Canadian Data Report of Fisheries and Aquatic Sciences 1106.

Stram, D., J.W. Balsiger, S. Miller, J.N. Ianelli, A.C. Haynie, L.E. Queirolo, and G.A. Harrington. 2016. Final environmental assessment/regulatory impact review for proposed Amendment 110 to the fishery management plan for groundfish of the Bering Sea and Aleutian Islands Management Area: Bering Sea Chinook Salmon and Chum Salmon bycatch management measures. National Marine Fisheries Service, Alaska Region.

Strong, A.L., K.J. Kroeker, L.T. Teneva, L.A. Mease, and R.P. Kelly. 2014. Ocean acidification 2.0: Managing our changing coastal ocean chemistry. BioScience 64: 581-592.

Summit Environmental Consultants. 2010. Okanagan water supply and demand project: Phase 2 Summary Report. Report for the Okanagan Basin Water Board, Kelowna, B.C.

Swales, S., R. Lauzier, and C. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64: 1506-1514.

Symonds, B. 2000. Background and history of water management of Okanagan Lake and River. Prepared by Ministry of Environment, Lands, and Parks (Water Management), Penticton, BC.

Tappel, P.D., and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3: 123-135.

Taylor, E.B. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98: 185-207.

Tierney, K., and A. Farrell. 2004. The relationships between fish health, metabolic rate, swimming performance and recovery in return-run Sockeye Salmon, *Oncorhynchus nerka* (Walbaum). Journal of Fish Diseases 27: 663-671.

Tiffan, K.F., T.J. Kock, C.A. Haskell, W.P. Connor, and R.K. Steinhorst. 2009. Water velocity, turbulence, and migration rate of subyearling fall Chinook Salmon in the free-flowing and impounded Snake River. Transactions of the American Fisheries Society 138: 373-384.

Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-Century climate change on hydrologic extremes in the Pacific Northwest Region of North America. Journal of the American Water Resources Association 50: 1461-1476.

Trudel, M., and D.W. Welch. 2005. Modeling the oxygen consumption rates in Pacific salmon and steelhead: model development. Transactions of the American Fisheries Society 134: 1542-1561.

Trudel, M., D.R. Geist, and D.W. Welch. 2004. Modeling the oxygen consumption rates in Pacific salmon and Steelhead: an assessment of current models and practices. Transactions of the American Fisheries Society 133: 326-348.

U. S. Fish and Wildlife Service. 1995. Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Vol 2. Stockton, CA: Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group.

Van Gaest, A.L., J.P. Dietrich, D.E. Thompson, D.A. Boylen, S.A. Strickland, T.K. Collier, F.J. Loge, and M.R. Arkoosh. 2011. Survey of pathogens in hatchery Chinook Salmon with different out-migration histories through the Snake and Columbia rivers. Journal of Aquatic Animal Health 23: 62-77.

Vander Zanden, M.J., and J.D. Olden. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences 65: 1512-1522.

Vedan, A. 2002. Traditional Okanagan environmental knowledge and fisheries management. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, BC.

Vronskiy, B. 1972. Reproductive biology of the Kamchatka River Chinook Salmon (*Oncorhynchus tshawytscha* (Walbaum)). Journal of Ichthyology 12: 259-273.

Wagner, G.N., S.G. Hinch, L.J. Kuchel, A. Lotto, and others. 2005. Metabolic rates and swimming performance of adult Fraser River Sockeye Salmon (*Oncorhynchus nerka*) after a controlled infection with *Parvicapsula minibicornis*. Canadian Journal of Fisheries and Aquatic Sciences 62: 2124-2133.

Wang, T., S. Lefevre, I.K. Iversen, I. Findorf, R. Buchanan, and D.J. McKenzie. 2014. Anaemia only causes a small reduction in the upper critical temperature of sea bass: is oxygen delivery the limiting factor for tolerance of acute warming in fishes? The Journal of Experimental Biology 217: 4275-4278.

Waples, R.S., D.J. Teel, J.M. Myers, A.R. Marshall, and J. Hey. 2004. Life-history divergence in Chinook Salmon: historic contingency and parallel evolution. Evolution 58: 386-403.

Waples, R.S., G.R. Pess, and T. Beechie. 2008a. Evolutionary history of Pacific salmon in dynamic environments. Evolutionary Applications 1: 189-206.

Waples, R.S., R.W. Zabel, M.D. Scheuerell, and B.L, Sanderson. 2008b. Evolutionary responses by native species to major anthropogenic changes to their ecosystems: Pacific salmon in the Columbia River hydropower system. Molecular Ecology 17: 84-96.

Ward, D.L., and M.P. Zimmerman. 1999. Response of Smallmouth Bass to sustained removals of Northern Pikeminnow in the Lower Columbia and Snake rivers. Transactions of the American Fisheries Society 128: 1020-1035.

Weitkamp, L.A., P.J. Bentley, and M.N. Litz. 2012. Seasonal and interannual variation in juvenile salmonids and associated fish assemblage in open waters of the lower Columbia River estuary. Fishery Bulletin 110: 426-450.

Weitkamp, L.A., D.J. Teel, M. Liermann, S.A. Hinton, D.M.V. Doornik, and P.J. Bentley. 2015. Stock-specific size and timing at ocean entry of Columbia River juvenile Chinook Salmon and Steelhead: implications for early ocean growth. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7: 370-392.

Welch, D.W., E.L. Rechisky, M.C. Melnychuk, A.D. Porter and others. 2008. Survival of migrating salmon smolts in large rivers with and without dams. PLoS Biology 6:e265.

Wells, B.K., J.A. Santora, M.J. Henderson, P. Warzybok, J. Jahncke, R.W. Bradley, D.D. Huff, I.D. Schroeder, P. Nelson, J.C. Field, and D.G. Ainley. 2017. Environmental conditions and prey-switching by a seabird predator impact juvenile salmon survival. Journal of Marine Systems 174: 54-63.

Wiese, F.K., J.K. Parrish, C.W. Thompson, and C. Maranto. 2008. Ecosystem-based management of predator-prey relationships: piscivorous birds and salmonids. Ecological Applications 18: 681-700.

Wilcox, C., N.J. Mallos, G.H. Leonard, A. Rodriguez, and B.D. Hardesty. 2016. Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. Marine Policy 65: 107-114.

Withler, R.E., M.J. Bradford, D.M. Willis, and C. Holt. 2018. Genetically based targets for enhanced contributions to Canadian Pacific Chinook Salmon populations. DFO. Can. Sci. Advis. Sec. Res. Doc. 2018/019. viii + 183.

Wright, H., and K. Long. 2005. Documentation of Chinook (*Oncorhynchus tshawytscha*) information from Okanagan Nation Alliance Fisheries Department field work (1999-2004). Okanagan Nation Alliance Fisheries Department March 2005.

Wright, R.H., C. Bull, and K.D. Hyatt. 2002. Possible impacts of exotic species introductions on the indigenous aquatic communities of the Okanagan Valley mainstem lakes. American Fisheries Society special publication on Okanagan System - May Ecosystem conference.

Wydoski, R.S., and R.R. Whitney. 2003. Inland Fishes of Washington. American Fisheries Society 332. University of Washington Press, Seattle, WA.

Young, J.L., S.G. Hinch, S.J. Cooke, G.T. Crossin, and others. 2006. Physiological and energetic correlates of en route mortality for abnormally early migrating adult sockeye salmon (*Oncorhynchus nerka*) in the Thompson River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 63:1067-1077.

Zaugg, W.S. 1982. Some changes in smoltification and seawater adaptability of salmonids resulting from environmental and other factors. Aquaculture 28: 143-151.

Zimmerman, M.P. 1999. Food habits of Smallmouth Bass, Walleye, and Northern Pikeminnow in the lower Columbia River basin during outmigration of juvenile anadromous salmonids. Transactions of the American Fisheries Society 128: 1036-1054.

Zimmerman, M.P., and D.L. Ward. 1999. Index of predation on juvenile salmonids by Northern Pikeminnow in the lower Columbia River basin, 1994–1996. Transactions of the American Fisheries Society 128: 995-1007.

