COLUMBIA MOUNTAINS INSTITUTE *of Applied Ecology*

Regulated Rivers II: Science, Restoration, and Management of Altered Riverine Environments

May 8-9, 2019
Nelson, British Columbia
Canada

Columbia Mountains Institute of Applied Ecology

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Posters

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- **Catherine Craig**, Hemmera
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- **Virgil Hawkes**, LGL Ltd. Environmental Research Associates
- **Mike Miller**, LGL Ltd. Environmental Research Associates
- **Carrie Nadeau**, Associated Environmental Consultants Inc.
- **Pier van Dishoeck**, Selkirk College
- **Brendan Wilson**, Selkirk College
- **Michael Zimmer**, Okanagan Nation Alliance
- **Hailey Ross** and **Mia King**, Columbia Mountains Institute

We ***thank*** our conference volunteers, Catherine Craig, Hemmera, Mat Ferraro, Selkirk College, Phillip Lemire, Selkirk College, Geneviève Létourneau, Selkirk College.

Our presenters and the people who brought posters and displays travelled from various communities in British Columbia, Idaho, and Utah. We are grateful for your willingness to share your knowledge with us, and for the support of your agencies in sending you to our event.

Conference description

Regulated waterways provide important services such as flood regulation, power generation with low greenhouse gas emissions, and energy storage. Nevertheless, the damming and regulation of rivers incurs ecological costs via the operation of reservoirs and alteration of downstream flows, combined with the often permanent loss of valley bottom habitat. Regulation affects both upstream (reservoir) and downstream environments, and does so at a range of scales. An increase in smaller hydro-electric (i.e. run-of-river) projects has led to a spike in research around their unique impacts, and many of these projects are concluding their 5-10 year monitoring programs. Several multi-year studies on large reservoir systems (e.g., Arrow Lakes and Kinbasket) in the Columbia River basin are also now nearing completion and these results may play a role in determining future operational scenarios under the Columbia River Treaty. Despite their large footprints, considerable ecological function remains in these regulated systems. The wealth of research that continues to emerge increases our understanding of ecosystem processes within regulated rivers with the potential to mitigate footprint and operational impacts to plants, fish, and wildlife.

This 2019 conference, which was a follow-up to the 2015 "Regulated Rivers: Environment, Ecology and Management" conference held in Castlegar, provided a platform for the dissemination of findings to peers, First Nations, stakeholders, students, and community members from studies that were nearing completion or had been completed since 2015. With two days of presentations, a poster session, and networking opportunities, this conference provided an opportunity for scientists and managers to share results of recent research on regulated river environments, processes, and operations in the Pacific Northwest and elsewhere. Eva Schindler gave a public talk on May 8 which was open to the public with a crowd of about 100 people.

This conference was held in Nelson at the Prestige Lakeside Resort and Convention Centre, May 8-9, 2019. Approximately 105 people attended the conference.

The summaries of presentations in this document were provided by the speakers. Apart from small edits to create consistency in layout and style, the text appears as submitted by the speakers.

The information presented in this document has not been peer reviewed.

About the Columbia Mountains Institute of Applied Ecology
www.cmiae.org

The Columbia Mountains Institute of Applied Ecology (CMI) is a non-profit society based in Revelstoke, British Columbia. CMI is known for hosting balanced, science-driven events that bring together managers, researchers, educators, and natural resource practitioners from across southeastern British Columbia. CMI's website includes conference summaries from all of our events, and other resources.

Summaries of presentations

Ecosystem impacts of dams in the East and West Kootenays

Presenter: **Alan Thomson**, Mountain Station Consultants

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Introduction

The Dam Impacts presentation provides a brief overview of a project initated by the The Fish and Wildlife Compensation Program: Columbia Basin (FWCP:CB) in 2005[1]. The FWCP:CB was established to offset footprint impacts of BC Hydro dams and reservoirs on fish and wildlife in the basin. Objectives of the FWCP:CB are to: 1) meet BC Hydro water license obligations with regard to compensation of fish and wildlife impacted by dam construction in the Columbia Basin, and 2) to sustain and enhance fish and wildlife populations by undertaking projects with potential to mitigate impacts resulting from BC Hydro projects. The FWCP:CB program area includes the BC portions of the Kootenay and Columbia drainages, east of the Monashee Mountains. The program addresses impacts related to 12 dams and associated reservoirs, including impacts on Kootenay Lake (see Fig. 1).

[1] This paper and the conference presentation are adapted from the Dam Footprint Impacts Report and its Executive Summary authored by G. Utzig and D. Schmidt, available at: http://www.sgrc.selkirk.ca/bioatlas/pdf/FWCP-CB_Impacts_Summary.pdf

