REVIEW OF POTENTIAL IMPACTS ASSOCIATED WITH RECENT AND PROPOSED OKANAGAN SOCKEYE SALMON FRY INTRODUCTIONS TO SKAHA AND OKANAGAN LAKES

Context

The Columbia River Basin supports a Sockeye Salmon (*Oncorhynchus nerka*) aggregate that is composed of three Sockeye Salmon populations including: the Okanagan population from British Columbia (BC), Canada, the Wenatchee Lake population from Washington State, and a small population from Redfish Lake in Idaho that is listed under the United States Endangered Species Act (ESA). On average, the Okanagan population has accounted for greater than 80% of all Sockeye Salmon returning to the Columbia Basin in the most recent decade.

Anadromous Sockeye Salmon and freshwater-resident kokanee are two ecotypes within *Oncorhynchus nerka* that occur frequently as sympatric paired populations sharing a common nursery (juvenile-rearing) lake. The closely related ecotypic pairs typically develop naturally, with the presence of Sockeye Salmon believed to give rise to the subsequent development of kokanee. Okanagan Lake currently provides no access to Sockeye Salmon but contains shore- and stream-spawning kokanee that display limited morphological and genetic differentiation and may constitute incipient ecotypes. Okanagan Lake has experienced extensive environmental perturbation over the past 100 years and the evolutionary trajectory of the kokanee ecotypes (stable, increasing or decreasing genetic differentiation) is not known.

As part of a program to introduce Sockeye Salmon into Okanagan Lake, the Okanagan Nation Alliance (ONA) initiated introductions of hatchery-origin Sockeye Salmon to Skaha Lake as an initial, 12-year experiment to provide results to inform future introductions to Okanagan Lake. The ONA conducted an evaluation phase on Skaha Lake from 1999 to 2003; and then began introducing hatchery-origin Sockeye Salmon fry to rear in Skaha Lake, as part of a collaborative “Skaha Re-introduction Project”. Observational data to assess both disease and other ecological impacts have been gathered on an ongoing basis by the ONA and subjected to annual review by the three-party (ONA, DFO, BC-FLNRO) Canadian Okanagan Basin Technical Working Group since the program’s inception (Alexander and Hyatt eds. 2015). A recent genetic study suggests that significant introgression has occurred in the Skaha Lake Sockeye/kokanee Salmon populations since the introduction of Sockeye Salmon in 2004 (Veale and Russello 2016); with unknown long term consequences on resident kokanee salmon.

In British Columbia, a federal – provincial Introductions and Transfers Committee (ITC) reviews applications to introduce or transfer cultured aquatic species to assess risks for possible disease, ecological and genetic effects on native species and ecosystems, and to ensure that the licensing requirements of s. 56 of the Fishery (General) Regulations are met. When issuing a licence, the ITC may also prescribe certain measures to minimize risks associated with transfer activities (e.g. egg disinfection, quarantine of stock). Specifically, the ITC can recommend the Minister issue a licence if:

a) the release or transfer of the fish would be in keeping with the proper management and control of fisheries;

b) the fish do not have any disease or disease agent that may be harmful to the protection and conservation of fish; and

c) the release or transfer of the fish will not have an adverse effect on the stock size of fish or the genetic characteristics of fish or fish stocks.

The ONA has applied to release up to 750 000 Sockeye Salmon fry into Okanagan Lake in 2017, and has indicated that their hatchery facility has the capacity to rear 7 million fry; with maximum single-year introductions estimated at 3.5 million fry. To provide a recommendation regarding whether or not to authorize the release application, the ITC requires science advice on potential ecosystem disruption, pathogen transfer, or genetic interference impacts associated with the proposed release. Consequently, DFO Aquaculture Management Division has requested that DFO Science review the literature and results from the ongoing assessment of the Skaha Lake experimental re-introduction program, as well as other applicable sources of information, and provide advice regarding the potential risks, impacts and uncertainties associated with variable scale introductions of Sockeye Salmon fry into Okanagan Lake. The assessment and advice arising from this Canadian Science Advisory Secretariat (CSAS) Science Response (SR) will be used to assist in arriving at a regulatory authorization decision.

This Science Response Report results from the Science Response Process of May 2017 Review of proposed Okanagan Sockeye fry introduction to Skaha and Okanagan Lakes: history, uncertainties, and implications.