Zimmerman, M.S., C. Kinsel, E. Beamer, E.J. Connor, and D.E. Pflug. 2015. Abundance, survival, and life history strategies of juvenile Chinook Salmon in the Skagit River, Washington. Transactions of the American Fisheries Society 144: 627-641.

APPENDIX A: POPULATION VIABILITY ANALYSIS OF CANADIAN OKANAGAN CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*)

INTRODUCTION

Although escapement data are limited, existing data indicate that Okanagan summer Chinook Salmon (*Oncorhynchus tshawytscha*) are a highly depressed component among the extant Upper Columbia River Chinook Salmon populations; with fewer than 40 spawners counted since 1965 (COSEWIC 2006). Chinook Salmon residing in the Canadian section of the Okanagan River were originally believed to be a member of a continuous population extending downstream to the confluence of the Okanagan with the Columbia River. However, genetic data taken from the naturally spawning Chinook Salmon in the Canadian Okanagan suggest that this group may be reproductively isolated from lower Okanagan River spawners (COSEWIC 2006). Given the recent evidence for their reproductive isolation and imperiled status, a population viability analysis (PVA) was warranted[3]. Due to limitation on available data for this population, the PVA herein largely relies on data from the United States component of the upriver summer Chinook Salmon populations that spawned above Rock Island dam in the US (Figure A1, adapted from COSEWIC 2006).

METHODS

Population Dynamics Model

The technique used here is similar to PVAs used elsewhere in conservation biology for evaluating extinction risk (e.g., Emlen 1995, Fieberg and Ellner 2000, Ellner and Fieberg 2003). The Ricker spawner recruit function (Ricker 1974) was utilized as the basis for the model, owing to the observation that Chinook Salmon often exhibit over-compensatory mechanisms of recruitment. We modeled these recruitment processes using the log-normal form of the Ricker curve (Hilborn and Walters 1992), where the number of juvenile recruits produced in the following year (i.e., $y + 1$) is predicted by the number of spawners returning S_y by the following equation:

$$R_{y+1} = \alpha \cdot S_y \cdot e^{-\frac{S_y}{\beta}} \cdot e^{\epsilon_y} \tag{1}$$

where α is the density independent parameter that relates the number of spawners (S_y) to the number of juveniles produced, β is the density dependent parameter and ϵ_y represents process error used in the simulation (i.e., $\epsilon_y \sim N(0, \sigma_R)$). This implies that the stochasticity in the number of juvenile recruits will be log-normally distributed.

During out-migration juveniles can be expected to experience dam passage mortalities (D_{juv}) observed in the Colombia River (Petrosky et. al. 2001, Schaller et. al. 1999), as well as early ocean mortality (ϕ_{ocean}). Therefore, the number of outmigrating smolts that survive to become age two adults are the product of the number of recruits,

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[3] The computer source code that supported this analysis is available on GitHub.

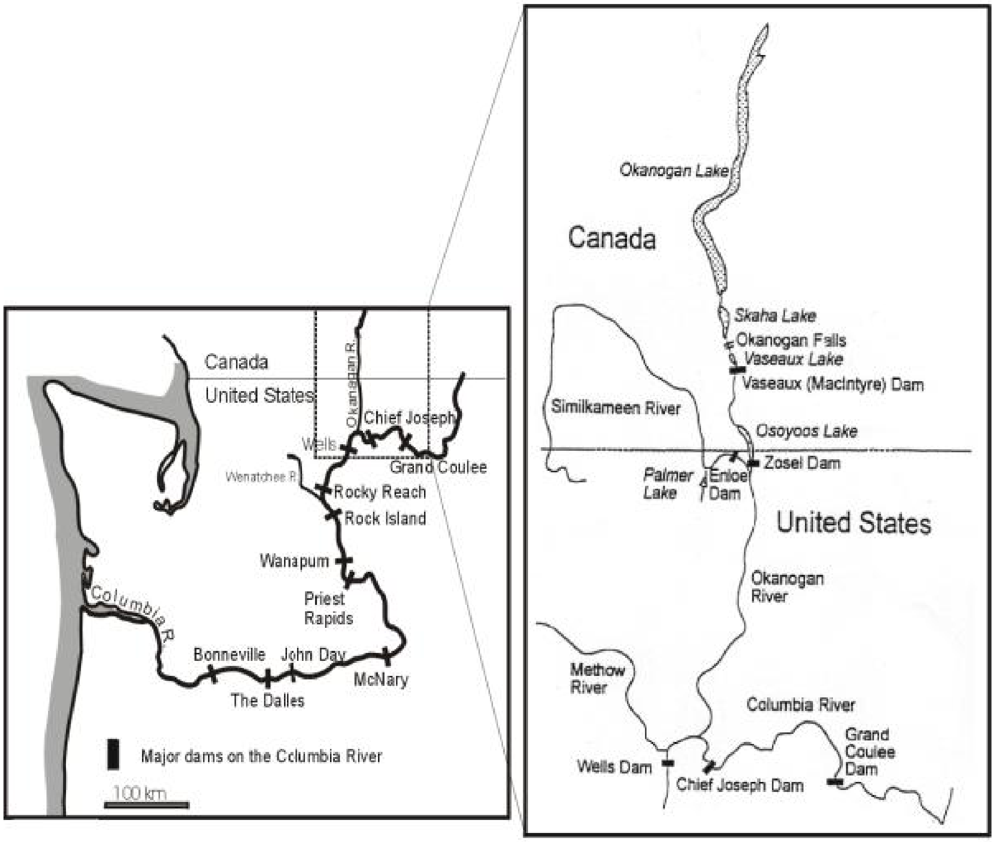

Figure A1. Overview of the location of the Okanagan Summer Chinook Population and related surrogate populations.

$$N_{y,a=2} = R_{y-1} \cdot D_{\text{juv}} \cdot \phi_{\text{ocean}} \tag{2}$$

where $N_{y,2}$ are the abundance of age two adults in the ocean. The abundance subsequent years up to the final age class (i.e., age 5) are determined by the abundance in the previous age, natural mortality, harvest rates and maturation. That is,

$$N_{y,a} = N_{y-1,a-1} \cdot (SU)_a \cdot (1 - \text{HR}_{\text{ocean}}) \cdot (1 - M_a) \;\; a \in \{3,4,5\}, \tag{3}$$

where $(SU)_a$ represents the survival from the previous age class to the current age class, HR_{ocean} is the ocean harvest rate and M_a is the probability of maturing and returning to spawn that year. Here $1 - M_a$ represents the probability of not maturing and remaining in the ocean. Therefore, the number of adults of a given age expected to return on a given year is determined as:

$$N_{y,a}^{\text{return}} = N_{y-1,a-1} \cdot (SU)_a \cdot (1 - \text{HR}_{\text{ocean}}) \cdot M_a \quad a \in \{3,4,5\}. \tag{4}$$

This is nearly identical to (3) except for the maturation term. It is assumed that the maturation rate is 100% for the terminal age class (i.e., age 5). Finally, the number of spawners (S_y) were the product of the number returning in each age class ($N_{y,a}^{\text{return}}$) after accounting for in-river fishers (HR_{river}) and inter-dam survival rates (D_{adult}):

$$S_y = \sum_{a=2}^{5} N_{y,a}^{\text{return}} \cdot (1 - \text{HR}_{\text{river}}) \cdot D_{\text{adult}}. \quad (5)$$

The population dynamic model did not consider straying from nearby population as the rate is not well documented and likely to be a relatively small contribution (e.g. Davis et al. 2007) given the current low spawner abundances and the size of the recovery target (i.e., 1,000 spawners; see Element 12).

Simulation Structure

Forward simulation was used to assess the population viability, with the simulator structure (Figure A2) based on combining equations (1) to (5). The population was projected from 2020 to 2065, with spawners in the first 5 years fixed to a seed value of 50 total spawners in the Okanagan (unpublished data collected by ONA and DFO, Rick McNicol, Chuck Parkin, Richard Bailey, and Howie Wright; COSEWIC 2006).