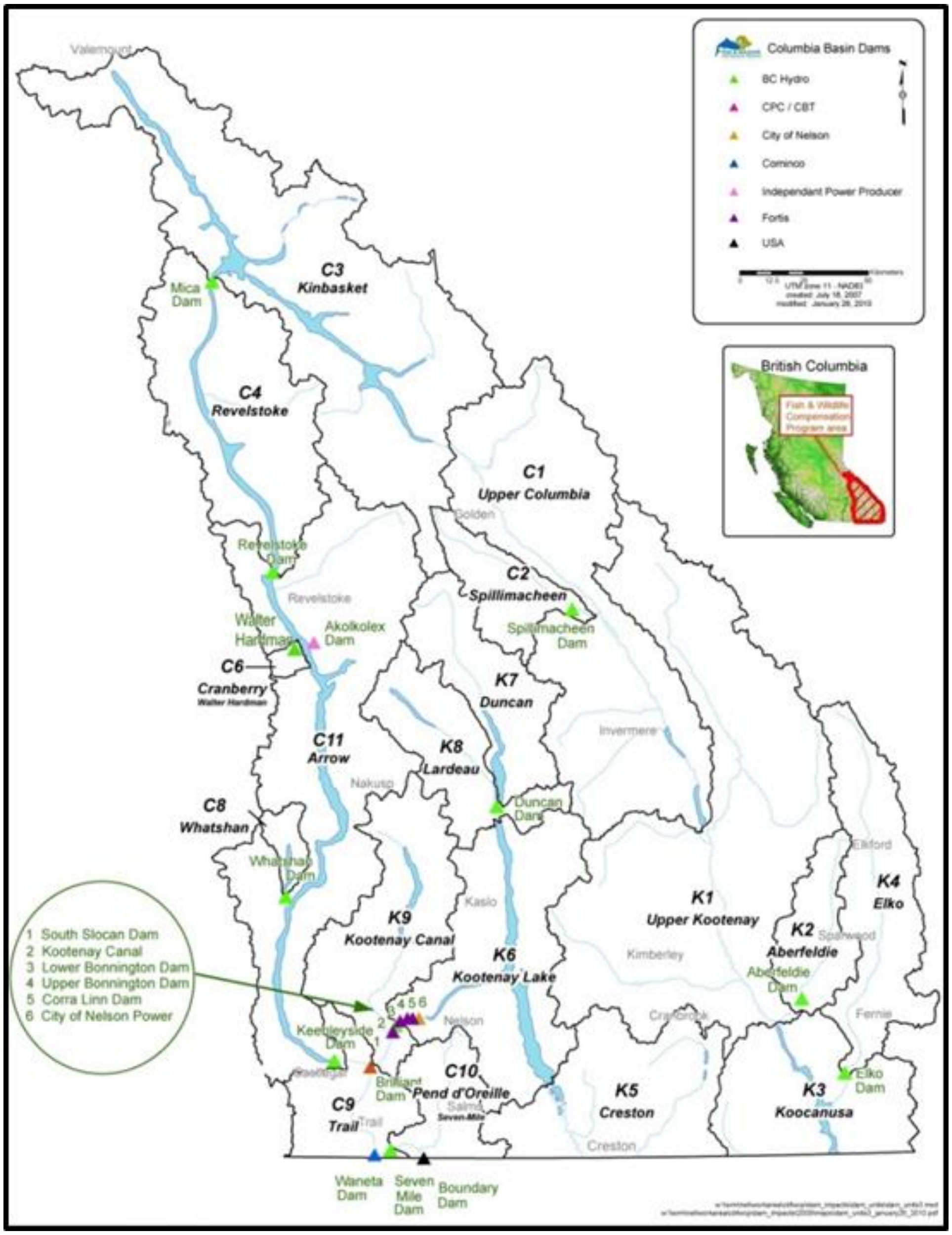

Figure 1. Columbia/ Kootenay basins in Canada; major dams, reservoirs and study units.

They undertook the dam impacts project to update understanding of the impacts of the dams, to support ongoing strategic and program planning, to assist in prioritization of compensation options, and to facilitate reporting the progress of addressing impacts. Study objectives included: improved quantification and increased understanding of the significance of the impacts to fish and wildlife, their habitats, ecosystem function and fish-wildlife interactions, and the identification of the range of compensation options.

The Columbia River has been extensively altered by dams built for flood control and hydroelectric power production in both Canada and the United States. At the time of dam construction, the amount and quality of impact assessments for fish and wildlife were not sufficient to fully assess the significance of potential impacts to ecosystems and species, particularly poorly understood species. The lack of this information has made it difficult for agencies, program sponsors and stakeholders to assess the progress toward compensation for the range of dam impacts.

Methodology and Results

The project was composed of five broad elements: 1) mapping of basic aquatic and terrestrial ecosystems within the dam footprints; 2) assessing changes in primary productivity; 3) assessing changes to aquatic and terrestrial habitats; 4) assessing impacts on individual fish and wildlife species; and 5) the identification of compensation options.

Pre-dam aquatic, wetland/floodplain and terrestrial ecosystems were mapped from pre-dam information sources, including aerial photographs, topographic maps and land class mapping. The ecosystem mapping demonstrated that each reservoir was unique with regard to the types, amounts and proportions of ecosystems impacted. The Arrow and Kinbasket Reservoirs occupy the largest footprints at 51,270 and 42,650 ha respectively. The Revelstoke (11,450 ha), Duncan (7,300 ha) and Koocanusa (6,685 ha) reservoirs are also fairly extensive. The Whatshan (1,770 ha) and Pend d'Oreille (430 ha) are somewhat smaller, and Kootenay Canal, Aberfeldie, Elko, Cranberry, and Spillimacheen reservoirs are less than 50 ha each. The pre-dam ecosystem composition of the Arrow and Whatshan Reservoirs were dominated by pre-existing lakes, while the Kinbasket, Revelstoke, Koocanusa, Pend d'Oreille, and Spillimacheen were dominated by forested ecosystems and large river systems, and the Kootenay Canal by forested ecosystems. The Duncan footprint included a complex mix of lakes, forests and wetlands. All footprints included varying lengths of river and/or stream ecosystems.

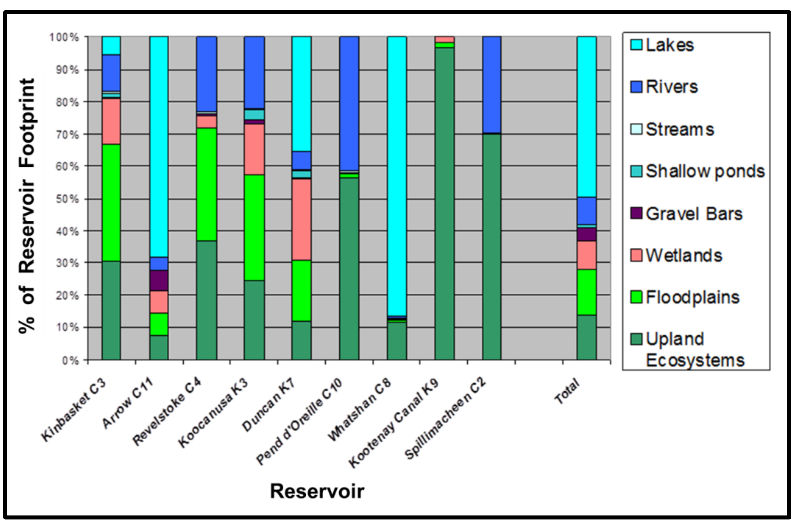

Figure 2. Area percentages for various pre-dam aquatic and terrestrial ecosystems by reservoir.