Analysis

Potential impacts of Sockeye Salmon fry introductions on the Okanagan Lake ecosystem and resident fish

Sockeye Salmon fry (from the anadromous ecotype), and all age groups of kokanee (freshwater ecotype of O. nerka), share the same zooplankton taxa as food; consequently, competitive interactions are potentially a concern with respect to management of either allopatric or sympatric populations of *O. nerka*. More than a decade of results from bioenergetics, fish population and food-web assessments in Osoyoos, Skaha and Okanagan lakes have been considered to anticipate the potential impacts of proposed introductions of 750,000 to 3.5 million Sockeye Salmon fry (equivalent to 30 – 141 per ha) on the pelagic ecosystem of Okanagan Lake.

Although each of the three principal lake systems providing results for this review has a unique nutrient profile and species composition, there are general similarities which provide the basis for meaningful comparisons. For example, both Okanagan and Skaha lakes have undergone a documented decrease in biologically available phosphorus loads, and a decrease in several lake productivity metrics (including kokanee densities) since the 1970s; and Okanagan lake presently supports about half the *O. nerka* biomass as Skaha Lake. Nevertheless, both Skaha and Okanagan Lake are currently classified as oligotrophic systems and share similar zooplankton species composition, and similar age, species, biomass structure and diets of their pelagic fish communities. Consequently, it is anticipated that from a bioenergetics perspective, the pressure exerted by age-0 fry on their forage base in Okanagan Lake, where detailed bioenergetics analysis has not been done, will be proportionate to their relative biomass contribution, as in Skaha Lake, where detailed bioenergetics analysis has been done.

Additionally, the ranges of Sockeye Salmon fry densities reported for Skaha and Osoyoos Lake during the past 12 years exceed the range of the sum of both Sockeye Salmon and kokanee fry densities expected in Okanagan Lake due to the proposed introduction described in the application under review. Consequently, the results from bioenergetics, fish population and food-web studies from the Skaha and Osoyoos Lake systems are considered applicable and relevant to anticipating potential impacts, and identifying uncertainties, associated with the proposed introduction of Sockeye Salmon fry into Okanagan Lake.

Bioenergetics and Food-web Assessments for Evidence of Impacts

O. nerka fry are numerically dominant in the pelagic fish communities in Osoyoos, Skaha and Okanagan Lakes (e.g. 65-85%), but make up a much smaller proportion of the total biomass of all pelagic fish (e.g. only 6.3-7.8% in Skaha and Okanagan lakes).

In both Osoyoos and Skaha lakes, detailed assessments of the bioenergetics of growth and zooplankton consumption by various classes of pelagic fish (*O. nerka* fry, older and larger kokanee, Lake Whitefish), along with production of zooplankton, indicate that Sockeye salmon and kokanee fry as a group consume less than 5% of the common, zooplankton forage-base consumed by all pelagic fish. These results support the conclusion that *O. nerka* fry in these lakes have little to no controlling impact on their prey (e.g. *O. nerka* fry do not strongly affect the total prey biomass).

The food webs and resident fish community of Skaha Lake have been subjected to introductions of Sockeye Salmon fry initiated since the spring of 2004. Annual to seasonal comparisons of food-web and resident fish community attributes before, during and after introductions of a wide range (0-800 per ha) of Sockeye Salmon fry to Skaha Lake indicate:

- No detectable change in the Skaha Lake food webs attributable to Sockeye Salmon fry introductions.
- No detectable association between annual variations in kokanee fry survival and variations in introduced Sockeye fry numbers or biomass.
- Minor reductions to kokanee fry summer growth, and no impacts on the size of kokanee fry by the end of the growing season attributable to Sockeye Salmon fry introductions.
- Detectable density dependent interactions appear to be restricted to impacts of larger older fish on each other and on *O. nerka* fry, independent of Sockeye Salmon fry stocking.

Demonstrations of statistically significant associations between increasing fish abundance and decreasing growth or survival of various classes of fish (species, age groups, etc.) are generally considered as evidence for the occurrence of competitive interactions within or between species in a given lake community (references in Hyatt et al. 2011). Multi-trophic level assessments have identified relatively minor impacts of Sockeye Salmon fry introductions on kokanee growth, and no evidence of direct impacts on kokanee fry survival or Skaha Lake food webs over the 12 year duration of studies there.

