APPENDIX B: Directed Studies
TECHNICAL STUDY #2 (2023)
Phase 2. Pilot Plan for Experimental Reintroduction of Anadromous Salmon into Upper Columbia River: Proposed Implementation, Monitoring, and Evaluation

The Columbia River Salmon Reintroduction Initiative

BRINGING *the* SALMON HOME
kɬ cṕəlḱ stim̓ iʔ ntytyix
ʔatɬ suʔkiniɬ swaq́mu
Tspelq'entém re Sqlélten

Technical Study #2 (2023)

Phase 2. Pilot Plan for Experimental Reintroduction of Anadromous Salmon into Upper Columbia River: Proposed Implementation, Monitoring, and Evaluation

APPENDIX B DIRECTED STUDIES

Study 2 Pilot Investigation for Adult Chinook Salmon Presence and Distribution

The Columbia River Salmon Reintroduction Initiative

BRINGING *the* SALMON HOME
kɬ cṕəlk̓ stim̓ iʔ ntytyix
ʔatł suʔkinił swaq́mu
Tspelq'entém re Sqlélten

c/o #101, 3535 Old Okanagan Hwy, Westbank, BC V4T 3L7 ColumbiaRiverSalmon.ca

From: Misun Kang and Will Warnock, TWG Co-Chairs on behalf of the Technical Working Group

To: Rosalie Yazzie, IT Chair, on behalf the Implementation Team

Date: May 17, 2022

Re: Pilot investigation for adult chinook salmon presence and distribution monitoring in the Transboundary Reach region testing multiple methods, July to October 2022

Proposal

In the summer of 2022, reconnaissance surveys will be implemented to test the efficacy of various methods within the Transboundary Reach where summer chinook adult salmon are confirmed to have recently occupied (i.e., 2019, 2020, and 2022 via UCUT ceremonial release programs in the US) and investigate preferred sites for future fisheries monitoring and evaluation platforms.

Rationale

In the spirit of reconciliation, this is an Indigenous led survey to include all three Nations engaged in the field and in reporting of lessons learned for the reintroduction of anadromous salmon to the Upper

Columbia –and re-establishing our relationship with Salmon to the Upper Columbia. Salmon outplants in the US via US Tribes from 2017 and onwards has presented an opportunity for salmon to occupy the waters within the Transboundary Area. In 2019, a total of 100 acoustic tagged adults were released upstream of Grand Coulee as part of ceremony. Based on BC Hydro arrays, a total of 26 adults were detected moving upstream to Canada, and an estimated 30% of the detected adults resided in Canada for 20+ days; final fates of these fish remain inconclusive. The UCUT tribes continue to release 100-300 adults annually, and its our intention to reconnaissance the area in years when adults are released and determine final date and distribution of fish in parallel with the current program CRSRI, in collaboration with Canada, BC, Ktunaxa Nation, Shuswap Nation Tribal Council, and Okanagan Nation.

Study objectives

1. Determine the efficacy of various methods to detect adult chinook within the Canadian portion of the Transboundary Salmon Planning Unit, to better inform decisions for design of future reintroduction experimentation;
2. Collect abundance, distribution, movement, site data to inform future studies and expansion of monitoring program;
3. Knowledge transfer, training, and collaboration among three Indigenous Nations technical staff, related to remote technologies, which may include biotelemetry, sonar, eDNA, etc.; and

Methods

Conventional methods used in the area of interest, as well as novel approaches to inform monitoring and evaluation program design. Methods including aerial helicopter and ground surveys will be pair tested with other methods including: detection of acoustic and pit tagged fish via UCUT, eDNA sampling live and carcass holding hot spots (sediment and water), and if available high resolution drone video imagery, and sonar imaging (ARIS or DIDSON). Key physical features for site investigation related to fish collection may include profiling bathymetry, hydraulics (i.e., shoreline complexity, risk management (debris, wildlife, humans), and access (for rating and ranking gears that may include dipnets, hoop nets, fish baskets, seining, fishwheels). Key areas including the confluence (1 Kootenay, 2. Norns Creek, and 3. Beaver Creek; if time permits investigate key features such as Rock Island, proximate to border) will be surveyed more frequently from mid-August to End of September, with peak efforts the last week of August or first week of September.

Data Analysis and Use

- Possible information that will be collected: presence/absence, # live, # carcasses, # redds, key holding and spawning validated, locations observed/detected
- Data report prepared by all Nations involved in the field training and operations, will collectively report results and descriptive statistics,
- To be drafted by November 2022, for planning 2023 studies.

Study 6B Potential for trapping juvenile salmon in the Columbia River

Based on work by ONA, DFO, and CRITFC

OVERVIEW

For salmon, juvenile rearing and downstream migration are associated with high rates of mortality. A better understanding of the factors influencing a fish's survival through this these time periods can help direct mitigation measures. A key issue in monitoring juvenile fish is having an effective platform for the capture of target fish, for the collection of biological data and to supply fish for tagging and tracking experiments. Collection of juvenile salmon in tributaries and smaller rivers throughout the range of Pacific salmon is done through the use of rotary screw traps, small incline plane traps, and juvenile fish weirs (Copeland et al. 2021). Within larger bodies of water these methods become less effective due to the limited amount of water they can sample, and the increased physical stress associated with a large discharge stream (Copeland et al. 2021).

Within the Transboundary reach unit, the primary spawning habitat for Summer/Fall Chinook Salmon is expected to be within the mainstem of the Columbia River, since tributary habitat is limited by both the number of available streams and the area within those streams that is accessible to migrating fish. Effectively monitoringjuvenile production in this study unit will require the development of a collection program within the mainstem Columbia River. The Idaho Department of Fish and Game (IDFG) uses larger juvenile traps such as Scoop Traps on the Clearwater and Salmon rivers, and a Dipper Trap on the Snake River to collect juvenile Chinook, Sockeye, and Coho salmon. These traps are based on designs by Raymond and Collins (1974) and Mason (1966), for the Scoop Trap and Dipper Trap, respectively.

SAMPLING PLAN

We propose to investigate the potential for using similar traps for the collection of juvenile salmon within the Transboundary reach with the following steps:

- Contact IDFG for further information on their program including water velocities and depths they operate within, insights and adjustments they have made to trap designs, and lessons learned as far as locational constraints that can be used to limit site selection
- In consultation with First Nations, identify an initial list of potential sample locations and the property owners associated with each location
- Conduct site visits to potential trap locations to identify preferred deployment location(s).
- Engage with property owners at the preferred location(s) about the potential for utilizing the site(s).
- Develop detailed plans for the construction of the desired collection equipment and procure quotes for the construction of the equipment.

References

Copeland, T., B. Barnett, W.C. Schrader, K.A. Apperson, L. Janssen, and R.V. Roberts. 2021. Protocols for trapping anadromous emigrants in Idaho. Idaho Department of Fish and Game (IDFG) Report Number 21-05.

Mason, J.E. 1966. The migrant dipper: a trap for downstream-migrating fish. The Progressive Fish-Culturist, 28: 96-102.