Primary productivity was calculated for the pre-dam aquatic, wetland/floodplain and upland ecosystems, and for the new reservoirs. Methods for determining primary productivity varied depending on the type of ecosystem; however, most pre-dam calculations relied on modeling and/or comparisons with other similar ecosystems in BC due to the lack of pre-dam information. Overall pre-dam gross primary productivity within the dam footprints was estimated at approximately 870,000 tons of C/yr, with approximately 95% of that from forested ecosystems. Post-dam reservoirs have an estimated gross primary productivity of about 29,600 tons of C/yr, resulting in a net loss of over 840,000 tons of C/yr. Variation in primary productivity changes between reservoirs was principally dependent on footprint area and the proportion of forested ecosystems.

Impacts on aquatic habitats were assessed by comparing the pre-dam habitats within the footprints with the total aquatic habitats within the Columbia Basin (see Fig. 3). Significant areas of lotic (riverine) habitats were lost because of flooding (1600 linear km or 12,000 ha), with low elevation, low gradient rivers having the most significant losses. Lentic (lake/reservoir) habitat has been significantly increased in area, from 41,450 ha to 110,800 ha. However, the diversity and type of lentic habitats has been altered, with 12 lakes being replaced by 12 reservoirs. Changes in littoral habitats vary from reservoir to reservoir. Littoral habitats within storage reservoirs are subjected to larger variations in water levels than natural lakes, while most of the run of the river reservoirs and regulated Kootenay Lake, have water level stability similar to or more than that of comparable natural lakes in the region, including some lakes that were inundated. A risk assessment, based on losses as a proportion of similar terrestrial habitats available in the Columbia Basin (see Fig. 4), demonstrated that across the various dam units, loss-induced risks were: very high for very wet forests (4780 ha, 19%), wetlands (7700 ha, 26%) and gravel bars (3660 ha, 53%); high for wet forests (28,760 ha, 10%), cottonwoods (5530 ha, 21%) and shallow water/ponds (1070 ha, 31%); and medium high for intermediate forests (15,660 ha, 2%). Losses of lake and river shoreline habitats were rated high for Kinbasket (980 km) and Arrow (680 km) reservoirs, while Revelstoke (350 km), Duncan (200 km) and Koocanusa (310 km) were rated medium high. Within the drawdown zones of some reservoirs there have been new ecosystems established, especially in the Revelstoke Reach of the Arrow Reservoir. Even though some of these simplified communities produce large quantities of vegetation, their value for higher trophic levels is limited.

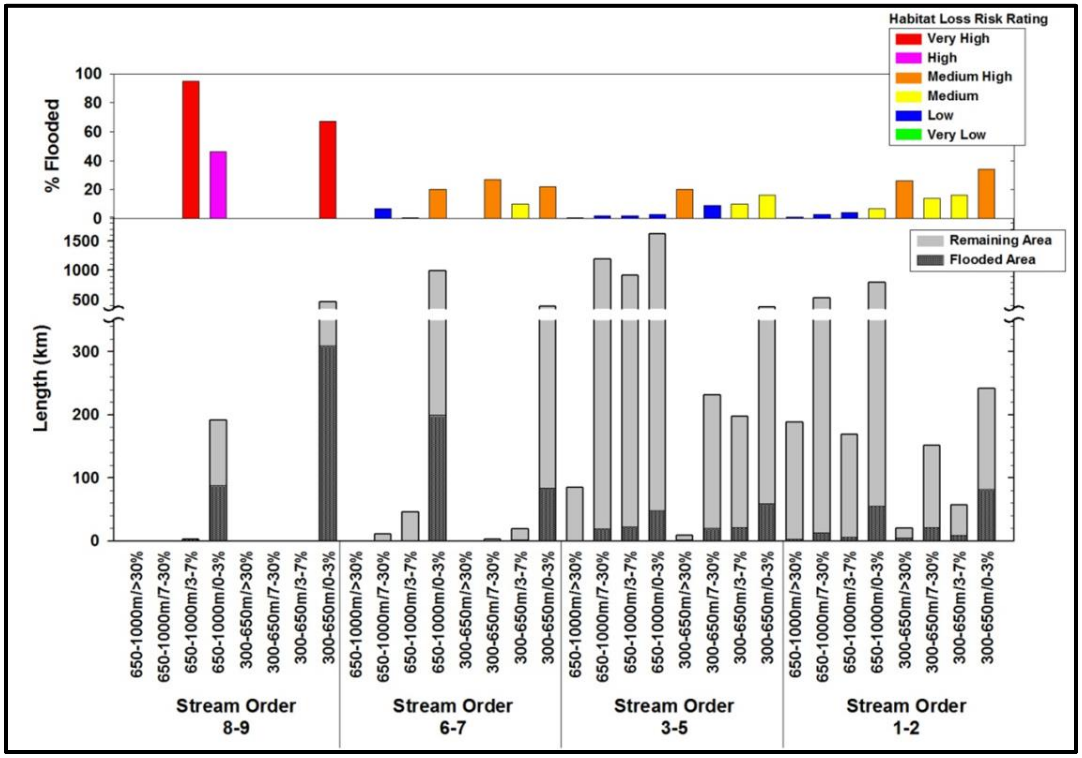

Figure 3. Total length and significance of aquatic stream losses by stream order, elevation and gradient, across all affected Dam Units. Percent flooded relates to the pre dam baseline.