Okanagan lake has a longer time series of fish and water monitoring data, is of lower productivity than Osoyoos Lake, and, on the basis of morphoedaphic indicators (Rieman and Myers 1992), may be of moderately lower productivity than Skaha Lake. There is evidence that recruitment of kokanee fry to the fall of the year exhibits a density dependent association with increasing numbers of spawning adults, such that total abundance generally fluctuates between 4.6 to 8.8 million fall fry at escapement levels in excess of 100,000 adults. In the most recent decade of apparently lower productivity in Okanagan Lake, average annual fry abundance has been approximately 6 million (range 4.8 – 8.5 M), despite several large escapements (>200,000).

There is no evidence of strong density dependent growth exhibited by Okanagan kokanee fry, as evidence of any strong competitive interactions among fry across most of their historic range of abundance. There is evidence that kokanee fry are subject to density dependent compensatory survival between the egg-incubation and fall fry stages of development; however, current data is insufficient to reliably identify whether the compensatory survival occurs on the spawning grounds or is associated with lake limitation on fall fry production, or both. Further, there is no statistically significant association between kokanee fall fry numbers and subsequent recruitment of adult kokanee.

Introductions of up to 3.5 million Sockeye Salmon fry proposed for Okanagan Lake are estimated to comprise incremental additions of a maximum of 5% to the all-year mean of pelagic fish biomass. Given the similar structure of the pelagic fish and zooplankton communities in Skaha and Okanagan lakes noted above, bioenergetics analysis of prey production, and predator consumption rates of zooplankton in Skaha lake suggest that *O. nerka* fry in Okanagan Lake are unlikely to exert control over their food supply at current or proposed fry abundance levels. Consequently, it is considered unlikely that the proposed range of Sockeye Salmon fry introductions will exert a detectable influence on either the food-web or the pelagic fish community of Okanagan Lake.

Potential for Pathogen Transfers or Range Expansion due to Sockeye Salmon Fry Introductions on the Okanagan Lake

The Okanagan Nation Alliance (ONA) conducted a 3-year disease risk assessment from 2000-2002 as part of the 12-year experimental re-introduction of Sockeye Salmon into Skaha Lake (Evelyn and Lawrence 2003). At the completion of the analysis, it was determined that fish populations above and below locations of high population abundance of anadromous Sockeye Salmon did not differ with respect to the five pathogens being assessed. Additionally, since the inception of the hatchery enhancement of Okanagan Sockeye Salmon, annual diagnostic testing of fry for virus infection have confirmed the absence of viral pathogens such as infectious pancreatic necrosis virus (IPNV) and infectious hematopoietic necrosis virus (IHNV), or any other cell culture replicating agent. The lack of IHNV infection of hatchery fry resulted despite high prevalence of IHNV (upwards of 85%) in adult broodstock. Thus it was concluded that the transfer of disease agents of concern posed a low risk of introduction into Skaha Lake from the transfer of either fry or adults.

For concomitant transfer of pathogens with introductions of Okanagan Sockeye Salmon fry into Okanagan Lake, the hatchery fry must first be exposed and infected with the transferring pathogen. As the Okanagan Nation Alliance Hatchery operates on a secure (closed) water source, it is unlikely that hatchery fry would be exposed to waterborne pathogens. Rather potential impacts related to pathogen exposure and infection of hatchery Sockeye Salmon fry are largely restricted to pathogens that may be transmitted vertically from the parental source. Thus, viral pathogens such as IPNV and IHNV are of concern due to their capacity to be transmitted vertically. As noted above, through the use of rigorous egg disinfection and containment procedures, the Okanagan Sockeye salmon hatchery program has mitigated risk of pathogen transmission in fry as no detection of IPNV, IHNV or other cell culture replicating agents has occurred since the inception of the program in 2003.

Potential Genetic Impacts of Sockeye Salmon Fry Introductions on Okanagan Lake Resident Fish

Genetically distinct ecotypes may arise within a species when there is more than one selective niche to occupy in the environment and there exists within the species sufficient genetic diversity to respond to the divergent selective forces through an adaptive process of ecotype development (Wellborn and Langerhans 2015). The process of ecotype development and maintenance is not always stable and irreversible, especially in the face of environmental change. Genetically distinct kokanee eggs and fry from another Upper Columbia River lake (Kootenay Lake) were repeatedly transplanted into Okanagan Lake between 1920 and 1991, but little or no genetic introgression of Kootenay kokanee genes into Okanagan Lake kokanee. The Kootenay kokanee did not establish populations in Okanagan Lake habitats and no apparent introgression of Kootenay kokanee genes has been observed in limited genetic analysis of recent samples of Okanagan Lake kokanee.