Both stochastic and deterministic parameters were utilized in the model. Many of the parameters are confounded, as such we chose to make only a few stochastic to illustrate the effect of uncertainty on the population growth rate. The first parameter we chose to make stochastic was the stock recruit relationship, which is influenced by process error (σ_ϵ). To avoid overemphasizing stochasticity, α and β values remained deterministic, but α was varied under productivity scenarios (Hilborn and Walters 1992, CTC 2002).

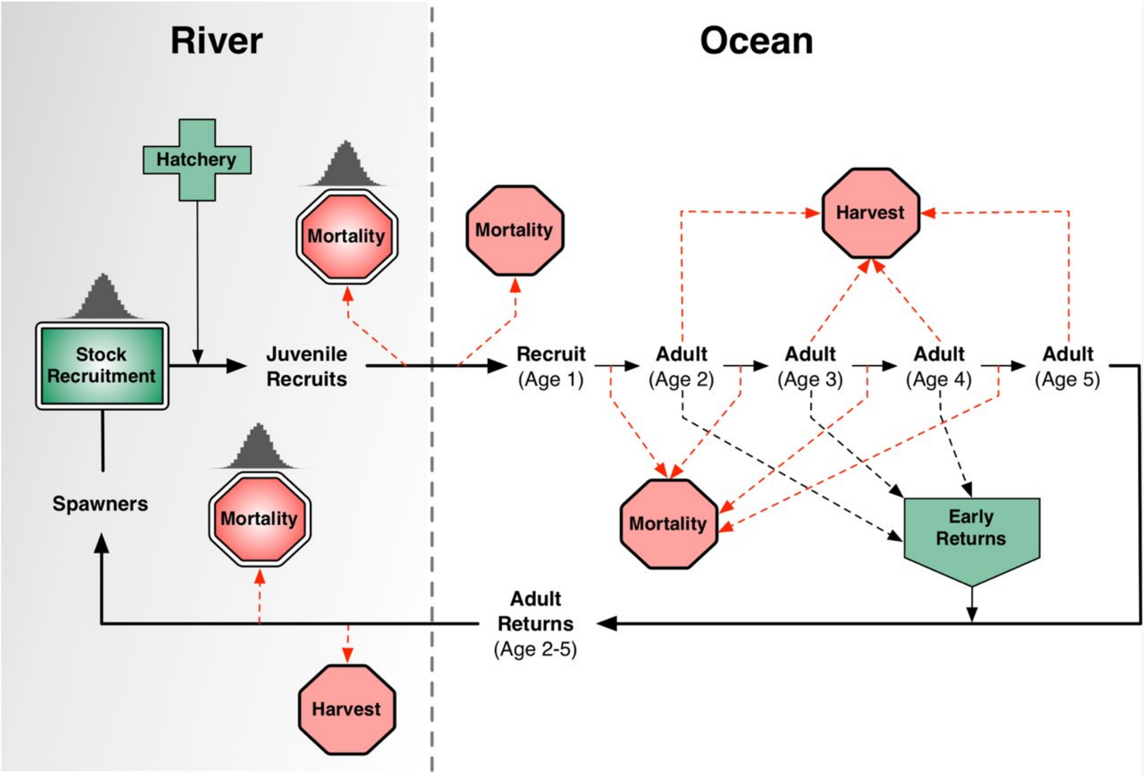

Figure A2. Diagram of the population simulator used to assess extinction risk of Okanagan summer Chinook Salmon spawning in Canada. Histogram icon indicates process that include stochastic parameters.

Other parameters such as D_juv and ϕ_ocean were confounded, so we elected to utilize the parameter which was accompanied by better data. We wished to assess differing ocean survival regimes (ϕ_ocean), and therefore we generally kept that parameter fixed. Finally, it has been demonstrated the population growth rate is most sensitive to changes in early life-cycle mortality (Kereiva et. al. 2000), so we kept survival in later ages as well as maturation rates deterministic, as most of the variability in salmon survival occurs in the year at ocean entry (Peterson and Schwing 2003, Lawson et.al. 2004, Logerwell et. al. 2004, Mueter et. al. 2002).

The analysis assessed probability of reaching a recovery target of 1,000 spawners within a given time frame was assess based on a 4-year geometric mean that was centered on a given year. The geometric mean was used instead of the arithmetic mean so that neither large nor small returns over influenced the averages and is recommended for Pacific Salmon species with log-normally distributed abundance data (Grant et al. 2011). A four-year time span was chosen to reflect the fact the majority of the returns will have occur by age 4 (Table A1). The probability of reaching the recovery target (i.e., at least one 4-year geometric mean at or above 1,000 spawners) was assessed over two time periods, 12 years (i.e., 3 generations) and 30 years. Population trajectories over these time periods were also assessed based on fitting log-linear trends to a 4-year geometric mean of total adult abundance.

Table A1. Stochastic or deterministic Parameters used in simulation; L corresponds to low sensitivity, and H to high sensitivity.

Component	Parameters	Structure	Impact	Value
Stock-recruitment	α	Deterministic	L	136
	β	Deterministic	L	2400
	σ_ϵ	Stochastic	H	0.53
Early Juvenile survival (i.e., out migration)	D_juv	Deterministic	H	0.35
	$\sigma_{D_{juv}}$	Stochastic	H	0.09
	ϕ_ocean	Deterministic	H	0.025
Ocean Survival and Maturation	$(SU)_2$	Deterministic	L	60%
	$(SU)_3$	Deterministic	L	70%
	$(SU)_4$	Deterministic	L	80%
	$(SU)_5$	Deterministic	L	90%
	HR_ocean	Deterministic	L	28%
Returns, escapement and in-river harvest	M_2	Deterministic	L	4%
	M_3	Deterministic	L	26%
	M_4	Deterministic	L	72%
	M_5	Deterministic	L	100%
	HR_river	Deterministic	L	18%
	D_adult	Deterministic	H	94%
	σ_{D_adult}	Stochastic	H	0.15

In addition to the recovery target and population trajectories, four measures of population stability were also assessed: minimum and average number of spawners along with the minimum adult population size and the adult population size in 2050. All could be considered important to population persistence and overall extinction risk (Connell and Sousa 1983, Grimm and Wissel 1997).

All metrics were assessed after running the simulator for 6 years in order to ensure results were stochastic and that only stochastic results were used when computing the 4-year geometric mean.

The analyses employed 10,000 forward simulations to visualize variance in primary recovery target as well population stability metrics. Multiple simulations were run to assess a variety of potential scenarios, which included:

1. baseline conditions, as described by the parameter values in Table A1;
2. habitat restoration measures;
3. cessation of fishing mortality and or natural increases in productivity;
4. hatchery supplementation; and
5. combinations of the preceding scenarios.

Habitat restoration measures are still in the early phase so biological effect sizes were not known, but it was assumed habitat measures would positively affect juvenile survival. Place holder effects of 10%, 30%, and 50% reduction in juvenile mortality were used to investigate the potential effects of habitat restoration. Given that the spawner-recruit function was used to predict the number of smolts available for out migration (prior to dam passage) the place holder mortality reductions were used to adjust the number of outmigration smolts. Given the preliminary nature of habitat restoration measures it was also not know what portion of early lifecycle will be affected, therefore we assumed mortality rates would be comparable to dam mortality experienced during out migration (i.e., 65% mortality or 35% survival rates; Table A1). Therefore the 10%, 30%, and 50% reduction in juvenile mortality corresponds to juvenile mortality rates of 58.5%, 45.5%, and 32.5% respectively, or 1.2x, 1.6x and 1.9x increase in the number of smolts entering the Upper Columbia River.

Finally, the IPCC has adopted certainty categories which are helpful to discuss results in more descriptive and understandable language. This language will be used to discuss results in this report (Mastrandrea et al. 2010).