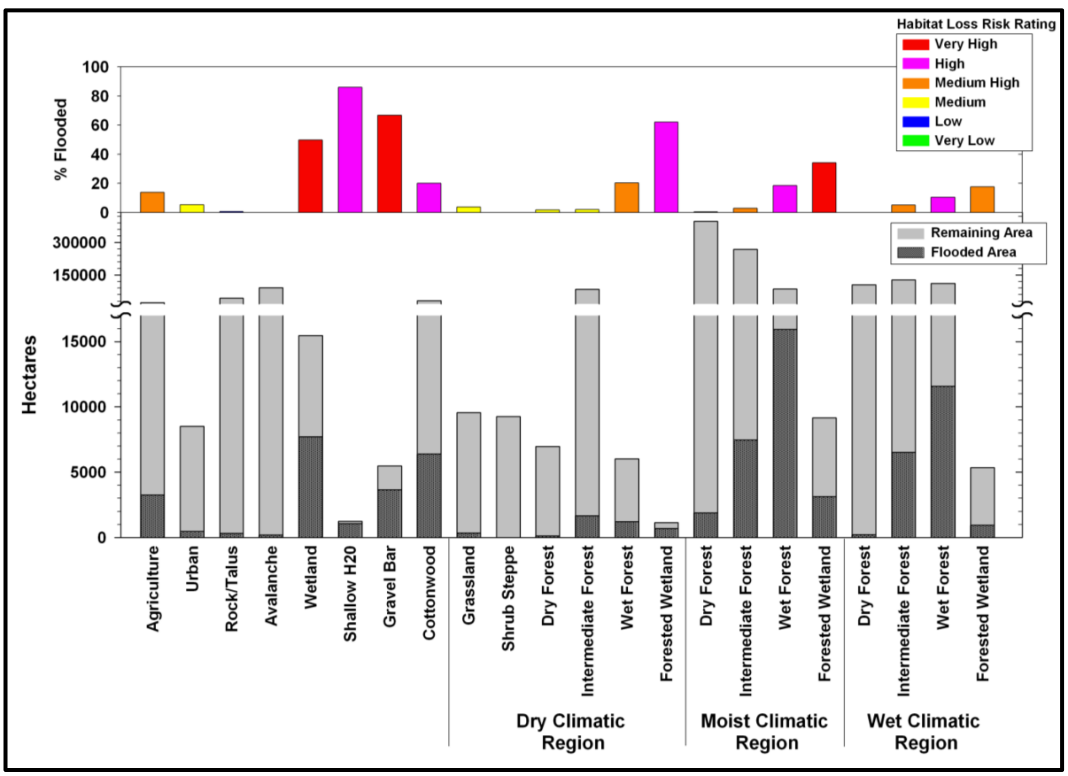

Figure 4. Significance of terrestrial habitat losses, by ecosystem type, across all dam units.

Fish species impact assessments described a wide range of impacts, although the significance of particular impacts on individual species varied considerably depending on the life history of the species. Impacts were assessed in detail for 5 fish species, and to a lesser extent for 19 other species. The major impacts reported include loss of riverine habitat affecting some stage of the life history (e.g., kokanee, rainbow trout, bull trout, sculpins, dace, minnows, suckers), nutrient losses (e.g., kokanee, piscivorous rainbow trout, bull trout, sculpins, chubs), changes in flow regimes (e.g., white sturgeon), changes in water quality/turbidity (e.g., white sturgeon, rainbow trout, kokanee, mountain whitefish, sculpins), habitat/population fragmentation (e.g., white sturgeon, bull trout, rainbow trout), and entrainment (e.g., kokanee). In contrast, species that were able to take advantage of the extensive increases in lentic habitat, may have benefited from reservoir establishment in some situations (e.g., kokanee, burbot, lake chub, bull trout).

Wildlife impacts were evaluated for 289 vertebrate species using habitat loss information and species-habitat associations (see Fig. 5). Sixty-four Priority 1 species including: 3 amphibians, 1 reptile, 45 birds and 15 mammals had high habitat impacts, and agency emphasis for conservation and/or management. Forty-six Priority 2 species including 38 birds and 8 mammals had high habitat impacts, but were low agency conservation or management priority. Species with the highest habitat impacts were wetland and riparian specialists such as amphibians, waterbirds, waders, songbirds, bats and aerial insectivores. Overall species impacts mirrored substantial habitat losses, particularly in Kinbasket, Arrow and Duncan dam units.

In addition to direct habitat and species impacts, the dams have also had significant impacts on ecological functions and processes. These include altered annual hydrologic regimes and floodplain processes, as well as disrupted biological processes such as natural disturbance regimes, trophic dynamics and nutrient cycling. The dams and reservoirs have impacted functions for individual species and populations, including seasonal migrations, genetic exchange, predator/prey relationships, reproduction and dispersal. These impacts can extend into non-impacted watershed units, especially those downstream of dams and reservoirs (e.g., Kootenay Lake, lower Columbia River).