The Sockeye Salmon population that spawns in the Okanagan River downstream of McIntyre Dam (Figure 1) is the source of brood fish that are hatchery-spawned to produce juvenile fry for re-introduction into the Canadian Okanagan River drainage above McIntyre Dam. The recent introduction of the hatchery-reared Sockeye Salmon into Skaha Lake, which hosts a kokanee population genetically similar to the kokanee of Okanagan Lake, resulted in a rapid increase in hybridization between the ecotypes that is likely to result initially in admixture of the Sockeye Salmon and kokanee populations; although the longterm evolutionary outcome on the two ecotypes is unknown (Veale and Russello 2016). Kokanee, hybrid Sockeye-kokanee, and both anadromous and residual (i.e. non-anadromous Sockeye Salmon that remained in the lake and matured in freshwater) individuals were identified genetically among carcasses sampled from the Skaha Lake spawning grounds in Penticton Channel in 2016.

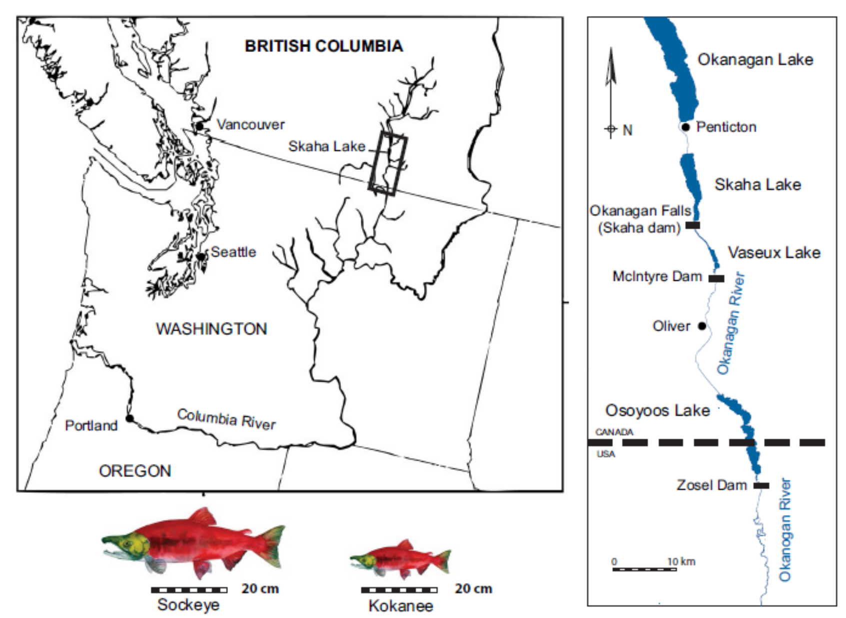

Figure 1. Map showing Okanagan River system, connections and barriers. Adapted from Veale and Russelio 2016.

The contrasting genetic outcomes observed from the introduction of Kootenay Lake kokanee into Okanagan Lake on native kokanee (no successful reproduction documented, little or no genetic introgression into local kokanee) and Okanagan River Sockeye Salmon into Skaha Lake on native kokanee (extensive introgression) indicates that Okanagan Lake kokanee may show some resilience, but are likely not immune, to introgression from related Upper Columbia drainage *O. nerka* populations. Hybridization of one or both Okanagan Lake kokanee ecotypes with Okanagan River Sockeye Salmon adults present in the lake due to residualization from fry introductions (or provision of lake access to adult Sockeye Salmon) is likely to occur; but the level of introgression that would ultimately result and the number of ecotypes that would persist in Okanagan Lake cannot be predicted.

Once novel genetic information is introduced into a population through hybridization, the process of introgression is not necessarily reversible by simply removing individuals of the introduced population. The fate of the introduced genetic information would subsequently be determined by its initial frequency (influencing the likelihood of stochastic loss from the population) and its effect on individual fitness (influencing ongoing natural selection for its increased or decreased frequency in the population).