RESULTS

Parameter Estimation

Stock-recruit Parameters

Stochasticity was modeled as a function of process error in the stock recruitment relationship that was estimated from juvenile and adult data in US waters (Yuen 2006) upstream of Rock Island (Figure A1). Data used to estimate the process error and fit are shown based on Yuen (2006) data (Figure A3).

Based on the fit and using the closed form solution of the lognormal error structure (Hilborn and Mangel 1997) we estimated process error (σ_{ϵ}=0.53, Table A1) that was used in our simulations (Figure A2). Juvenile density independent recruitment (α) was also based on these data and yielded an estimate of 136 smolts per spawner (Figure A4). Ricker (β) values were obtained from the Parken et al. (2004[4]) approach to estimate overall equilibrium population size, which was set to 2400.

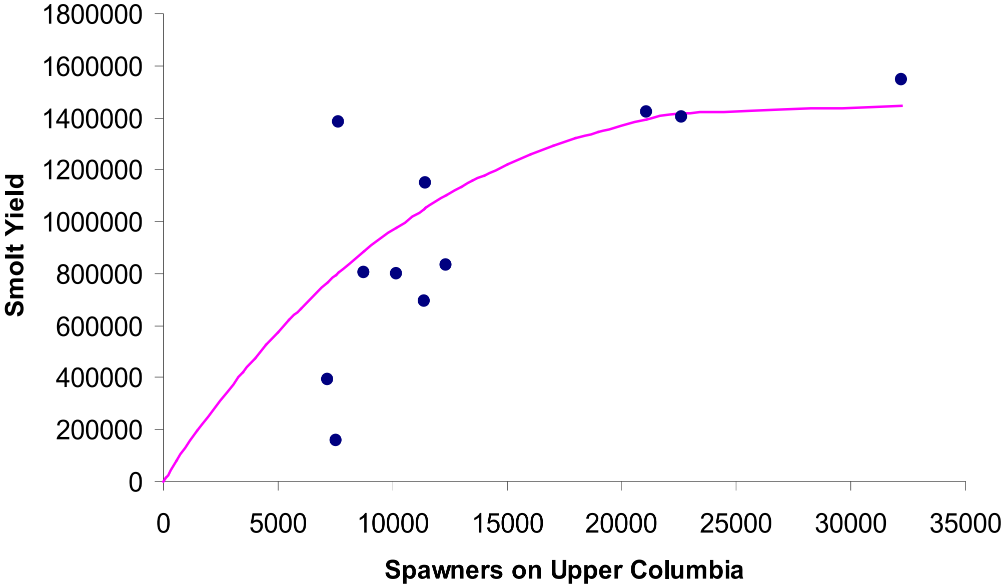

Figure A3. Smolt yield and spawner count estimated for upper Columbia summer Chinook Salmon from Yuen (2006).

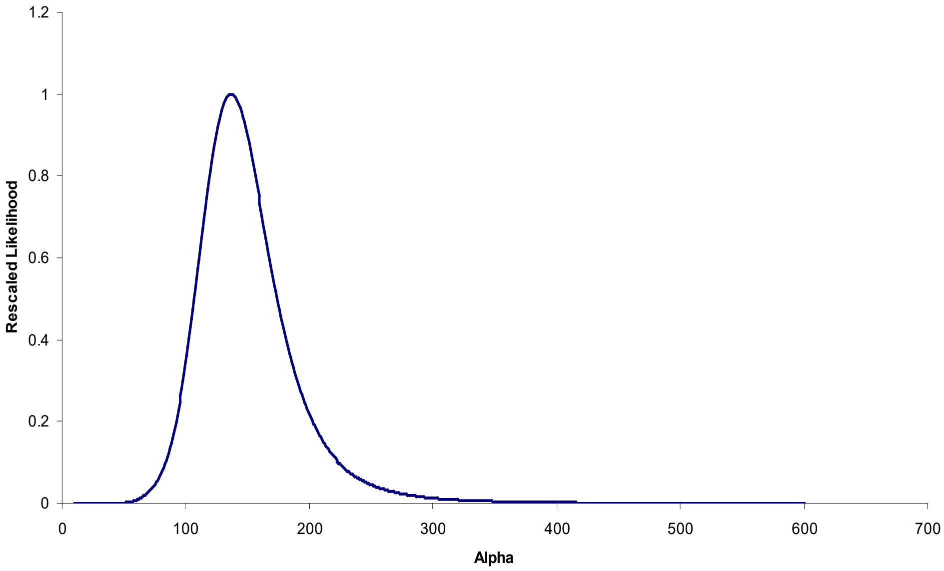

Figure A4. Uncertainty in α based on a model fit from the data shown in Figure A3.

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[4] Parken, C., R.E. McNicol, and J.R. Irvine. 2004. Habitat based methods to estimate escapement goals for Chinook Salmon stocks in British Columbia. PSARC Working Paper, British Columbia, Canada.

Dam Mortality Parameters

Stochasticity associated with juvenile (D_{juv}) and adult dam (D_{adult}) mortality. Parameters for juvenile mortality were obtained from Passive Integrated Transponder (PIT) Tag data obtained from the Fish Passage Center

Methods to estimate survival are a function of release to first detection site, and between the series of dams, by the Cormack-Jolly-Seber (CJS) release-recapture method outlined in Burnham et al. 1987[5]. Multiple survival events with their associated variance were estimated to McNary Dam (Figure A1) by assuming independent survival across dams and sites, which is plausible given that the migration times don't overlap (Table A2, Figure A5).

Adult survival data were obtained from the TC-Chinook Model (CTC 2016) that uses inter-dam loss values obtained from the Technical Advisory Committee, the technical team that conducts stock assessment activities in the Columbia River under the jurisdiction of the *United States Vs Oregon* court case (Lee 1993). Overall, adult inter-dam survival has been increasing linearly over time on the logit scale (Figure A6). The estimated trend was extrapolated for the simulation period to predict the yearly survival rates, with variation based on prediction error. Figure A5 contains an example distribution of adult survival values (mean 0.94) used in the simulation. A logit transformation was used to ensure adult survivals were constrained to a maximum survival of one (i.e., 100% survival rate) which changes the shape of the distribution near the boundary (Figure A5 right most panel).

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[5] This methodology is used to estimate survivals both to and between the dams in the hydro system possessing PIT tag detection capabilities, along with an estimate of collection efficiency at these dams. The CJS method is based on mark release-recapture theory in which the subsequent detection histories on a known number of marked fish re-released at a particular dam is used to estimate the number of fish that past that particular dam alive but undetected. The software program MARK (White and Burnham 1999) was used to perform the survival estimates with the "identity "design matrix and "identity" link function set. The program MARK provides estimates of survival between the tailraces of each detection site. Generating extended multi-dam reach survival estimates requires taking the product of a set of these shorter reach estimates. The associated variance for the extended reach estimate is computed using formulas for propagation of error in products of non-independent estimates (Meyer 1975). Extended reach survival estimates with associated 95% confidence intervals are obtained for each species, and release location and period of interest.

Table A2. Juvenile downstream survival ($\boldsymbol{D}_{juv}$) based on PIT tag data from Rock Island Dam to McNary Dam (Sheer 2018).