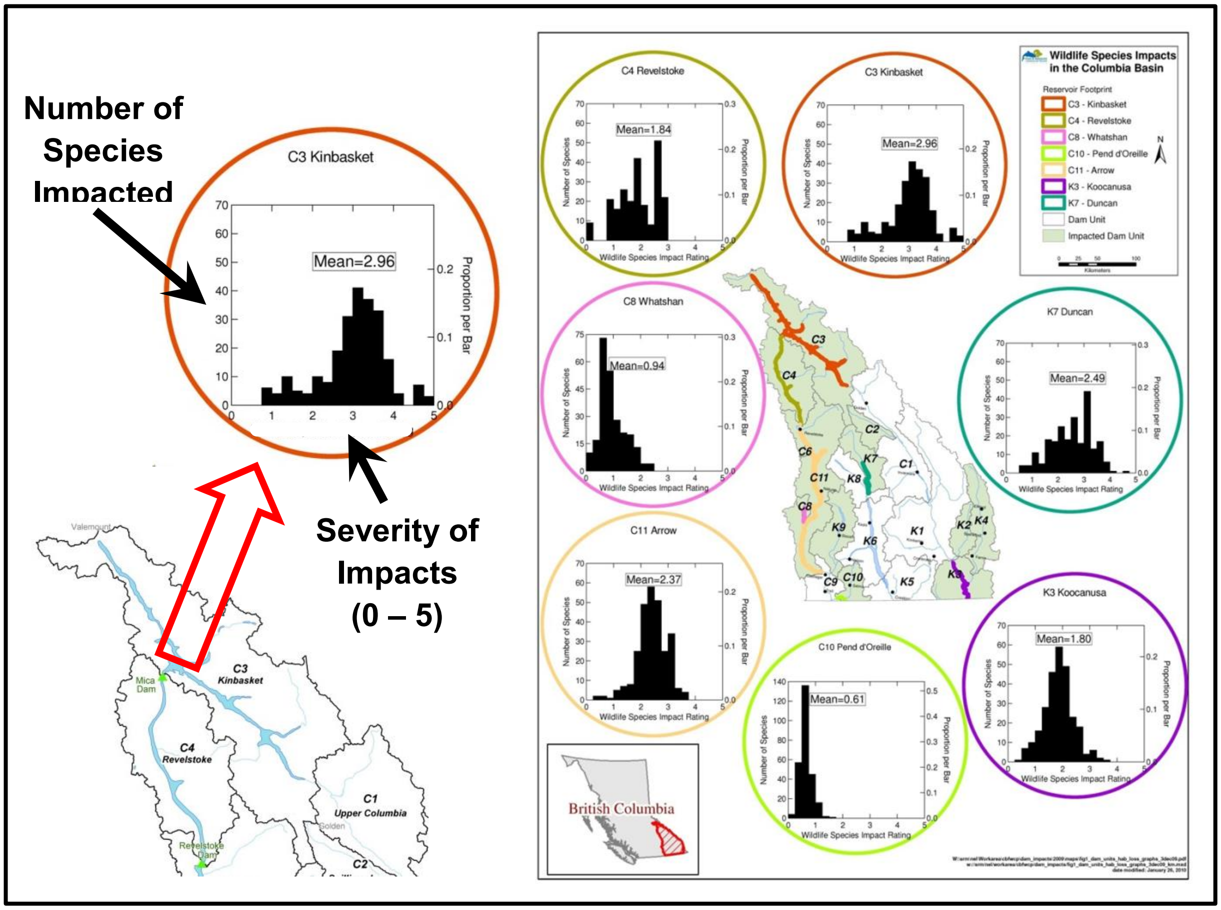

Figure 5. Species impacts by dam unit for the larger reservoirs. Graphs indicate the frequency and proportion of species for the range of Wildlife Species Impact Ratings (each bar represents a 0.25 increment of rating value, with 1.0 being very low and 5.0 very high).

Compensation Options

Potential compensation opportunities identified in the series of impact assessment reports were summarized. Compensation options included various projects for both aquatic and terrestrial ecosystem restoration and creation (e.g., stream channel works, lake fertilization, stand structure treatments, restoration of connectivity); habitat securement, stewardship and management (mainly off-site); and species-specific projects for inventory, research, predator/prey manipulation and artificial population/habitat enhancement (e.g., spawning channels, hatchery production, captive rearing, re-introductions, nest boxes). Long-term investments in these activities will contribute to meeting the water license conditions that gave rise to the FWCP:CB, and provide valuable support to maintaining the biodiversity of the Columbia Basin. Other presentations at this conference concerning the Stable Mid-Arrow study, First Nations Restoration projects and recommendations from UCBEC offer further options for improving and/or restoring ecosystems impacts by dams and reservoirs in the region.

Acknowledgements
This work was initiated and funded by the Fish and Wildlife Compensation Program: Columbia Basin (FWCP:CB). The report summarized here is based on various individual studies completed by a number of authors, all of whom are elaborated in the report available at the website indicated in footnote 1. Their original work is gratefully acknowledged. The presentation was adapted from an earlier version prepared by John Krebs and myself. Many thanks to Alan Thomson who delivered the presentation on my behalf.

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Assessing the relationship between flow and egg predator abundance within white sturgeon (*Acipenser transmontanus*) spawning habitat below Waneta Dam, Pend d'Oreille River, BC

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Co-author (lead author): Larry Hildebrand, RiverRun Consulting, Robson, BC
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Presentation Summary

The Waneta Dam, located on the Pend d'Oreille River, consists of the original Waneta Dam and generation plant (WAN) and the recently constructed Waneta Expansion Plant (WAX). White Sturgeon, an Endangered SARA listed species, spawn downstream of Waneta Dam within the confluence of the Columbia and Pend d'Oreille rivers (the Waneta area; Figure 1). A White Sturgeon Flow Augmentation Program (WSFAP-1998) was developed under the regulatory permitting process for WAN Upgrades in the late 1990s, to provide minimum daytime and nighttime flows from 1 June to 31 July in an attempt to provide conditions to promote spawning activity and help protect incubating sturgeon eggs. With the commissioning of WAX on 2 April 2015, permitted operations under the former WSFAP-1998 program were modified with agency approval to further enhance flow conditions in the Waneta area based on combined WAN/WAX operations. The revised operating order was called the WSFAP Post-Project Enhancement (WSFAP-PPE) program.