Raymond, H.L., and G.B. Collins. 1974. Techniques for appraisal of migrating juvenile anadromous fish populations in the Columbia River Basin. In: Symposium on methodology for the survey, monitoring and appraisal of fishery resources in lakes and large rivers. Food and Agricultural Organization of the United Nations, European Inland Fisheries Advisory Commission, EIFAC/74/I/Symposium-24, Rome, Italy.

Study 16 Egg Survival Studies

Based on work by ONA and DFO

Overview

Modeling exercises have indicated the potential for spawning habitat for Summer/Fall Chinook Salmon in the Transboundary Reach (Golder 2016, 2017) and for Sockeye Salmon in tributaries to Arrow Lakes Reservoir (Bussanich et al. 2017). Currently, fall spawning salmonids (Bull Trout, Brook Trout, Lake Trout, kokanee, and Brown Trout) are occasionally encountered in the mainstem Columbia River in the Transboundary Reach; however, there is no evidence that this river reach supports recruitment, or results in a self-sustaining population of any of these species (W. Warnock, BC FLNRORD, pers. comm.). Currently, kokanee use tributaries to Arrow Lakes Reservoir for spawning but there is some concern for spawning overlapping and competition with the reintroduction of Sockeye Salmon to the region. With the construction of Hugh Keenleyside Dam and creation of Arrow Lakes Reservoir, large amounts of habitat previously used for spawning were inundated (Arndt 2009), and spawning moved farther upstream into reaches not previously utilized (indicating there was unutilized spawning potential during the pre-dam era). High quality spawning habitat is a key requirement for the reestablishment of anadromous salmon runs upstream of Lake Roosevelt in the Canadian Columbia River.

Establishing egg-survival studies in potential spawning areas in the Transboundary Reach of the Columbia River and in potentially underutilized tributary areas in the Arrow Lakes Reservoir drainage would provide valuable information on the potential to re-establish anadromous fish populations at these sites.

Project Objectives

1. In consultation with First Nations, determine study sites at expected spawning locations for Chinook and Sockeye salmon, as well as in known spawning locations for kokanee (control group).
2. Install egg development capsules and monitor study sites from fall to the spring with samples collected during late September-October, December, and April.
3. Install water temperature probes in egg survival study areas as well as other potential spawning areas to confirm those locations' suitability.
4. With confirmation of egg viability in tributary locations, larger egg boxes can be utilized to "seed" these locations with juveniles that are imprinted on those locations.
5. Build an outreach/education component to engage with communities and the broader public.

Sampling Plan

We propose to determine the viability of potential sampling areas through the use of egg development capsules and environmental monitoring. After potential underutilized habitats are identified (through consultation with IKC), fertilized eggs will be placed in suitable substrate following methods utilized by Cope and MacDonald (1998). Standpipes will be deployed alongside egg capsules. Collection of egg capsules and monitoring of environmental conditions will be undertaken at regular intervals through the development period. Study locations would span a range of habitats/conditions (including flows and temperatures) throughout the SPUs. The same process will be undertaken in known kokanee spawning areas as a control. Identification of underutilized spawning habitats will provide information for identifying further underutilized habitats throughout the study areas.

Such experimental egg survival trials may not be possible for Chinook Salmon in the short term if we limit ourselves to the use of eggs from Columbia River Fall Chinook Salmon stocks. In the short term, researchers could obtain Fall Chinook Salmon eggs from elsewhere in BC and conduct the studies using incubation tubes that are designed so that nothing escapes (fry can hatch but are contained). For Sockeye Salmon, the source of eggs would be the kł cp̓əlk̓ stim̓ Hatchery in Penticton.

With the identification of underutilized spawning areas, there is the potential to "seed" these areas using instream incubation boxes. Utilizing incubation boxes will allow juvenile fish to imprint on these locations and may lead to them using those locations for spawning when they mature. Also, the success of redds from 'natural spawners' (i.e., from UCUT releases) could be compared with that of hatchery-origin eggs in incubation boxes. Monitoring could determine if eggs are present, if eggs are developing into viable embryos, if embryos hatch into alevins, and if fry emerge. Note that there may be some cultural sensitives associated with disturbing natural redds.

This study offers opportunities for public involvement including construction and placement of study materials, assisting with retrieval and monitoring of study materials, and anecdotal observations regarding the presence of adults in these locations in future years.

References

Arndt, S. 2009. Footprint Impacts of BC Hydro Dams on Kokanee Populations in the Columbia River Basin, British Columbia. Report for the Fish and Wildlife Compensation Program – Columbia Basin, Nelson, BC.

Bussanich. R, L. Bellingham, and G. Kehm. 2017. Tributary assessment of potential Sockeye, Chinook, and steelhead spawning habitat in the upper Columbia River, Canada, for prioritizing salmon reintroduction. Report for Okanagan Nation Alliance, Westbank, BC.

Cope, R.S., and J.S. Macdonald. 1998. Responses of Sockeye Salmon (*Oncorhynchus nerka*) embryos to intragravel incubation environments in selected streams within the Stuart-Takla watershed. *In* Forest-fish Conference: Land Management Practices Affecting Aquatic Ecosystems. Edited by M.K. Brewin, and D.M.A. Monita. Natural Resource Canada Information Report, NOR-X-356.

Golder Associates Ltd. 2016. Chinook Salmon spawning habitat availability in the Lower Columbia River. Report for Canadian Columbia River Inter-tribal Fisheries Commission, Cranbrook, BC. Report number 1538622. http://ccrifc.org/cms/wp-content/uploads/2015/10/Golder_2016_Salmon-habitat-availability-in-Columbia-R-TB-reach.pdf.

Golder Associates Ltd. 2017. Chinook Salmon spawning habitat availability in the Lower Columbia River – Year 2. Report for Canadian Columbia River Inter-tribal Fisheries, Commission, Cranbrook, BC.

Report number 1659612F. http://ccrifc.org/cms/wp-content/uploads/2017/06/Golder_2017_Salmon-habitat-availability-in-Columbia-R-TB-reach-phase-II.pdf.

Study 17A/B Using experimental trials to improve translocation protocols of anadromous Sockeye Salmon to Arrow Lakes Reservoir from Okanagan River

Based on work by ONA, DFO, and CRITFC

BACKGROUND

In the face of uncertainty, successful reintroduction programs should be designed within an adaptive experimental framework, as far as practicable, to inform future management (Mitchell et al. 2022). We propose to investigate how reintroductions influence the probability of successful population establishment in a study system, with regards to juvenile survivability and growth, while simultaneously monitoring changes in an established 'control' population with similar rearing requirements in the same environment.

We frame the reintroduction in two phases. In phase one we adopt an experimental approach where anadromous Sockeye Salmon (*O. nerka*) are translocated into a habitat from which they have been absent for decades but which contains a large population of the non-anadromous form of the same species (kokanee). In the initial phase, our aim is to trial and optimise transfer and release protocols for Sockeye Salmon. The management insights gained during this phase will inform larger scale translocation efforts in the future (i.e., during phase two), with the over-arching goal to re-establish populations of Sockeye Salmon in the Columbia River drainage upstream of the United States/Canada border.