Brood Year	Out Migration	Survival to MCN ($\boldsymbol{D}_{\mathbf{juv}}$)	Survival to Age 2	Early Ocean Survival ($\boldsymbol{\phi}_{\mathbf{ocean}}$)
1996	1997	0.250	0.011	0.043
1997	1998	0.290	0.043	0.147
1998	1999	0.370	0.045	0.122
1999	2000	0.210	0.011	0.055
2000	2001	0.210	0.037	0.176
2001	2002	0.450	0.022	0.049
2002	2003	0.460	0.018	0.04
2003	2004	0.250	0.010	0.041
2004	2005	0.340	0.019	0.057
2005	2006	0.380	0.018	0.047
2006	2007	0.260	0.035	0.134
2007	2008	0.370	0.011	0.03
2008	2009	0.280	0.023	0.08
2009	2010	0.320	0.026	0.083
2010	2011	0.530	0.012	0.022
2011	2012	0.250	0.054	0.221
	Average	0.326	0.025	0.08
	SD	0.095	0.014	0.06

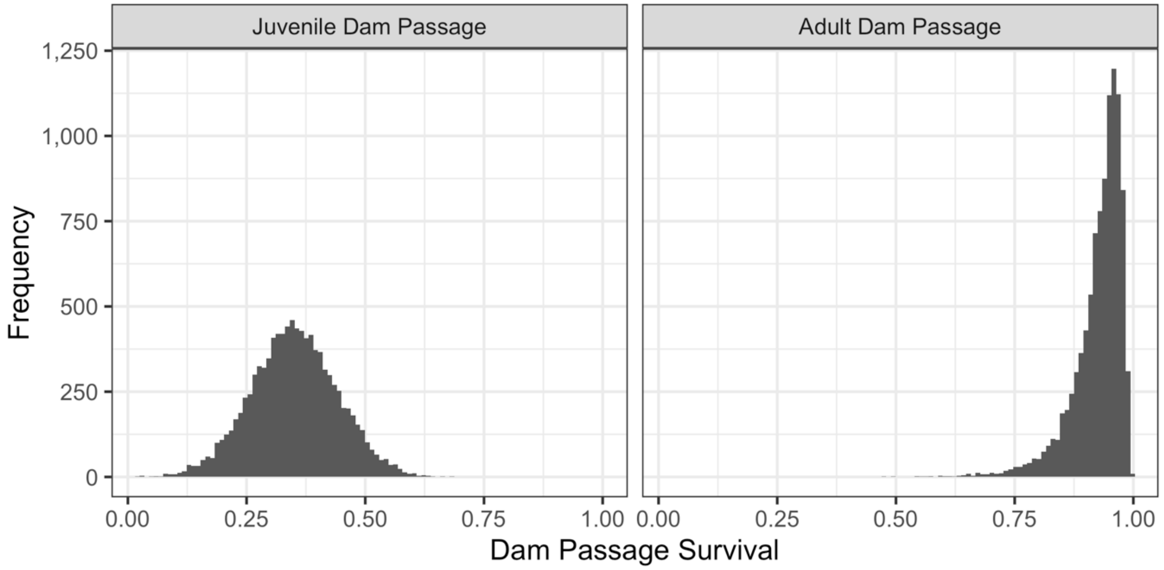

Figure A5. Downstream survival (Juvenile Dam Passage) from Rock Island Dam to McNary Dam and upstream (Adult Dam Passage) from McNary Dam to Rock Island Dam used in simulations.

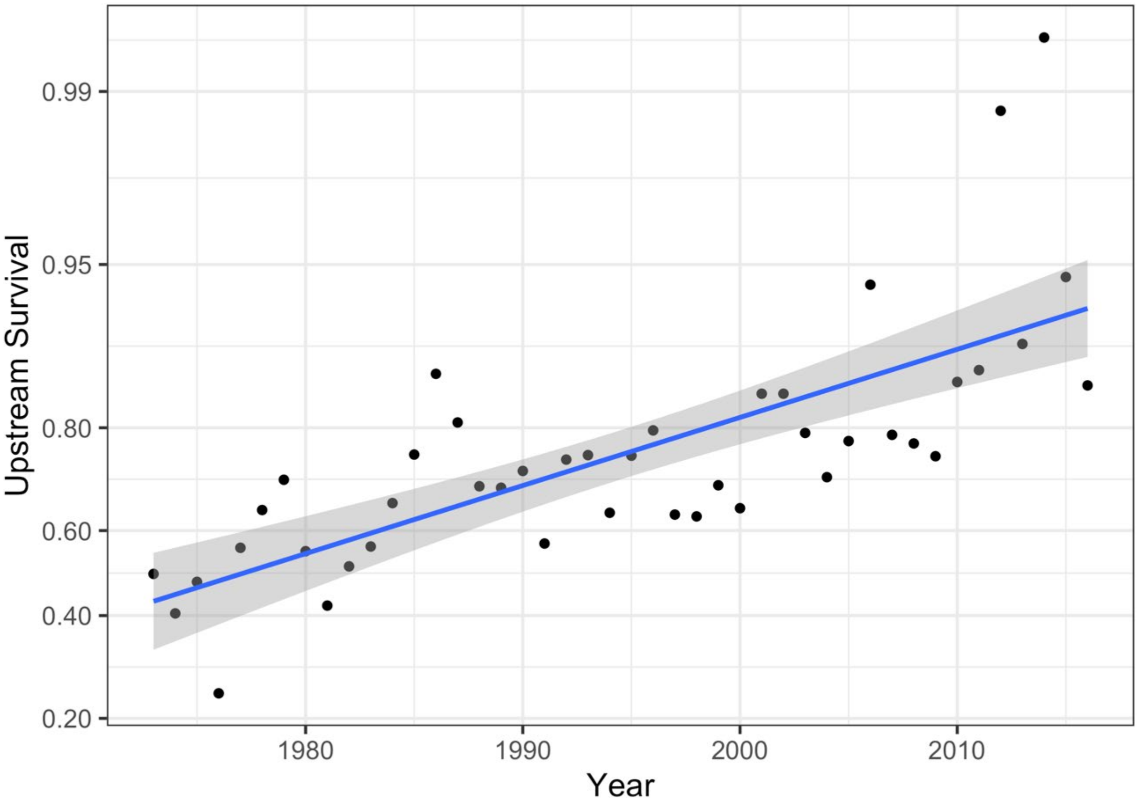

Figure A6. Yearly estimates of adult inter-dam survival rates from McNary Dam to Rock Island Dam, with logit-linear trend. Shading indicates 95% confidence interval.

Deterministic Parameters

Early Ocean Survival

Based on CWT data used by the Chinook Technical Committee (CTC) in the Exploitation Rate analysis we can estimate the survival to the ocean for fish tagged from the Wells and Similkameen Hatchery (CTC 2016). However, based on PIT Tag data, we can also estimate survival to Bonneville dam (Table A2). Using those data, early ocean survival was estimated as the average ratio between survival from release to age 2 based on CWT data, and dam passage survival:

$$\hat{\phi}_{\text{ocean}} = \sum_{y=1}^{Y} \frac{\widehat{CWTOC}_y}{\widehat{D}_{\text{juv},y}} \Big/ Y. \tag{6}$$

where $\widehat{CWTOC}_y$ represents the yearly survival to the ocean estimated from CWT data, $\widehat{D}_{\text{juv},y}$ represents the yearly dam passage survival, and Y represents the total number of years available.

Harvest Rates

Harvest rates were determined from CWT data as well (CTC 2016) and were averaged for the last 10 years (2001-2011) for ocean and freshwater fisheries; yielding HR_{ocean}= 28% and HR_{river} = 44% respectively (Table A3).

Table A3. Ocean and Terminal harvest rates based on CWT recoveries for Summer Chinook (from CTC-AWG [Analytical Working Group]).