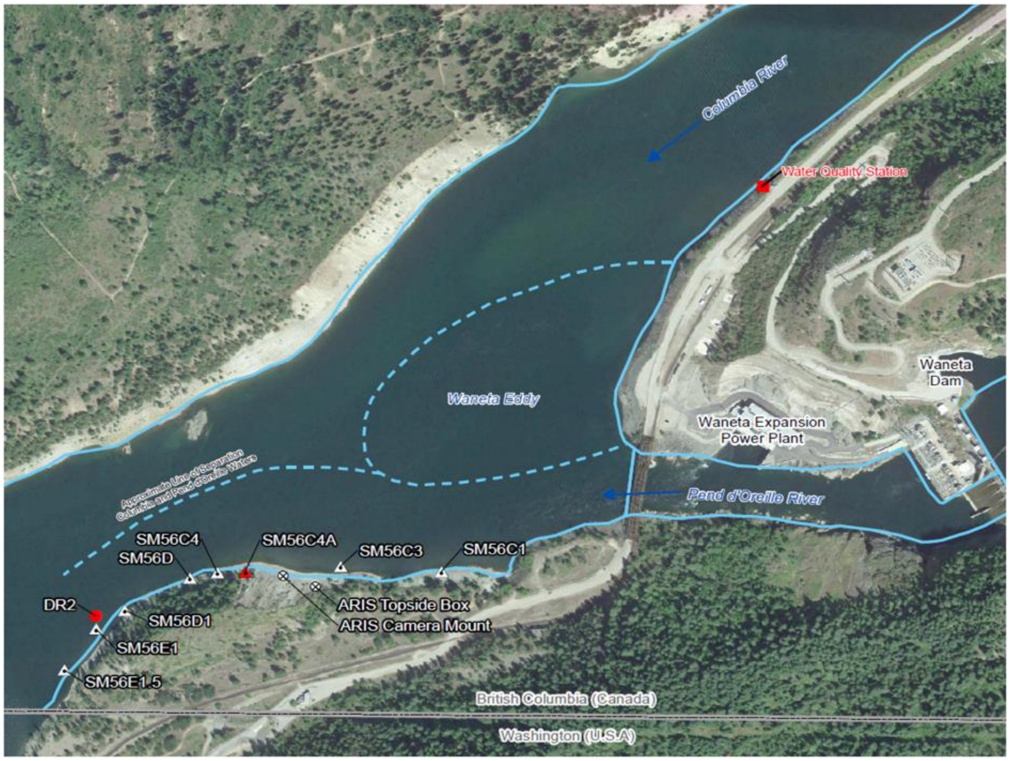

Figure 1. The confluence of the Columbia and Pend d'Oreille rivers below Waneta Dam and the Waneta Expansion, referred to as the "Waneta area" and a known White Sturgeon spawning location. White Sturgeon spawning monitoring

Under the WAX Environmental Assessment Certificate Application (EACA), the biological review concluded that WAX related changes to the downstream flow regime in the Waneta area would continue to provide conditions to stimulate spawning activity and would not result in a significant increase in predation on White Sturgeon eggs in the Waneta area to a degree that would have a detectable effect on White Sturgeon recruitment. To verify these predictions, the EACA required that the Owner (Columbia Power Corporation) conduct a multi-year study to assess post-Project effects on White Sturgeon spawning and egg predation within the Waneta area. These EACA commitments were addressed by the White Sturgeon egg predator and spawn monitoring program that was conducted annually from 2011 to 2017. The study consisted of a one-year pilot study in 2011 to validate the study design and methodologies, followed by six consecutive years of monitoring. The primary Study Objectives were 1) to monitor spawning intensity and frequency to determine spawning onset, cessation, and the number of annual spawning events, 2) to determine the relationship between spawn timing and egg predation, and 3) to identify relationships between the abundance of egg predators and flow during WSFAP-PPE operations at the Waneta facility. The presentation at the 8-9 May 2019 Regulated River Conference provided the results and comprehensive summary pertaining the relationship between egg predator abundance and operations at the Waneta Dam and the Waneta Expansion Projects (Study Objective 3).

Acoustic sonar cameras were deployed each study year to obtain egg predator density estimates in the vicinity of the main White Sturgeon egg deposition area. From 2014 onward, egg predator densities were recorded with an Adaptive Resolution Imaging Sonar (ARIS) camera deployed 65 m upstream of the SM56C4 index site at a location with moderate water velocity (see Figure 1). This ARIS monitoring site was selected due to its proximity to the main egg deposition area (near SM56C4) where historically, the majority of all White Sturgeon eggs have been captured (WEPC 2007; Golder 2015). In 2017, the ARIS sonar camera location was identical to the location used during the 2015 and 2016 studies, and within 15 m of the camera location used during the 2014 study. Deployment methodology, in terms of camera mounting and positioning, was the same across all study years (described in Golder 2015). ARIS data were processed following similar procedures as outlined in previous reports (see egg predator annual report series). Data were first subsampled to select two random 10-minute image files in each hour sampled. These files were then reviewed to estimate densities of potential egg predators. During the hours when not all six 10-minute files were complete (e.g., during servicing), files were randomly chosen from the number of files completed for those hours. At each 30 second interval within each 10-minute file (e.g., at 30, 60, 90, 120 seconds, etc.), the number of fish (i.e., potential egg predators) within the sample volume was estimated. Total numbers of fish were summed for each interval and mean hourly density estimates were calculated, along with 95% confidence limits, based on the 40 within-hour interval estimates (20 estimates for each of the two 10-minute files selected). Linear models were used to assess the effects of Pend d'Oreille River discharge and load shaping on the density of egg predators detected using the ARIS.