Uncertainties

Key uncertainties associated with the assessment of potential impacts of the proposed Sockeye Salmon introduction to Okanagan Lake include factors influencing predation, competition, and lake productivity properties such as:

- The role of mysids in controlling population and production levels of zooplankton prey, and consequently influencing growth, survival or recruitment success of Okanagan Lake kokanee fry.
- The extent to which older, larger pelagic fish classes may control growth, survival or abundance of kokanee fry or spawners in Okanagan Lake.
- The cumulative effects of human induced changes (e.g. water extraction, habitat alterations, nutrient loading or depletion, and climate change), on non-traditional food web responses and overall carrying capacity of Okanagan Lake.
- The potential ecosystem level downstream consequences of the sea-run Sockeye adults returning to the Okanagan River system.
- The genetic basis of the two Okanagan Lake kokanee ecotypes and their status as one or two populations; if two incipient populations exist, the current degree of reproductive isolation between them and their evolutionary trajectory (stable, increasing or decreasing genetic divergence).

Conclusions and Recommendations

- Based on data from Skaha and Osoyoos Lakes, Sockeye Salmon fry introductions, across the range of abundance currently proposed for Okanagan Lake, are unlikely to induce detectable changes to pelagic food-webs (i.e. phytoplankton and zooplankton), or to sensitive aquatic biota (all ages and size classes of pelagic fish) within Okanagan Lake.
- Okanagan lake has a longer time series of fish and water monitoring data, is of lower productivity than Osoyoos Lake, and on the basis of rough indicators may be of moderately lower productivity than Skaha Lake. Current kokanee fry production for the last decade has fluctuated between 4 and 8 million fry, despite large spawner variations. Observations indicate that kokanee fry are subject to density dependent compensatory survival between the egg-incubation and fall fry stages of development; however, current evidence is insufficient to reliably identify whether the compensatory survival occurs on the spawning grounds or is associated with lake limitation on fall fry production, or both. Despite these observations, there appears to be no strong linear association between large annual variations in kokanee fall fry numbers and subsequent adult recruitment in Okanagan Lake.

- Sockeye Salmon fry stocking rates for which detailed monitoring and evaluation have been conducted at Skaha Lake have already far exceeded the range of values proposed for Okanagan lake.
- The introduction of 750,000 fry (spring 2017) or ongoing introductions of up to 3.5 million (i.e. annually from 2017-2026) hatchery-origin Sockeye Salmon fry into Okanagan Lake is of low risk of spreading new or extending the range of known pathogens to this portion of the watershed.
- Since the inception of the hatchery enhancement of Okanagan Sockeye Salmon, annual diagnostic testing of fry for virus infection have not detected of IHNV, IPNV, or any other cell culture replicating agent. The lack of IHNV infection of hatchery fry resulted despite high prevalence of IHNV (upwards of 85%) in adult broodstock.
- Fish Stocking Aquaculture License requirements, coupled with rigorous egg collection and disinfection procedures implemented by the hatchery, minimize the risk that the proposed introduction of Sockeye Salmon fry into Okanagan Lake would introduce new or extend the range of known pathogens to fish in this portion of the Okanagan basin.
- Little genetic impact on the kokanee populations, including ecotype formation and persistence or degradation, would be expected to result from a one-time introduction of 750,000 Okanagan Sockeye Salmon fry to the lake, given the apparently limited impact of repeated Meadow Creek kokanee introductions into Okanagan Lake.
- The ongoing release of between 0.75 and 3.5 million Okanagan Sockeye Salmon fry would be expected to result in hybridization between residual Sockeye and kokanee in Okanagan Lake, given that hybridization has occurred between Sockeye Salmon and kokanee spawning in Penticton channel (Skaha Lake population).
- The evolutionary outcome of ongoing hybridization resulting from multiyear introductions of Sockeye Salmon fry in terms of the fitness of *O. nerka* within Okanagan Lake and the number of anadromous and/or resident ecotypes that subsequently develop cannot be predicted.
- Return migration of unharvested adult Sockeye Salmon from hatchery fry released in Okanagan Lake would be obstructed by flow control structures at the outlet of Okanagan Lake. Probable dispersion of these fish to downstream spawning habitat would be expected to exacerbate kokanee-Sockeye Salmon hybridization in Penticton Channel. In addition, some obstructed fish might travel further downstream to their parental natal spawning habitat south of McIntyre Dam. Here, they would be members of the local Okanagan River Sockeye Salmon spawning population and likely interbreed with other Sockeye Salmon with little genetic consequence.
- As noted above, there are several key uncertainties that may require further exploration to inform the current assessment of potential impacts associated with long term introductions of Sockeye Salmon fry to Okanagan Lake. For example, further exploration would be helpful to address potential non-traditional food-web functional and structural responses to introductions in varying nutrient-limited scenarios.
- Assessment of the potential impacts of a long-term introduction program would benefit from a clear articulation of the objectives of the proposed introduction in future applications.