STUDY SPECIES AND SYSTEM

Study Species

Sockeye Salmon and kokanee are different forms of the same species *O. nerka*. Both forms inhabit lakes for rearing and feed pelagically. Typically, after a year or two of rearing in a lake, Sockeye Salmon migrate to the ocean where they live until returning to spawn after 2-3 years. Kokanee remain in freshwater and continue to feed and grow in the lake before spawning. Sockeye Salmon and kokanee can use the same lake system, but many systems have only one of the life history forms.

Study Area and Site Characterization

In this study, we describe four lakes that should be monitored. The four lakes are comprised of two pairs. In each pair, there is a 'source' lake and a 'reintroduction' lake (i.e., fish come from the 'source' population to build a population in the 'reintroduction' lake). One of the lake pairs, considered the 'Study' pair, will actively be undergoing reintroduction efforts over the course of the study period. The lakes of the second pair, called the 'Control' pair, were selected to have similar characteristics to their counterparts in the Study pair, except that they have not been subject to reintroduction efforts related to Sockeye Salmon. We will monitor the 'Study Reintroduction' (Arrow Lakes Reservoir) populations of Sockeye Salmon and kokanee to track population trends and assess the outcomes of the different treatments. In parallel, we will continue monitoring of the 'Study Source' population (Okanagan Basin) trends to assess the impact of removing fish for translocation. For comparison, control populations of Kootenay Lake and Lake Wenatchee will also be monitored for trends.

Study Reintroduction System: The Arrow Lakes Reservoir drains a series of Canadian Lakes and Reservoirs of the mainstem Columbia River (Columbia, Windermere, Kinbasket, Revelstoke) into Lake Roosevelt which straddles the Canada-US border and flows south into the Columbia River in the US. Arrow Lakes Reservoir, is 240 km long, has a surface area at full pool of 46,400 ha (464 km^2), a volume of 8.8 km^3, a mean elevation of 441 m and a draw down of 12-15 m (40-50 feet), maximum depths of 287 m and 194 m (Upper Arrow and Lower Arrow, respectfully) and a mean depth of 101 m and 57 m (Upper Arrow and Lower Arrow, respectfully; Pieters et al 1999). Arrow Lakes currently maintains a population of kokanee and historically supported runs of Sockeye Salmon. In advance of reintroduction experiments there are no Sockeye Salmon present.

Study Source System: Okanagan Lake, elevation 342 m, measures 135 km in length, has a surface area of 351 km^2, volume of 25 km^3, maximum depth of 230m, mean depth of 76 m, and a variable water residence time (Sokal 2010, Stockner and Northcote 2011). Okanagan Lake supports both resident kokanee and anadromous Sockeye Salmon populations.

Control Source System: Wenatchee Lake, elevation 571 m, measures 8.0 km in length, has a surface area of 10 km^2, volume of 0.44 km^3, maximum depth of 74 m, mean depth of 45m, and an average water residence time of 14.8 months (Dion et al. 1976). Similar to the Okanagan Lakes source system, the Lake Wenatchee control site supports anadromous Sockeye Salmon population, although there is little to no resident kokanee present.

Control Reintroduction System: Kootenay Lake, elevation 532 m, measures 107 km in length, has a surface area of 395 km^2, volume of 0.37 km^3, maximum depth of 154 m, mean depth of 94 m, and an average water residence time of 18 months (Daley et al, 1981). Similar to Arrow Lakes treatment site, the Kootenay Lake control site supports a resident kokanee population, with no anadromous Sockeye Salmon present.

INITIAL RELEASE STRATEGIES

The initial release of Sockeye Salmon juveniles into Arrow Lakes Reservoir will likely include 50,000 to 100,000 fry weighing from 1-3 g raised in the Okanagan Hatchery from Okanagan Basin Sockeye Salmon. At these numbers, the proposed sampling described below will likely be ineffective. But once releases in the order of 1 million (or more) fish can be achieved, we propose the following work.

Fish will be released near Revelstoke in the Upper Arrow basin (**Error! Reference source not found.**) and near Caribou-Burton in the Lower Arrow basin (**Error! Reference source not found.**). These locations were chosen based on the presence of suitable habitat and the historical use by salmon prior to extirpation (Bussanich et al. 2017). We will have the ability to compare differing release strategies including: limnetic vs. littoral releases; immediate release vs. holding for an acclimation period; and/or releasing at a variety of photoperiods or moon phases. The consideration of these options is not treated in this appendix.

POST-RELEASE MONITORING

Salmon Sampling and Data Processing

Post release sampling will be conducted in all four lakes in a similar manner to monitoring in the Okanagan drainage (see Hyatt et al. 2017, which is quoted with minor editing below). Acoustic-and-trawl surveys (ATS) will be used to determine fish abundance on 5-7 dates each year. Density estimates from echo-integration analysis will be used to determine total numbers of fish. The abundance data are then partitioned into species and size or age classes within species based on the composition of fish in sample trawls.

Data from echosounding (i.e., target abundance) and trawl catch (otolith and/or DNA and/or otolith thermal mark patterns) can be used to identify proportion of the catch that are wild-origin kokanee vs. hatchery-origin Sockeye; and in future it will be possible to discern wild-origin Sockeye and wild-origin hybrids. We will use trawl-catch samples to identify the actual size-and-age classes of larger fish making up the mixture of pelagic fish present on a given survey date. Acoustic data files will be interrogated to estimate the abundance of the various size classes (based on their target strength) of pelagic fish known from trawl samples to be present in the lake.

The steps used to assign each fish to the appropriate taxonomic (*i.e.,* kokanee vs. anadromous Sockeye Salmon) or size (length, weight, age) category are as follows: (1) Total fish densities are assessed from acoustics data collected using a Biosonics DT-X sounder (200 kHz sounder with 300 W power, pulse width at 1 ms and a 6.6° transducer). (2) Fish size-frequency distributions are estimated using Sonar5-Pro software. (3) Lengths and weights are recorded from each fish caught in 3m × 7m trawl net sets. (4) Taxonomic designations for subsets of small fish can be based on marked otolith presence (age-0 hatchery Sockeye Salmon) or absence (age-0 wild kokanee) or on DNA fingerprinting. (5) Ages of larger fish (all kokanee) can be assessed from annulus patterns on scales.

For each sampling date, these five data sets are combined as follows: (i) Trawl-caught age-0 kokanee and age-0 Sockeye are separated based on otoliths or DNA as described above. (ii) Age-1, age-2 and age-3+ kokanee are separated based on scale ages. (iii) Because it was assumed that large kokanee would be more likely to escape the trawl, we will use the Sonar-5 length frequency data to separately estimate densities of Age 0 juveniles (could be either kokanee or anadromous Sockeye Salmon) vs. larger age-1, 2, and age 3+ fish (all kokanee). (iv) Use the trawl data to establish relationships between known fish ages and observed length frequencies and then to extrapolate these length categories to the length frequency data from the echosounder. With the combined trawl and echosounder data, and with otolith and DNA data, we will be able to estimate relative proportions for each of the several groups of fish: age-0 hatchery Sockeye, age-0 wild Sockeye, age-0 kokanee, age-0 hybrids, age-1 Sockeye (from prior year outplants, or eventually from natural origin), age-1 kokanee, age-2 kokanee, and age 3+ kokanee.