For Study Objective 3, cross-correlation of predictor variables, as well as autocorrelation, were identified during the 2011 pilot study and in the early years of the study program as potential obstacles that could limit the study's ability to delineate the effect of Waneta Dam operations on egg predation. Across all study years, the majority of egg predator density data recorded were confounded by cross correlation among the predictor variables that made it difficult to discern whether it was daylight, flow magnitude, or daily variability in flow that affected egg predator densities (Golder 2015). However, during the 2015, 2016, and 2017 studies, these confounded variables were resolved due to periodic disruptions of the typical diel load shaping operations (e.g., high flows during the day, low flows at night), interspersed with periods of either uniform flows or flow reversals (i.e., when peak flows occurred at night rather than during the day) and persisted over several diel light cycles (e.g., monitoring year 2015; Figure 2). These changes from load shaping operations to uniform flows did not disrupt the diel changes in egg predator density and provided evidence that the relative abundance of potential egg predators did not differ from random in relation to flow changes from the Waneta facility.

Through continual refinement of the study design based on lessons learned as the study progressed, the combined data from all study years successfully addressed the three primary Study Objectives. Intensive analysis of the study program results clearly showed:

- that there was no apparent relationship between flows from the Waneta facility and potential egg predator abundance;
- there was no detectable relationship between sturgeon spawning events and potential egg predator abundance, and;
- WAX operations do not have any discernable influence on White Sturgeon spawn timing or frequency.

These findings supported the initial EACA assessment of low impacts of WAX operation on White Sturgeon spawning activity and egg incubation success.

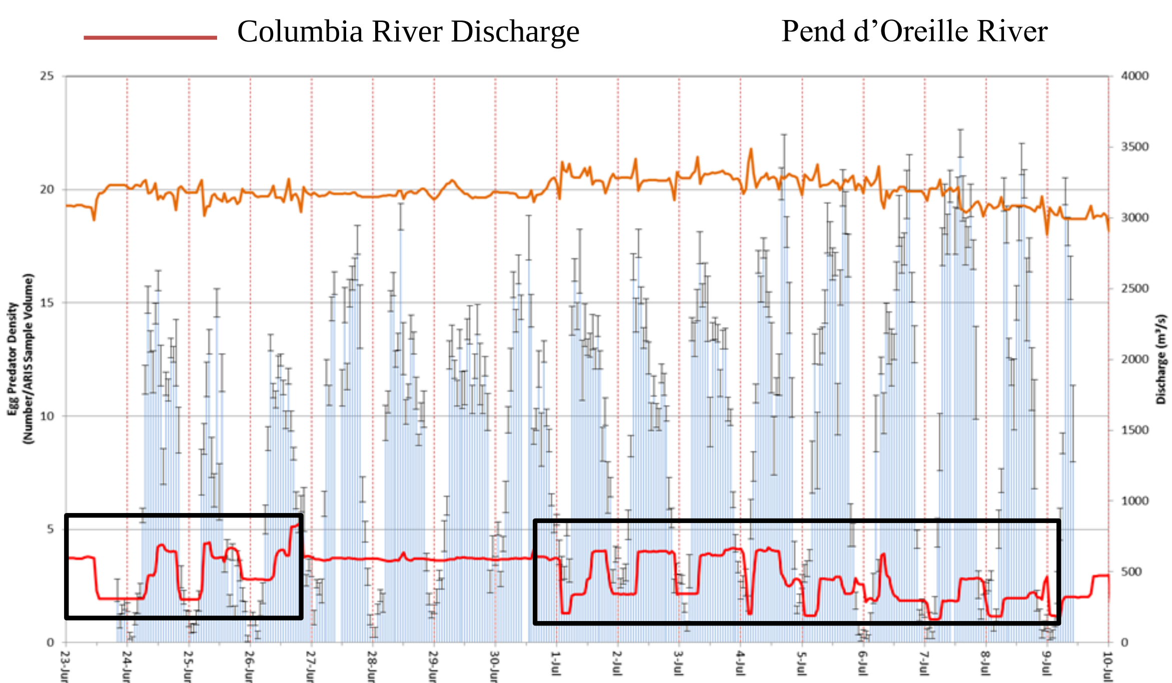

Figure 2. Hourly estimates of potential egg predator densities recorded by the ARIS near SM56C4 and plotted against Columbia River (orange line) and Pend d'Oreille River (red line) discharge, 23 June to 9 July 2015. Vertical dotted red line represent midnight. Black rectangles identify periods of load shaping flows at Waneta Dam under WSFAP PPE.

Acknowledgment
Funding for this study was provided by Columbia Power Corporation and BC Hydro.

Literature Cited

Golder Associates Ltd. 2015. Waneta White Sturgeon Egg Predation and Spawn Monitoring at Waneta: 2014 (Year 3) Investigations. Report prepared for Columbia Power Corporation, Castlegar, B.C. by Golder Associates Ltd., Castlegar, BC and LGL Environmental Ltd., Sydney, BC. Golder Report No. 1406038: 60 p.

Waneta Expansion Power Corporation (WEPC). 2007. Analysis of the potential for boundary release flow-through to affect White Sturgeon spawning/incubation success. Supplemental Analysis prepared for the Waneta Expansion EACA Review in collaboration with ASL Environmental Services, Golder Associates Ltd, and Klohn Crippen Berger Ltd. 34 pp + 4 app.

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Long-term consequences of anthropogenic flow fluctuations on population dynamics of coho salmon *(Oncorhynchus kisutch)*

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Presentation Summary

Flow regulation by dams can profoundly alter the natural flow regime of streams, creating conditions that differ from those to which native fish are adapted. Small-scale hydropower, and specifically Run-of-River (RoR) hydropower, has emerged as an alternative to traditional hydroelectric projects for providing renewable energy with perceived reduced environment impacts due to their smaller footprint (Abassi and Abassi 2011). RoR hydropower temporarily and opportunistically diverts a small absolute, but often large proportion, of river flow through underground tunnels that run for several kms until a powerhouse where electricity is produced, before all water is returned to the stream (Figure 1). The diversion of flow leaves a reach of the river, called the bypassed reach, with reduced flow compared to natural, un-regulated conditions. Many effects of flow regulation by RoR hydropower on stream ecosystems remain poorly understood, including on anadromous and resident salmonids that often inhabit the same regulated rivers (Gibeau et al. 2017).