Brood Year	OCN HR Reported	OCN HR Total Morts	TERM HR Reported	TERM HR Total Morts	TOTAL HR Reported	TOTAL HR Total Morts
1975	58%	68%	0%	0%	58%	68%
1976	49%	56%	6%	6%	52%	59%
1977	49%	57%	5%	5%	51%	59%
1983	44%	52%	28%	28%	58%	65%
1984	37%	44%	18%	18%	47%	55%
1985	39%	47%	27%	28%	54%	62%
1986	47%	56%	6%	6%	49%	59%
1987	30%	35%	9%	9%	36%	41%
1988	44%	54%	6%	6%	46%	57%
1989	35%	43%	15%	15%	44%	52%
1990	24%	29%	0%	0%	24%	29%
1991	65%	73%	0%	0%	65%	73%
1992	15%	19%	1%	2%	16%	21%
1993	14%	17%	2%	2%	15%	19%
1994	16%	21%	0%	0%	16%	21%
1995	30%	35%	6%	6%	34%	39%
1996	35%	41%	2%	2%	36%	42%
1997	56%	64%	11%	11%	60%	68%
1998	65%	74%	23%	24%	71%	80%
1999	54%	62%	48%	50%	72%	81%
2000	40%	46%	35%	36%	59%	65%
2001	37%	42%	34%	35%	57%	62%
2002	30%	34%	41%	42%	57%	62%
2003	30%	36%	42%	44%	57%	64%
2004	20%	25%	36%	36%	47%	52%
2005	25%	30%	40%	40%	53%	58%
2006	23%	26%	41%	42%	53%	57%
2007	28%	34%	52%	53%	63%	69%
2008	34%	40%	49%	50%	63%	70%
2009	28%	32%	51%	52%	62%	67%
2010	24%	28%	44%	45%	56%	60%
2011	30%	35%	51%	52%	64%	69%
Avg (01-11)	28%	33%	44%	44%	57%	63%
Avg (91-00)	39%	45%	13%	13%	44%	51%
Entire Avg	36%	42%	23%	23%	50%	56%

Maturation and Survival

Maturation and survival rates were based on estimates obtained over all Chinook used in the exploitation rate analysis and model calibration by the CTC (CTC 2005) and are shown in Table A1.

Simulation Results

The likelihood of reaching the recovery target over 12 years (i.e., 3 generations) and 30 years was assessed in addition to population trajectories under a variety of scenarios after running the simulation for an initialization period of 6 years (Table 12). Under the current conditions it is very unlikely that recovery target will be reached under either time interval. The population is also predicted to decline over both time intervals. Without straying from nearby Upper Columbia populations, which was not considered in the PVA, the population was predicted to have very few spawners (Figure A7a) and to undergo a collapse by 2050 (Figure A8a). This indicates that if the population persists without intervention it will likely be the result of straying from the nearby Upper Columbia populations and that management actions will be required to reach the recovery target.

A number of different management actions were considered including freshwater habitat improvements, supplementation programs and as well as additional scenarios that looked at other management options including combining approaches. Due to lack of information about juvenile freshwater habitat improvements, the effect was investigated by using place holder effects sizes from 10% to 50% reduction in juvenile mortality. None of these place-holder effects resulted notable gains in the number of spawners (Figure A7a) with adult population projections showing a similar pattern of collapse (Figure A8a). None of these scenarios were able to meet recovery target on the short-term or long-term (Table 12).

Hatchery supplementation programs of differing sizes ranging from 50,000 smolts per year to 500,000 smolts per year (Figure A7b and Figure A8b). Smolts were assumed to have the same fitness as wild stock smolts. Only the larger supplementation programs (e.g., 250,000 and 500,000 full fitness smolts per year) appeared to meet the recovery target in the short-term or with a high likelihood in the long-term (Table 12). The intermediate supplementation program (i.e., 150,000 full fitness smolts per year) was unlikely meet the recovery target on the short-term but was likely to meet the recovery target on the long-term. This indicates intermediate supplementation program could be feasible if it was combined with other management measures.

Combinations of management scenarios were considered (Figure A7c and Figure A8c) along with a cessation of fishing and improvements in natural productivity. Combining a medium sized supplementation program with a habitat improvement measures (i.e., “Hatchery 150K + 30% Mort Reduction”) or a cessation of fishery mortality (i.e., “Hatchery 150K + No Harvest”) resulted in comparable number of spawners (Figure A7c) and number of adults (Figure A8c) as a larger hatchery program (e.g., “250K Hatchery”) and both were very likely to reach the recovery target (Table 12). Improvements in productivity (i.e., a doubling of natural productivity) were very unlikely to meet the recovery target over either the short- or long-term (i.e., “Productivity 2x; Table 12). A complete cessation of fishery harvest (i.e., “No Harvest ”; Figure A7c and Figure A8c) may not result in reaching the recovery target in the short-term, but was very likely to meeting the recovery target in the long-term (Table 12). Finally, combining habitat measures with a complete cessation of fishery mortality (i.e., “No Harvest + 30% Mort Reduction”) is predicted to meet the recovery goal within the short-term time horizon (Table 12), but minimum population size was predicted quite small (i.e., Figure A8c) which could elevate the risk of extinction if straying is not available to rescue the population.

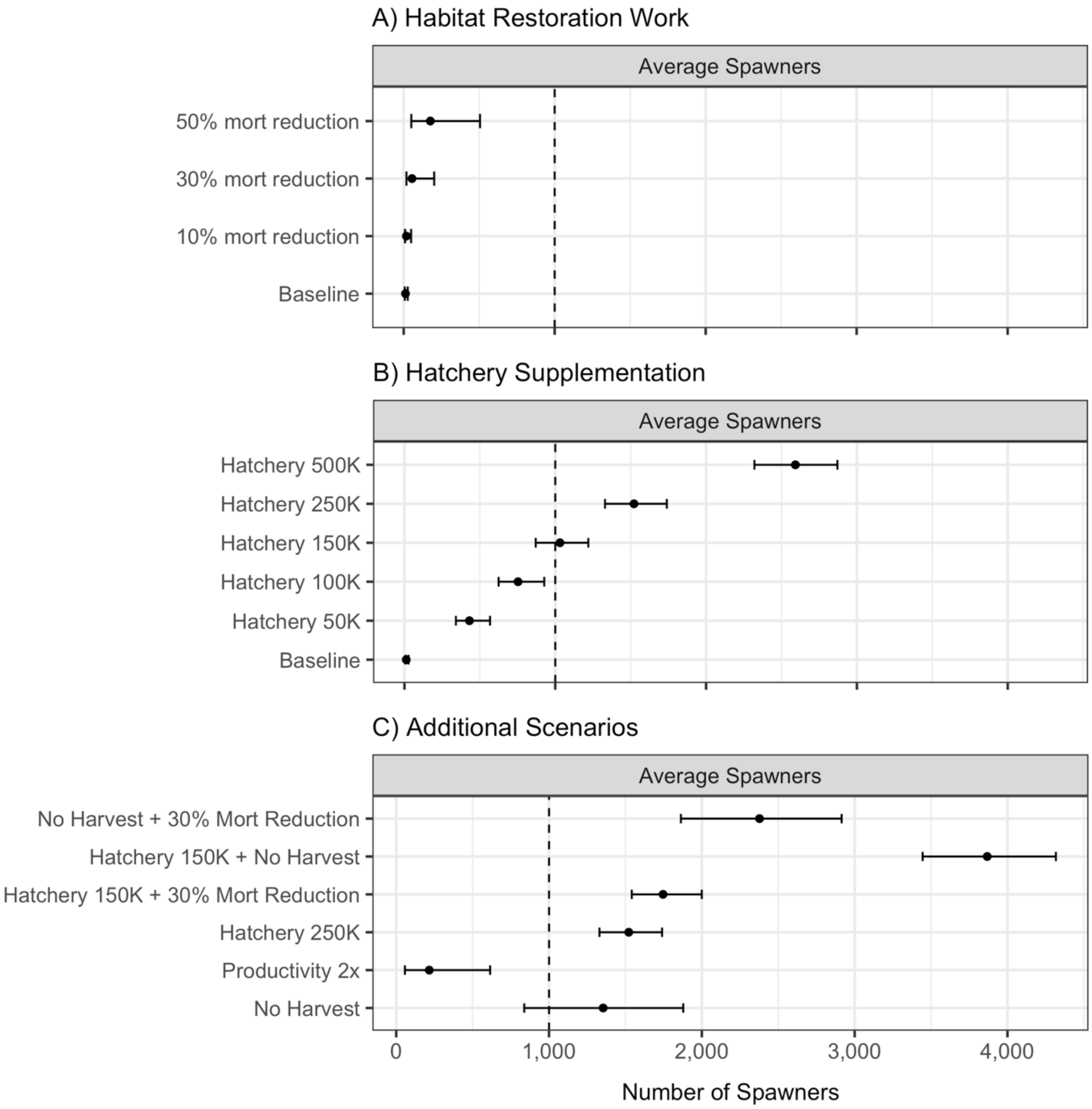

Figure A7. Average number of spawners (right panel) predicted by the PVA under scenarios of A) habitat restoration, B) hatchery supplementation, and C) additional scenario combinations. Vertical dashed lines indicate the recovery target of 1,000 spawners, the closed circle indicate the 50th percentile, while error bars indicate the 1st and 99th percentiles from the simulated population projections.