This will allow us to calculate age-frequency densities for each sampling date based on total densities from the acoustic samples.

Notes on Salmon Sampling

For age-0s and age-1s, trawl catches should be high with trawl-based length frequencies well defined and can be reliably extrapolated to the length frequencies derived from the echosounder. For kokanee age-2 and age-3, trawl numbers will likely be higher in the spring and decline through the summer-fall. These small trawl catches will almost certainly result in trawl-based length frequencies that are less reliable, therefore larger errors will be encountered when applying these length frequencies to the echosounder data. However, the total densities derived from the echosounder will nevertheless be more reliable than densities derived from trawl nets alone; thus, the errors attributed to the protocol described above are errors in ageing rather than errors in density assessment. If we assume that the echosounder-based density estimates are the best available, then our protocol will produce an unbiased estimate of density total, but may be biased for specific age categories. These age-related miss-assignments are less likely to be important for the age-0 and age-1 fish (i.e., for most of the population), and are more likely for the relatively rare age-2 and age-3 fish. Because the true densities of age-0 and age-1 *O. nerka* will be high, our echosounder-based density estimates will likely be as good as the *total* echosounder-based estimates, whereas the subdivided densities for age-2 and age-3 kokanee should be used only with caution.

Density estimates based on samples collected from a single lake over a period of time (i.e., time series) raise pseudo-replication issues around the calculation of confidence intervals (Hurlbert 1984, Millar and Anderson 2004). To avoid this problem, we will use two density estimates per lake-year to characterize annual to seasonal changes in *O. nerka* abundance for bioenergetics modelling purposes. The July-November estimate will be collected after full recruitment of fry to the limnetic zone is certain to have occurred. The pre-smolt density estimate will be based on the average of all samples collected from October through winter, i.e., after both spring recruitment and spring-summer mortality outcomes are complete. We chose overlapping time periods because the July to November estimate is useful for assessments of the impacts of the fish on their zooplankton prey over the summer production interval, and the October to winter average of juvenile Sockeye density is our most reliable index of annual production of smolts destined to migrate seaward at age-1 in May-June after a single summer and winter of lake residence.

PRODUCTIVITY SAMPLING

During each lake-year, water chemistry, phytoplankton, zooplankton, and *Mysis diluviana* will be intensively monitored from spring to fall. Two primary objectives are: (1) quantification of the effects that hatchery-reared Sockeye Salmon may have on abundance and productivity of Arrow Lakes Reservoir kokanee; and (2) estimation of pelagic *O. nerka* carrying capacities for both basins of Arrow Lakes Reservoir.

The question for the experiment is whether the presence of hatchery-reared age-0 Sockeye Salmon plus *Mysis diluviana* plus the presence of a substantial population of wild-origin kokanee Salmon, might limit the recruitment growth and survival of age-0 kokanee, and the growth and survival of hatchery-reared age-0 Sockeye Salmon in the relatively oligotrophic Arrow Lakes system. Evidence from the Skaha program (Hyatt et al. 2021a) does not support this assumption, but it remains to be determined in Arrow Lakes Reservoir.

The Arrow Lakes productivity monitoring experiment has five components. These are: (i) food-web manipulations resulting from annual changes in stocking density, (ii) assessment of long-term performance measures, (iii) application of bioenergetics-based production and consumption analysis, (iv) extrapolation of results from Okanagan Lake where Sockeye densities are comparable, and (v) the use of adaptive management.

Changes in stocking density: During a proposed 10-12 year experimental period, the numbers of Okanagan hatchery outplants will vary by an order or magnitude (from 400,000 to 4 million). This variation will provide an opportunity to assess effects of various outplant densities on the growth and survival of wild age-0 kokanee, and of hatchery-origin age-0 Sockeye.

Extrapolation from Okanagan Lake: Okanagan Lake is regional control for Arrow Lakes Reservoir. Both have the same zooplankton species composition, and both have approximately the same biomasses of *Mysis diluviana*. Given that age-0 Sockeye Salmon and kokanee in both lakes would have identical diets, we can use our production and consumption data to make inferences about what could happen in Arrow Lakes Reservoir if stocking densities were greatly increased. We can also apply these data to answer questions about the potential effects of releasing various densities of Sockeye spawners into Arrow Lakes.

Performance Metrics

Key *Performance Measures* include:

- Numbers of wild and hatchery Sockeye Salmon smolts leaving Arrow Lakes Reservoir, and detected downstream at Rocky Reach Juvenile Bypass
- Rates of growth and survival for wild and hatchery Sockeye Salmon in Arrow Lakes Reservoir, Lake Roosevelt, Wenatchee, Osoyoos, Skaha and Okanagan lakes
- Rates of growth and survival for resident kokanee in Skaha Lake and Arrow Lakes Reservoir
- Numbers and sizes of kokanee spawners in Arrow Lakes.

In all 12 years of the study, we will analyze changes in these performance measures against a background of changing water temperature, river flow, mysid biomass, resident kokanee densities, and both wild and hatchery-origin Sockeye densities in other reference systems.

Adaptive Management

The Sockeye Salmon reintroduction experiment is based on principles and practices of adaptive management. Our program adheres to structured decision-making based on information gathered from ongoing experiments and iterative engagement (Holling 1978, Walters 1986). On several occasions we may modify our experimental design and methodologies in response to required changes in experimental protocols. An example from Skaha, when concerns were raised about the possibilities of hybridization between Sockeye Salmon and kokanee in the spawning channel, a DNA fingerprinting program was implemented.

MEASURES OF SUCCESS

There are multiple tiers of success for this project with the ultimate goal of re-establishing self-sustaining Sockeye Salmon returns to the Canadian portion of the Columbia River drainage while not harming or limiting production in the Source population. Successful steps will involve gaining insights into factors impacting the growth and abundance of juvenile Sockeye Salmon in Arrow Lakes Reservoir including those factors under the control of the reintroduction team such as the quantity of fish released, fish size at release, release location, and timing of release.

REFERENCES

Bussanich. R, L. Bellingham, and G. Kehm. 2017. Tributary assessment of potential Sockeye, Chinook, and steelhead spawning habitat in the upper Columbia River, Canada, for prioritizing salmon reintroduction. Report for Okanagan Nation Alliance, Westbank, BC.

Daley, R. J., E.C. Cakmack, C.B.J. Gray, C.H. Pharo, S. Jasper, and R.C. Wiegand. 1981: The effects of upstream impoundments on the limnology of Kootenay Lake, British Columbia. — National Water Research Institute 117.