- In the event that the hatchery program at this facility was altered from the current licence, a review of the established disinfection/containment and other biosecurity procedures would be required to ensure the provide effective mitigation for potential pathogen transfer.
- To provide further information, and to ensure early detection and mitigation of potential impacts, an effective monitoring, mitigation, and evaluation program would provide a basis to inform an adaptive management approach to the potential long-term introduction of Sockeye Salmon fry into Okanagan Lake.
- If the Okanagan Lake hatchery origin anadromous Sockeye Salmon are provided access to return as adults to lakes with kokanee populations (Skaha and Okanagan lakes for example), the longer term consequences to food webs, kokanee, and other components of the ecosystem resultant of Sockeye fry introductions to Okanagan Lake would require reevaluation.

Contributors

Contributor	Affiliation
Kim Hyatt	DFO Science, Pacific Region
Ruth Withler	DFO Science, Pacific Region
Kyle Garver	DFO Science, Pacific Region
Mark Higgins	DFO Science, Pacific Region
Dan Selbie	DFO Science, Pacific Region
Dean Allan	DFO Fisheries Management, Pacific Region
Sarah Murdoch	DFO Policy, Pacific Region
Gerald Chaput	DFO Science, Gulf Region
Marc Trudel	DFO Science, Maritimes Region
Mike Ramsay	Province of British Columbia
Paul Askey	Freshwater Fisheries Society of BC
Ken Ashley	British Columbia Institute of Technology
Lesley MacDougall	DFO Science, Pacific Region

Approved by

Carmel Lowe
Regional Director
Science Branch, Pacific Region
Fisheries and Oceans Canada

May 16, 2017

Sources of information

Alexander, C. A. D. and K. D. Hyatt (eds) 2015. Proceedings of the Peer Review Workshop for the Okanagan Sockeye Re-introduction Experiment, Final Draft. Summary report to the Okanagan Nation Alliance and Canadian Okanagan Basin Technical Working Group. 125 p. Available from the Okanagan Nation Alliance, 101-3535 Old Okanagan Highway, Westbank, B. C. V4T 3L7.

Evelyn, T. and S. Lawrence. 2003. OBJECTIVE 1 Disease Risk Assessment. Contribution No.1 to an Evaluation of an Experimental Re-introduction of Sockeye Salmon into Skaha Lake: YEAR 3 of 3. Presented to Colville Confederated Tribes. 78 pp.

Hyatt, K. D., D. J. McQueen, D. P. Rankin, and E. Demers. 2011. Density dependent growth in juvenile sockeye salmon (*Oncorhynchus nerka*). Open Fish Sci. J. 4:49-61

Rieman, B. E. and D. L. Myers. 1992. Influence of fish density and relative productivity on growth of kokanee in ten oligotrophic lakes and reservoirs in Idaho. Trans. Am. Fish. Soc. 121: 178-191.

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

Wellborn, G.A. and Langerhans, R.B. 2015. Ecological opportunity and the adaptive diversification of lineages. Ecology and Evolution 5(1):176–195.

This Report is Available from the

Centre for Science Advice
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: (250) 756-7208
E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2017. Review of potential impacts associated with recent and proposed Okanagan Sockeye Salmon fry introductions to Skaha and Okanagan Lakes. DFO Can. Sci. Advis. Sec. Sci. Resp. 2017/031.

Aussi disponible en français :

MPO. 2017. Examen de l’introduction proposée d’alevins de saumon rouge de l’Okanagan dans les lacs Skaha et Okanagan : historique, incertitudes et répercussions. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2017/031.