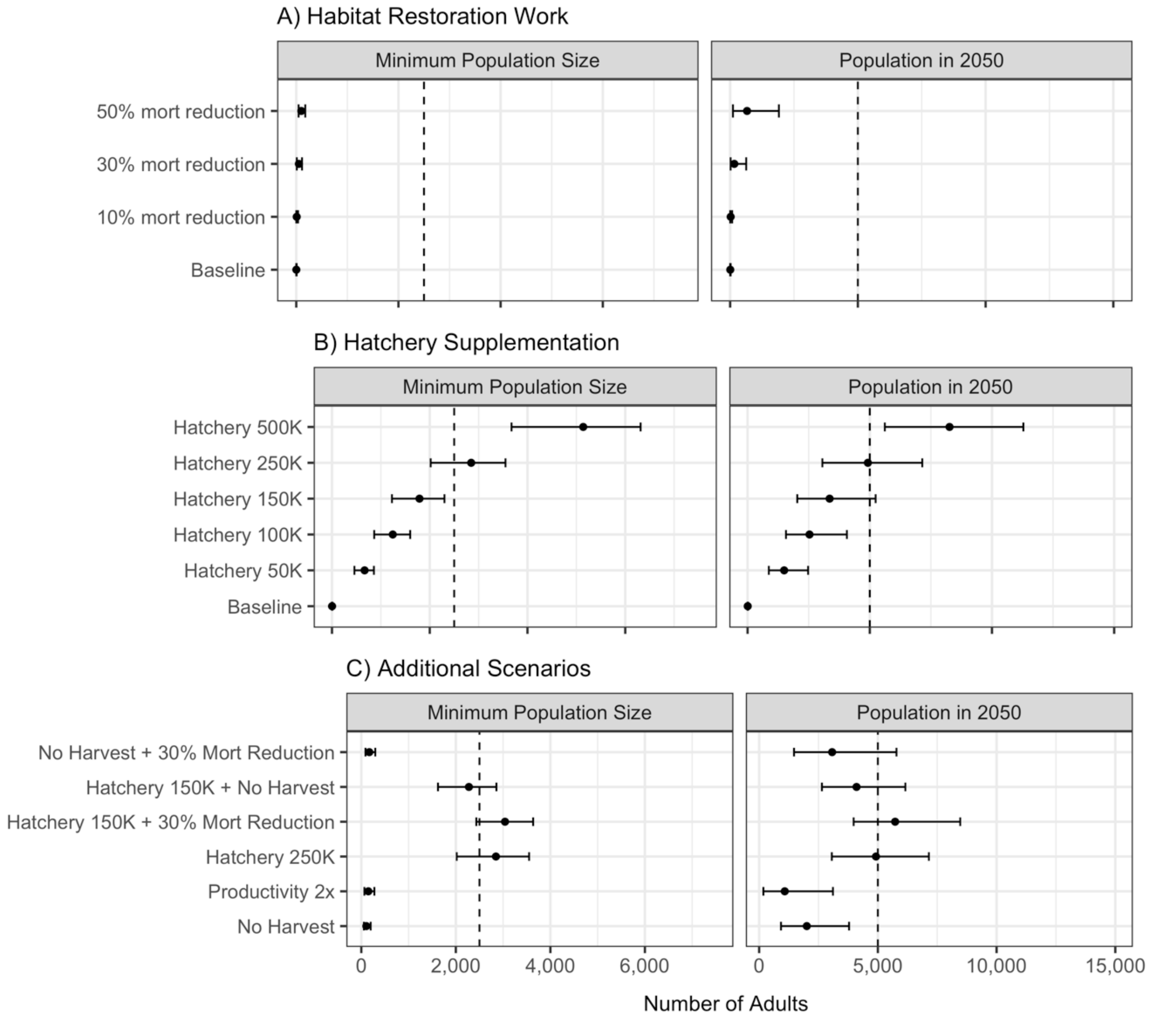

Figure A8. Adult population predicted by the PVA under scenarios of A) habitat restoration, B) hatchery supplementation, and C) combinations of differing scenarios. Closed circles indicate the 50th percentile, while error bars indicate the 1st and 99th percentiles from the population projections.

DISCUSSION

The forward simulations demonstrated that under current conditions there is unlikely that summer Chinook Salmon in the Canadian range of the Okanagan will meet the recovery target. Based on these analyses, natural increases in productivity are very unlikely to result in the recovery target being reached and even a cessation of fishing is incapable of meeting the recovery target within the short-term (i.e., 3 generations), without other actions such as a hatchery supplementation program or extensive measures taken to improve juvenile freshwater habitat. While cessation of fishing could meet recovery target in the long-term (i.e., 30 years) this scenario was still marked by low adult abundance in some years and thus represents a higher risk of extinction than other scenarios if straying from nearby populations is not available. If these types of management actions are not feasible, then a large hatchery supplementation program (i.e., 250,000 full fitness smolts per year or larger) will be required to ensure recovery goals are met. If hatchery smolts are anticipated to have lower fitness than wild-stock smolts, then the final number of smolts released will need to be adjusted to compensate for any hatchery related fitness differentials.

These results are similar to those that Schaller et. al. (1999), Petrosky et. al. (2001) and Yuen and Sharma (2005) concluded with Snake River Chinook Salmon and Steelhead populations. This is not surprising given that the upper Okanagan is similarly impacted by dam passage obstacles; requiring juveniles and adults to navigate nine dams to reach the Okanagan versus eight for Snake River populations. Even if juvenile survival through each of the hydro-power facilities was 90%, the overall survival to Bonneville Dam (the lowermost Columbia River dam) suffers from the cumulative impact of nine dams and would result in a survival rate of only 39% overall. This is roughly what we obtained in our analysis, with survival rates of 33% from Rock Island Dam to McNary Dam, based on PIT tag data (Table A2). The observed survival rate of 33% actually translates to an individual survival rate of 88% for each of the nine dams.

Early ocean survival also represented significant mortality, but the values used within this study included some of the best ocean survival values observed in the recent past (e.g., the 1998 brood exhibited a four-fold increase over the last decade, but the 1999 brood was about half of the 1998 brood survival based on Coded Wire Tags). It is unlikely that this component will show future improves so additional scenarios considering improvements in early ocean survival were not considered.

Given that it is unlikely that juvenile passage through the hydro-power system will improve, and that ocean fisheries will decline (prior to 2002, summer Chinook in-river fisheries were non-existent), it appears likely that the natural population will not meet the recovery target without aggressive management intervention. One alternative, modeled here, is the use of hatchery production, which was considered in isolation as well as in combination with other management actions. However, achieving natural escapement goals would require hatchery production on the order of 250,000 full fitness smolts annually; far in excess of what could be supported by the collection and use of natural origin adults in broodstock. Thus, to implement a supplementation program (i.e., based on natural-origin local broodstock) would require centuries of effort under baseline conditions. Without straying from nearby populations, a program of this type would be accompanied by substantial risks associated with the extinction of the natural population (e.g., the time required to achieve production goals might exceed the estimated time to extinction for the population) and could also be compromised in the long-term by the potential presence of inbreeding or loss of genetic diversity that may have occurred as a result of bottlenecks within the natural population. Alternatively, adults from the US portion of the Okanogon River could be used as broodstock. This would reduce the period required to achieve production goals but could compromise the potentially unique genetic composition observed for the summer Chinook Salmon residing in the Canadian portion of the Okanagan River (COSEWIC 2006).