Dion N.P., G.C. Bortelson, J.B. McConnell, and J.K. Innes. 1976. Data on Selected Lakes in Washington. United States Geological Bulletin, Water Supply Bulletin 42, Part 5.

Holling, C.S. 1978. Adaptive Environmental Assessment and Management. John Wiley & Sons., New York, NY.

Hurlbert, S. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs, 54: 187-211.

Hyatt, K.D., D.J. McQueen, D.P. Rankin, M.M. Stockwell, H. Wright, S. Lawrence, A. Stevens, C. Mathieu, and L. Wiens. 2017. Methods and summary data for limnology and food web structure in Skaha Lake, B.C. (2005-2013); Revised. Canadian Data Report of Fisheries and Aquatic Sciences, 1275.

Hyatt, K.D., D.J. McQueen, A.D. Ogden, R. Benson, and H. Wright. 2021a. Age-structured interactions among reintroduced Sockeye Salmon, resident kokanee, invasive mysids, and their zooplankton prey in Skaha Lake, British Columbia. North American Journal of Fisheries Management, 41: 1246-1273.

Millar, R.B., and M.J. Anderson. 2004. Remedies for pseudoreplication. Fisheries Research, 70: 397-407.

Mitchell, W.F., R.L. Boulton, L. Ireland, T.J. Hunt, S.J. Verdon, L.G. M. Olds, C. Hedger, and R.H. Clarke. 2022. Using experimental trials to improve translocation protocols for a cryptic, endangered passerine. Pacific Conservation Biology, 28: 68–79.

Pieters, R., L.C. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, M. Derham, K. Ashley, B. Lindsay, G. Lawrence, D. Sebastian, G. Scholten, F. McLaughlin, A. Wüest, A. Matzinger, and E. Carmack. 1999. ALR Limnology and Trophic Status Report, Year 2 (1998/99). RD 72. Fisheries Branch, Ministry of Environment, Lands and Parks, Province of British Columbia.

Sokal, M. 2010. Okanagan Large Lakes Water Quality Monitoring Program. Environmental Protection Division, Ministry of Environment - Presentation.

Stockner, J., and T. Northcote. 2011. Recent limnological studies of Okanagan Basin lakes and their contribution to comprehensive water resource planning. Journal of the Fisheries Research Board of Canada, 31: 955-976.

Walters, C. 1986. Adaptive Management of Renewable Resources. Macmillan, New York, NY.

Study 18 Entrainment Study at Hugh Keenleyside

Based on work by ONA, BioSonics, and Aquacoustics.

Overview

Hugh Keenleyside Dam was constructed on the Columbia River in 1968, at which time it blocked anadromous fish (Chinook, Sockeye, and possibly Coho salmon, as well as steelhead) and resident fluvial and adfluvial fish populations (Rainbow and Bull trout), in addition to White Sturgeon and Burbot from accessing upstream habitats. The impact of the dam is substantial as former spawning, rearing, and overwintering areas were permanently lost or seasonally reduced due in some degree to the reservoir flooding, flow diversions, or operating flows. There is interest in re-establishing fish passage to the historical range.

UCUT are currently in the process of an experimental reintroduction of anadromous salmon to the Upper Columbia. Several other feasibility reports been prepared in the past (e.g., UCUT papers Fish Passage, Reintroduction High Head Dams, Lifecycle modeling). One of the most critical knowledge gaps identified by these feasibility reports and members of the UCUT was fish entrainment and resulting fish mortality. Entrainment (and possibly mortality) rates need to be quantified to ensure that establishing fish passage will have a beneficial, rather than detrimental, effect on Upper Columbia River salmonid populations.

Project Objectives

1. Gather appropriate expertise and determine the effectiveness of hydroacoustic technologies to estimate entrainment of juvenile salmon through Hugh Keenleyside Dam.
2. If hydroacoustic methods are successful, estimate passage rates through the spillway and turbines (entrainment rate).
3. Develop recommendations for optimal hydroacoustic equipment configuration and monitoring plan for future entrainment study.

Quantifying entrainment (and, if needed, entrainment mortality) is a necessary step in identifying the biological benefits of re-establishing fish passage for anadromous salmonids and resident adfluvial fish. Should entrainment rates be high enough to be of concern, further studies into mortality rates and/or entrainment mortality mitigation strategies (e.g., scheduled turbine shutdowns, increased spillage, louvers, screens, bypass systems) may be warranted. However, since there are currently no juvenile fish bypass structures in place at any of the dams, the only method for smolts to move downstream is by passing through the dams via spillway or turbines.

This project will address objectives and key priorities outlined in the Large Lakes Action Plan (FWCP 2019) and ONA prospectus (ONA, 2015). The entrainment assessment will meet objectives for research and information acquisition of species of interest in the Fish & Wildlife Compensation Program (FWCP) strategic vision, and meets First Nations engagement. This would increase access to the resource by First Nations Food, Social and Ceremonial (FSC) fisheries that are currently confined to the Lower and Middle Columbia River below the Chief Joseph Dam and have failed to meet their needs for many years. In addition, it may provide wide-ranging benefits as Columbia River salmon are caught in traditional, recreational, and commercial fisheries throughout the Columbia River and along the entire Pacific coast of British Columbia and Alaska.

PROJECT AREA DESCRIPTION

The 52 m high Hugh Keenleyside Dam is located 12 km upstream of Castlegar, BC with an elevation of 445 m at the dam crest. The dam was constructed for water storage purposes and was updated in 2002 with the Arrow Lakes Generating Station which produces electricity utilizing two Kaplan turbines. A spillway is located in the central portion of the dam with four gates and a maximum capacity of 6,700 m^3/s. The powerhouse consists of two turbine units with a combined capacity of 185 MW, and a hydraulic capacity of 1,200 m^3/s. At full pool the Generating Station operates with a head of 23.6 m. Additionally, the dam has a boat lock to allow for the upstream and downstream movements of watercraft (and potentially, migrating fish).

SAMPLING PLAN

Pilot and Feasibility Phase

We propose to determine the feasibility of using hydroacoustic split beam technology at Hugh Keenleyside Dam to verify seasonal, diel movement and distribution, and passage routes of juvenile Sockeye Salmon, which have been identified as the anadromous target species for the Arrow Lakes SPU. If successful, the method will be able to provide site-specific salmon smolt entrainment rates for future Hugh Keenleyside Dam fish passage management actions. Test fish will be sourced from a hatchery operated by ONA Fisheries. Following a release of hatchery fish in the spring of 2023, hydroacoustic split beam technology will be used to detect smolts and resident fish distribution in the forebay of the dam, and their passage through the spillway and through the turbine intake. This approach is similar to other entrainment studies completed at BC Hydro facilities (e.g., Revelstoke Dam, Mica Dam, Seton Dam, Wilsey Dam).

Due to site and design variations, each hydroelectric dam system is unique, making difficult the extrapolation of entrainment data beyond the site at which they were collected. Commonly-used methods for estimating entrainment and mortality include tagging studies, mark-recapture experiments, and hydroacoustic studies. Hydroacoustic (fixed and mobile, active and passive technologies, combined) are the most practical methodology for assessing juvenile salmon entrainment at high head dams such as Hugh Keenleyside Dam. We propose to approach the entrainment issue in a phased fashion.

Hydroacoustic monitoring systems have been used extensively at hydropower dams and flood control projects throughout North America for investigating anadromous fish passage and estimating entrainment. Split-beam and single beam technologies have been the standard methodologies for measuring entrainment of juvenile salmonids at hydropower dams in the Pacific Northwest for several decades (e.g., Johnson et al. 2001 - Hiram M. Chittenden Lock and Dam; Ploskey et al. 2005 - Bonneville Dam; Johnson et al. 1990, Biosonics 1999 - Seton Dam).

We propose to assess both split-beam and imaging sonar (DIDSON or ARIS), for estimating entrainment rates. These tools each have their own strengths with respect to monitoring fish (e.g., split-beam sonar can sample fish over a longer range and position fish in 3-D, allow for further range and 3-D positioning of fish, whereas imaging sonar provides near-video quality imaging with a better ability to distinguish fish among debris). All these methods are complementary, and their simultaneous use can provide better information on fish spatial distribution.

Each hydropower project has a unique set of physical and environmental conditions that influence the ability to sample effectively with acoustic technologies. It is therefore important to assess the given environment and to test equipment at potential sampling locations to determine the best placement and sampling program for effective monitoring of fish movement through the intakes and over the spillway.

The three main components of the feasibility study are:

Step 1. Preparatory gathering of existing information: assemble existing information relevant to acoustic sampling, including drawings of the dam structure, discharge and operational information, flow and bathymetric information (if no bathymetric information is available, a coarse bathymetric survey may have to be conducted as part of the feasibility study).

Step 2. Test fixed-site acoustic monitoring: Based on the structure, flow and bathymetric information, identify potential sampling locations. Deploy sonar systems for an in-situ assessment of background noise and coverage. Test sequentially each intake and other possible passage routes (e.g., spillway).

Step 3. Mobile acoustic surveys to determine abundance and spatial distribution of fish: A series of mobile acoustic surveys will be conducted in the forebay area to assess vertical and horizontal distributions of salmonid smolts and resident fish during late winter or late spring for future survival and movement studies of species of interest. To differentiate between resident fish activity and newly released salmonids, we propose 3 surveys before the release of juvenile salmonids (3 days, 1 day, and immediately before the release) and 3 surveys after the release (immediately, 1 day, and 3 days after the release). The survey will follow parallel transects spaced 50 m apart from the face of dam to approximately 300 m upstream of the dam, 25 m apart from 25 m to 50 m upstream, and 50 m apart for the remaining distance to approximately 300 m upstream of the dam. The goal is to obtain a time series of the spatial distribution of fish that may provide clues to their travel routes through the forebay as they approach the dam. ONA will lead the acoustic field operations (with invitation to SNTC and KNC fisheries for training and knowledge transfer). Characterization of the fish community assemblage in the forebay will be achieved through a series of trawl hauls from the acoustic survey boat while performing the acoustic survey.

Assumption Test – Target Testing

All access above the dams is blocked to anadromous salmon, therefore hatchery smolts are needed for use as test fish for this study. ONA has agreed to provide up to 10,000 sockeye smolts from the Penticton hatchery for this purpose (i.e., three replicate release events of ~3,300 fish).

The hatchery fish would be released as yearling smolts (10-15 g). Naturally produced Sockeye Salmon typically migrate as yearlings (10-18 g; Braden Judson, DFO, pers. comm.). Recent work by Biosonics (2011) at BC Hydro's Revelstoke Dam indicates that split-beam hydroacoustic systems successfully sampled age-0 kokanee fry as small as 40 mm fork length (approx. 1 g); therefore, it is expected that even entrained fry would not pose a detection problem in future years, even at freshet, if it is found that the hydroacoustic equipment works under the flow, debris and noise levels at Hugh Keenleyside Dam.

The primary objective of this study is to test whether the hydroacoustic equipment is able to detect smolts during the most challenging flow conditions and debris loads, when a large portion of fish in the system are known to migrate, and therefore the timing is not considered to be a substantial issue. Presumably, if the equipment is able to detect fry during the most challenging flow conditions it is also expected to be suitable for smolts and for any fish during non-freshet conditions.

Smolt releases will be scheduled to coincide with typical sockeye smolt migration timing. Hydroacoustic sampling will be performed immediately following release to ensure that a maximum number of smolts is available for detection. Smolt release timing may be slightly adjusted to coincide with streamflows that are typical during peak smolt migration should abnormal conditions be encountered during the sample year (i.e., atypically high or low flows). This will ensure that the hydroacoustic methodology will work under typical conditions encountered during smolt migration in future years.

Entrainment (and mortality) studies in the future should be supplemented with a smolt outmigration trapping program during years when the habitat above the dam is seeded (i.e., soft hatchery or spawner transplants), to define migration timing for those populations, due to its implications for estimating entrainment and subsequent mortality through the dam.

Addressing Key Uncertainties

Characterization of fish community assemblage – Other fish species of the same size as the released Sockeye Salmon smolts may be present in the forebay and migrate through either passage route (spillway or turbine intakes). Characterization of the fish community assemblage in the forebay will be achieved through a series of trawl hauls from the acoustic survey boat while performing the acoustic survey, and through the use of Nordic gillnets. The net will be directed in the main fish layer for species and size verification and reference for age class size structure. This will aid in the proper identification of sockeye smolts on the hydroacoustic images.

DATA PROCESSING AND ANALYSIS

The acoustic data will be processed and analyzed by Aquacoustics in Echoview software. The analysis will include a manual review of the data, noise filtering, algorithm-based fish tracking and a final manual review to ensure best possible accuracy.

The analysis of the fixed-site test data will focus primarily on an examination of potential noise issues and general tracking performance. More quantitative results are expected from the mobile surveys, which will be processed to produce a time series of abundance and spatial patterns by fish size.

In addition, imaging sonar may be able to provide some qualitative high-resolution information on fish behavior.

PROJECT TIMELINE

The following timeline is proposed:

- early April: Acoustic Reconnaissance Site Visit
- mid–April: Acoustic deployment at spillway, intake and Noise Level Detection
- late April: Adjustment of acoustic gear (if needed based on Noise Level Detection)
- June: Smolt release and mobile acoustic surveys: (this may be adjusted slightly based on flows and temperature)
- June–August: Data processing
- August–November: Data Analysis
- November–February: Reporting

KEY DELIVERABLES

The final deliverable will be a detailed report including the following pieces of information:

1. Assessment of the suitability of split beam hydroacoustic systems for performing (a) mobile surveys of fish distribution and density in the forebay, and (b) fixed monitoring of the spillway and intakes.
2. Species assemblage in the Dam forebay derived from sampling.
3. An estimate of entrainment rates for juvenile sockeye smolts and resident fish (if technology is suitable).
4. Recommendations for optimal hydroacoustic equipment configuration and monitoring plan for future entrainment studies.