Either type of hatchery program will also be accompanied by uncertainty regarding the long-term impacts of hatchery production on the productivity of natural populations (e.g., as summarized in ISRP 2005). Nonetheless, it has been demonstrated that hatchery production can yield a significant survival advantage in the early life-cycle relative to natural production and that this survival advantage can translate into a significant increase in adult abundance (Rinne et al. 1986 and Johnson and Jensen 1991). Likewise, for imperiled populations, hatcheries can serve as a vehicle to maintain or increase genetic variation (Hedrick et al. 1994) and potentially contribute to life-history diversity (Franklin 1980) that might be lost in the absence of intervention.

LIMITATIONS

Given the paucity of data relevant to the stock of interest, our analysis relied on parameters derived from a neighboring US summer Chinook Salmon population. Despite the fact that the US population offers the nearest approximation for which certain parameters can be derived, it still assumes that these values are representative of Canadian Okanagan summer Chinook

Salmon; which may be an erroneous assumption. In addition, Yuen (2006) notes that some of the juvenile data used required expansion factors that might have positively biased the study's results. Thus, the derived estimates of productivity used in this report may also be positively biased. Regardless, even if the productivity estimate used in this report (136 smolts per spawner) is positively biased, our analysis suggests that the population is very unlikely to reach the recovery target, even if this parameter was doubled. As such, if realized productivity is lower, the overall conclusions are unlikely to change. The same is true for ocean survival. It is unlikely that ocean survival will improve relative to conditions experienced in the 1990's and early 2000 (Peterson and Schwing 2003), which were a function of good ocean conditions and northern euphausid abundance in waters off the mouth of the Columbia in those years.

In addition, in-river data on US Okanagan stocks indicate that the fish might mature at later ages (primarily age 5 and 6) and using average maturation rates across all indicator tag Chinook used by the Chinook Technical Committee (as done herein) might provide a more optimistic result. If a later maturation schedule was used, the overall spawners returning would probably be lower than currently modeled as the fish would face another year of natural and fishing mortality in the ocean before returning to face the same inter-dam and in-river fishing mortality sources. This would decrease the overall likelihood of reaching the recovery target.

Finally, straying rates from nearby populations were not directly considered in the model. Given the persistent low spawning abundances in the years preceding the analyses, it is unlikely that straying will contribute significantly to the achievement of the recovery target.

OVERALL CONCLUSION

We employed a parameter estimation and sensitivity analysis, using stochastic and deterministic elements to evaluate population trajectories under baseline conditions and explored the potential impacts of multiple management alternatives. It is unlikely that recovery targets can be achieved without a hatchery supplementation program as even a complete cessation of fishing combined was unlikely to meet recovery targets in the short-term. Given the uncertainty around being able to dramatically improve juvenile and adult survival through the hydro-power system, it appears that hatchery production will be critical to achieving the recovery target. The magnitude of production required to meet escapement goals would be large (approximately 250,000 full fitness smolts annually) and would be accompanied by its own array of risks not assessed within this study. Combining smaller hatchery programs (e.g., 150,000 full fitness smolts annually) with other management actions (e.g., habitat restoration) was another viable option, which could be preferable if managers wish to distribute risk across multiple initiatives.

APPENDIX A REFERENCES

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5.

Connell, J.H., and W.P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. American Naturalist 121(6):789-823.

COSEWIC. 2006. Assessment and Status Report on the Chinook Salmon (*Oncorhynchus tshawytscha*) Okanagan population in Canada.

CTC. 2002. Relating risk of management error to lower bounds for additional management actions. Report TCCHINOOK (2002)-2. Vancouver, BC.

CTC. 2005. Joint Chinook Technical Committee Report - Annual exploitation rate analysis and model calibration. Report TCCHINOOK (05)-3. Vancouver, BC.

CTC. 2016. Pacific Salmon Commission Joint Chinook Technical Committee annual report of catch and escapement for 2015. Report TCCHINOOK (16)-3. Vancouver, BC.

Davis, C., H. Wright, T. Brown, B. Phillips, R. Sharma, and C. Parken. 2007. Scientific information in support of recovery potential analysis for Chinook Salmon Okanagan population, *Oncorhynchus tshawytscha*. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/065. ix + 88.

Ellner, S. P. and J. Fieberg. 2003. Using PVA for management despite uncertainty: effects of habitat, hatcheries, and harvest on salmon. Ecology 84:1359-1369.

Emlen, J.M. 1995. Population viability of the Snake River Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 52: 1442-1448.

Fieberg J., and S.P. Ellner. 2000. When is it meaningful to estimate an extinction probability? Ecology 81: 2040-2047.

Franklin, I. R. 1980. Evolutionary change in small populations. Pages 135-149 *in* M. E. Soule and B. A. Wilcox, editors. Conservation biology: An evolutionary-ecological perspective. Sinauer Assoc., Sunderland, MA.

Grant, S. C. H., B. L. MacDonald, T. E. Cone, C. A. Holt, A. Cass, E. J. Porszt, J. M. B. Hume, and L. Pon. 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.

Grimm, V. and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. Oecologia 109: 323-334.

Hedrick, P.W., D. Hedgecock, and S. Hamelberg. 1994. Effective population size in winter-run Chinook Salmon. Conservation Biology 9: 615-624.

Hilborn, R and C. Walters 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, Inc.

Hilborn, R and M. Mangel. 1997. The Ecological Detective. Princeton University Press.

ISRP (Independent Scientific Review Panel). 2005. Monitoring and evaluation of supplementation projects. Northwest Power and Conservation Council.

Johnson, J.E. and B.L. Jensen. 1991. Hatcheries for endangered freshwater fish. *In* W. L. Minckley and J. E. Deacon (eds), Battle against extinction, p. 199-217. University of Arizona Press, Tucson.

Lawson, P.W., E.A. Logerwell, N.J. Mantua, R.C. Francis, and V.N. Agostini. 2004. Environmental factors influencing freshwater survival and smolt production in Pacific Northwest Coho Salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 61: 360-373.

Lee, K. 1993. Compass and Gyroscope: Integrating science and politics for the environment. Island Press.

Logerwell, E.A., N. Mantua, P.W. Lawson, R.C. Francis, and V.N. Agostini. 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon Coho (*Oncorhynchus kisutch*) marine survival. Fisheries Oceanography 12: 554-568.

Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L.Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.K. Plattner, G.W. Yohe, and F.W. Zwier. 2010. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. Intergovernmental Panel on Climate Change (IPCC).

Mueter, F., D. Ware, and R. Peterman. 2002. Spatial correlation patterns in coastal environmental variables and survival rates of salmon in the northeast Pacific Ocean. Fisheries Oceanography 11: 205-218.

Peterson, W.T. and F.B. Schwing. 2003. A new climate regime in northeast Pacific ecosystems. Geophysical Research Letters 30: 1896.

Petrosky, C. H. Schaller, and P. Budy. 2001. Productivity and survival rate trends in the freshwater spawning and rearing stage of Snake River Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 58: 1196-1207.

Ricker, W.E.1975. Computation and Interpretation of Biological Statistics of Fish populations. Fisheries research Board of Canada, Bulletin No. 191.

Rinne, J.N., J.E. Johnson, B.L. Jensen, A.W. Ruger, and R. Sorenson. 1986. The role of hatcheries in the management and recovery of threatened and endangered fishes. pp. 271-285 *in* Stroud, R.H (ed.). Fish Culture in Fisheries Management. American Fisheries Society, Bethesda, MD.

Schaller, H. C. Petrosky. and O. Langness. 1999. Contrasting patterns of productivity and survival rates for stream type Chinook Salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia rivers. Canadian Journal of Fisheries and Aquatic Sciences 56: 1031-1045.

Scheer, G. 2018. Memorandum re: 2017 Wells Hatchery Report. Accessed October 2019.

Yuen, H. 2006. Alternative method of estimating Mid-Columbia Summer Chinook Escapement Goal using adult to smolt recruitment rates. Letter of Agreement Funding Report, NOAA, Seattle, WA.

Yuen, H. and Sharma, R. 2005. Using simulation techniques to estimate management parameters on Snake River steelhead: Declines in productivity make rebuilding difficult. North American Journal of Fisheries Management 25: 446-463.