RISKS & BENEFITS

There are no anticipated major negative impacts on the fish, wildlife, habitat, or heritage resources associated with the execution of this study. Minor impacts include entrainment and possible mortality of hatchery test fish released into the head-pond which has been supported by DFO. A permit will be obtained from DFO's ITC for releasing the smolts above the dam.

There are inherent safety risks when working around hydroelectric dams. Field staff will receive safety training by BC Hydro as outlined in the attached safety plan. The safety plan will be reviewed by BC Hydro and implemented throughout the project duration.

Benefits to potential non-targeted environmental components include the assessment of entrainment of resident fish through the dam. Entrainment of resident fish is suspected to occur but has never been confirmed or quantified.

MEASURE OF SUCCESS

The effectiveness testing of acoustic technologies for assessing entrainment at Hugh Keenleyside Dam will be achieved based on analysis of background noise levels and ability of the tools to sample targets at each passage route location. The test results will be used to characterize the effectiveness of each deployment and gear type by listing strengths and limitations of each. The project objectives will be met when it is clear whether the technology is feasible (i.e., can or cannot detect test fish) and there is a clear set of hydroacoustic methodologies and configurations developed for the forebay, intake and spillway survey locations.

REFERENCES

Biosonics, Inc. 2011. Revelstoke Reservoir kokanee behavior and entrainment rate assessment. Interim Report: 10-87057-002 submitted 5 July 2011 to BC Hydro, Burnaby, BC.

Fish & Wildlife Compensation Program (FWCP). 2019. Columbia Region: reservoirs and large lakes action plan. Report for Fish & Wildlife Compensation Program, Vancouver, BC.

Johnson, R., I. Yesaki, and S. Grant. 1990. Hydroacoustic monitoring of sockeye salmon smolt outmigration at Seton Dam. Unpublished report prepared for BC Hydro by Canadian Biosonics Ltd. 22 p.

Johnson, P. N., F. A. Goetz, M. E. Hanks and G. R. Ploskey. 2001. Fish passage investigations at the Hiram M. Chittenden Locks, Seattle, Washington, in 2000. Technical report submitted to the U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Ploskey, G. R., M. A. Weiland, C. R. Schilt, P. N. Johnson, M. E. Hanks and J. R. Skalski. 2005. Hydroacoustic evaluation of fish passage through Bonneville Dam in 2004. Technical report submitted to the U.S. Corps of Engineers, Portland District, Portland, Oregon.

Study 19 Acoustic Tag Based Smolt Survival Study

Based on work by Blue Leaf Environmental

STUDY DESIGN

Statistical Design

To estimate the survival of out-migrating juvenile salmon through areas of interest (Study Reach) with little or no passage and survival information, we propose the application of a paired release study design (Townsend et al. 2006) with a tag life correction (Skalski & Whitlock 2020), similar to that used in the 2007, 2008 and 2010 Chelan PUD survival evaluations (Skalski et al. 2008a,b, 2010) and 2014 - 2018 Grant County PUD survival evaluations (Hatch et al. 2015, 2016, 2017, 2018). This design utilizes fish releases paired temporally at upstream and downstream release locations, with detection arrays at two locations downstream of the lower release site. The paired upstream and downstream release groups are treated the same way in every respect (same taggers, same transport times, etc.), except that the upstream groups are released into the river in advance of their paired downstream group. Using these methods, the upstream fish will pass the downstream release location at the same time that the downstream fish are being released; therefore, both release groups become mixed as they continue downstream. In locations with unknown travel times between release sites, historical precedence from other studies in similar systems can be used as a guide.

The proportion of the upstream release group that is recorded on the detection arrays will be a function of the proportion that survive the tagging and handling effects, the proportion that survive through the Study Reach, the proportion that survive from the downstream release location and the detection arrays, tag life effects, and array detection probabilities. By contrast, the proportion of the downstream release group that is detected will be a function of all the same factors except for the survival proportion through the Study Reach. As such, the ratio of the detection proportions of the two groups is equal to the survival rate for fish that travelled through the Study Reach (Figure 1). All other factors affecting the survival and detectability of the upstream group will also affect the downstream group and are therefore ‘cancelled out’ in the analysis. Nevertheless, we recommend that the paired release design be optimized with an independent Tag Life Study to detect and correct for any potential issues regarding tag failure events (e.g., Skalski & Whitlock 2020). Two schematics are provided as examples for studying survival from Arrow Lakes through Keenleyside Dam (Figure 1) and from the Transboundary Reach to Lake Pateros (Figure 2). When studying survival over such a distance as the Transboundary Reach to Lake Pateros it may be desired to include additional release and detection locations (for example at Grand Coulee and Chief Joseph dams) to identify areas along the migration which have lower survival. Also, additional receiver arrays would provide finer-scale information about movements, and locations where mortality may be an issue. Additionally, a greater number of receivers would be required to determine the passage route (powerhouse vs spillway) used by individual fish.

As an interim step, a smaller survival study could be done which monitored out-migrating smolt to a point (for example Kettle Falls or the mouth of the Spokane River) where existing studies by UCUT could provide insight into survival from that point downstream to Lake Pateros.

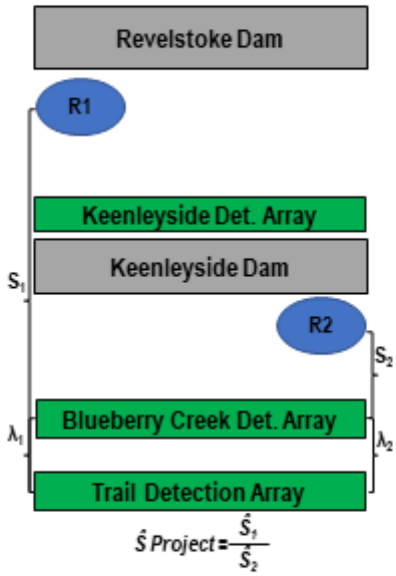

Figure 1. Schematic outlining a simplified layout of the paired release survival model through Keenleyside Dam.

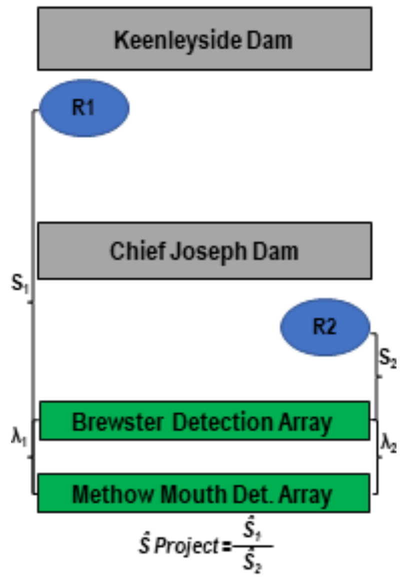

Figure 2. Schematic outlining a simplified layout of the paired release survival model through Lake Roosevelt and Rufus Woods Lake.

Alternative release designs are available (e.g., single release design) and have their advantages (e.g., fewer tags required). However, we believe that the paired release design with a tag life correction is the most appropriate method for this application because it is effective at controlling for handling effects and tag life effects, thus reducing the bias of the resulting survival estimates. Other survival models are being used in other jurisdictions (e.g., ViPRe, and ViRDCt; Harnish et al 2020), but these are designed to work with 'virtual release groups' (i.e., in-river fish that reach a given location, and are treated as if they were purposefully released there as part of the experimental design). The virtual releases are necessary when route-specific survival estimates are required, or when dam vs. pool survival needs to be parsed out.

Acoustic Telemetry System

Our team believes that JSATS acoustic tag technologies (McMichael et al. 2010) are the best choice for the survival study. JSATS has been adopted basin wide as the preferred technology for juvenile salmonid survival and behavior studies. JSATS was specifically designed and developed for that purpose by the Pacific Northwest National Laboratory (PNNL), and for the last decade it has exclusively been used for survival studies at Federal Columbia River Power Systems, at Public Utility District No. 2 of Grant County (Grant PUD), and by many other hydropower operators in the Columbia River basin. JSATS tags were developed to transmit at 417.6 kHz which allows optimization for small tag size, long battery life, large detection ranges, and resistance to noise interference. The tags use a 31-bit binary phase-shift keyed (BPSK) signal to transmit unique tag codes which, due to their short (744 µs) transmission time and the nature of BPSK phase modulation, minimizes the degree of signal corruption in noisy environments around hydropower facilities (McMichael et al. 2010). Both cabled and autonomous receivers are available to construct detection arrays on and near dams, or in-river. Autonomous receivers have a battery life of 100 days and can be deployed with minimal cost/time/infrastructure on the riverbed with anchors and acoustic releases (minimizing navigation hazards or tampering). Following study completion, acoustic releases can be activated, bringing the loggers to the surface for retrieval and download. JSATS and these deployment methods have been successfully used for smolt survival studies at Wanapum, Priest Rapids, and Rock Island dams since 2011 (e.g., Thompson et al. 2012, Hatch et al. 2018). Regardless, it should be noted that JSATS is not the only technology available for survival studies. Use of Vemco / Innovasea gear would follow the same methods and protocols, but would differ in a few ways, such as the size of fish that can be tagged (JSATS tags are smaller and can be implanted in smaller fish). Conversely, there are extensive Vemco receiver arrays in place in the Transboundary Reach (BC Hydro), in Wells, Rocky Reach, Wanapum, and Priest Rapids reservoirs (Douglas, Chelan, and Grant PUDs), and in marine areas (NOAA, DFO) that can be leveraged to reduce overall costs of a survival study.

Sample sizes

The numbers of fish required to conduct these survival analyses will be based on precision goals, and expected survival rates and detection probabilities. For example, a study that required 2.5% precision on survival estimates would require many more tags than one with 10% precision (the former might be needed to meet licencing requirements or for a statistical comparison between dams or across different operational periods; whereas the latter may suffice for reintroduction planning needs). Smaller numbers of fish are required in situations where survival and detection efficiency are expected to be high. This is because the precision of the survival estimate is related the total numbers of fish that are detected at the downstream-most arrays in the study area (if a high proportion of the fish are detected, then fewer fish need to be released to achieve the same level of precision). For reference, a recent survival study at Rocky Reach Dam was able to achieve 1% precision with a total sample size of 1003 smolts, in a situation where survival was high (94.4%) and detection probability approached 100% (Hatch et al. in prep).

References

Hatch, K.B., M.A. Timko, L.S. Sullivan, S.E. Rizor, J.R. Skalski, R.L. Townsend, and C.L. Dotson. 2015. Behavior and survival analysis of juvenile steelhead and yearling Chinook Salmon through the Priest Rapids Hydroelectric Project in 2014. Report for Public Utility District No. 2 of Grant County, Ephrata, WA.

Hatch, K.B., L.S. Sullivan, M.A. Timko, J.R. Skalski, R.L. Townsend, and C.L. Dotson. 2016. Behavior and survival analysis of juvenile steelhead and Sockeye Salmon through the Priest Rapids Hydroelectric Project in 2015. Report for Public Utility District No. 2 of Grant County, Ephrata, WA.

Hatch, K.B., L.S. Sullivan, M.A. Timko, N.L. Ogan, J.R. Skalski, R.L. Townsend, and C.L. Dotson. 2017. Behavior and survival analysis of juvenile steelhead through the Priest Rapids Hydroelectric Project in 2016. Report for Public Utility District No. 2 of Grant County, Ephrata, WA.

Hatch, K.B., M.A. Timko, L.S. Sullivan, N.L. Ogan, J.R. Skalski, R.L. Townsend, and C.L. Dotson. 2018. Behavior and survival analysis of juvenile steelhead through the Priest Rapids Hydroelectric Project in 2017. Report for Public Utility District No. 2 of Grant County, Ephrata, WA.

McMichael, G.A., M.B. Eppard, T.J. Carlson, J. A. Carter, B.D. Ebberts, R.S. Brown, M. Weiland, G.R. Ploskey, R.A. Harnish, and Z.D. Deng. 2010. The Juvenile Salmon Acoustic Telemetry System: A New Tool. Fisheries 35(1): 9-22.

Skalski, J.R., and S.L. Whitlock. 2020. Vitality models found useful in modeling tag-failure times in acoustic-tag survival studies. Animal Biotelemetry. DOI: 10.21203/rs.3.rs-27303/v1

Skalski, J.R., R.L. Townsend, T.W. Steig, P.A. Nealson, and A. Grassell. 2008a. Survival of yearling Chinook Salmon smolts through the Rock Island Project in 2007. Report for Public Utility District No. 1 of Chelan County, Wenatchee, WA.

Skalski, J.R., R.L. Townsend, T.W. Steig, P.A. Nealson, and S. Hemstrom. 2008b. Final report: survival of yearling Chinook Salmon, steelhead, and Sockeye Salmon smolts through the Rock Island Project in 2008. Report for Public Utility District No. 1 of Chelan County, Wenatchee, WA.

Skalski, J.R., R.L. Townsend, and T.W. Steig. 2010. Survival of yearling Chinook Salmon and steelhead smolts through the Rock Island Project in 2010. Report for Public Utility District No. 1 of Chelan County, Wenatchee, WA.

Thompson, A.M., R.R. O'Connor, M.A. Timko, L.S. Sullivan, S.E. Rizor, J.L. Hannity, C.D. Wright, C.A. Fitzgerald, M.L. Meagher, J.D. Stephenson, J.R. Skalski, and R.L. Townsend. 2012. Evaluation of downstream juvenile steelhead survival and predator-prey interactions using JSATS through the Priest Rapids Reservoir in 2011. Report for Public Utility District No. 2 of Grant County, Ephrata, WA.

Townsend, R.L. J.R. Skalski, P. Dillingham, and T.W. Steig. 2006. Correcting bias in survival estimation resulting from tag failure in acoustic and radiotelemetry studies. Journal of Agricultural, Biological, and Environmental Statistics 11: 183.