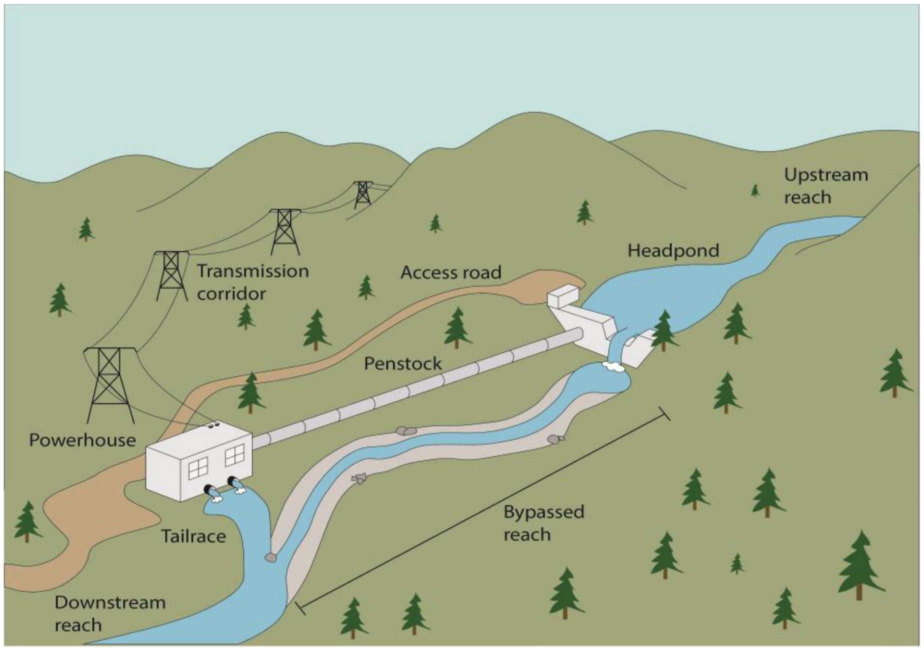

Figure 1. Representation of a typical RoR hydropower facility (from Gibeau et al. 2017).

One way how RoR hydropower may influence stream ecosystems and salmonids is by inducing anthropogenic flow fluctuations. Flow fluctuations occur because sudden changes in the amount of water running through the turbines to produce electricity directly translate into temporary, but sometimes drastic, declines in flow downstream of the powerhouse due to the lag in travel time through the bypassed reach as opposed to through the penstock. Flow fluctuations created by operations of RoR hydropower dams can induce fry mortality by stranding fish on dewatered river margins, with unknown consequences for population dynamics over time.

We hypothesized that the timing of RoR-induced flow fluctuations relative to salmonid density-dependent mortality bottlenecks (e.g. spring, winter) could moderate the potential for population-level negative impacts. Specifically, we evaluated how much fry mortality caused by RoR-induced flow fluctuations in the spring would reduce population sizes and increase the probability of local extinction if extra mortality occurred after the density-dependent bottleneck associated with fry emergence. We built a stochastic stage-structured matrix model parameterized with vital rates estimated from the literature to test these hypotheses for Coho salmon (*Oncorhynchus kisutch*), which spend up to 1.5 years in freshwater. We simulated population sizes and the 45-year extinction risk under scenarios that varied the frequency and magnitude of RoR-induced flow fluctuations compared to an un-impacted baseline population. Scenarios combined low (n=1 to 5), mid (n=6 to 10) and high (n=11-20) frequency of flow fluctuation events with low (1-2%) and high (5-10%) extra mortality due to the events. All events either occurred before or after the density-dependent mortality bottleneck associated with fry spring emergence, and simulations were performed for a stable (population size at equilibrium for the deterministic model) and a depressed population (set at half the stable population size). We assumed that the smaller, depressed population would be more vulnerable to the extra mortality induced by the anthropogenic flow fluctuations. The density-dependent function was parameterized with a Beverton-Holt model using data from 16 Coho populations of the Pacific North-West (Bradford 1995, Korman and Tompkins 2014) and adjusted to model strong (a=6.8) and mild (a=1.3) density-dependent mortality. The smolt carrying capacity was set to 1300 smolts, based on the generally small size of most streams with RoR hydropower infrastructure in British Columbia. Stochasticity was added to two rates (survival at emergence and ocean survival) by drawing random values from beta distributions.

Preliminary results suggest that the spring density-dependent mortality bottleneck can compensate for extra mortality caused by RoR-induced flow fluctuations, when the mortality occurs prior to the density-dependent bottlenecks and when stranding mortality is relatively small in magnitude. When the spring density-dependent mortality bottleneck was mild, the number of adults decreased only for the scenario with high frequency and high magnitude of events (Figure 2, blue lines). However, number of female spawners decreased as soon as the frequency of events was medium when the events occurred after the density-dependent mortality bottleneck (Figure 2, yellow lines). The population size was dramatically reduced when the frequency of events was medium or high, with high mortality; in fact, in the most extreme case (high frequency and high magnitude), the populations became extinct for all nearly all simulations. Results were similar when the density-dependent mortality was strong, except that then, the compensatory reserve within the density-dependence was able to compensate for all frequencies and magnitudes of events occurring prior to the bottleneck (Figure 3). Probability of extinction increased only for the medium frequency/high magnitude scenario (5.5% for the mild and 0.7% for the strong density-dependence cases) and for the high frequency/high magnitude scenario (99.9 and 92.2%, respectively). Results were similar for the depressed populations, suggesting that a low number of female spawners was enough to fully seed the simulated creek.

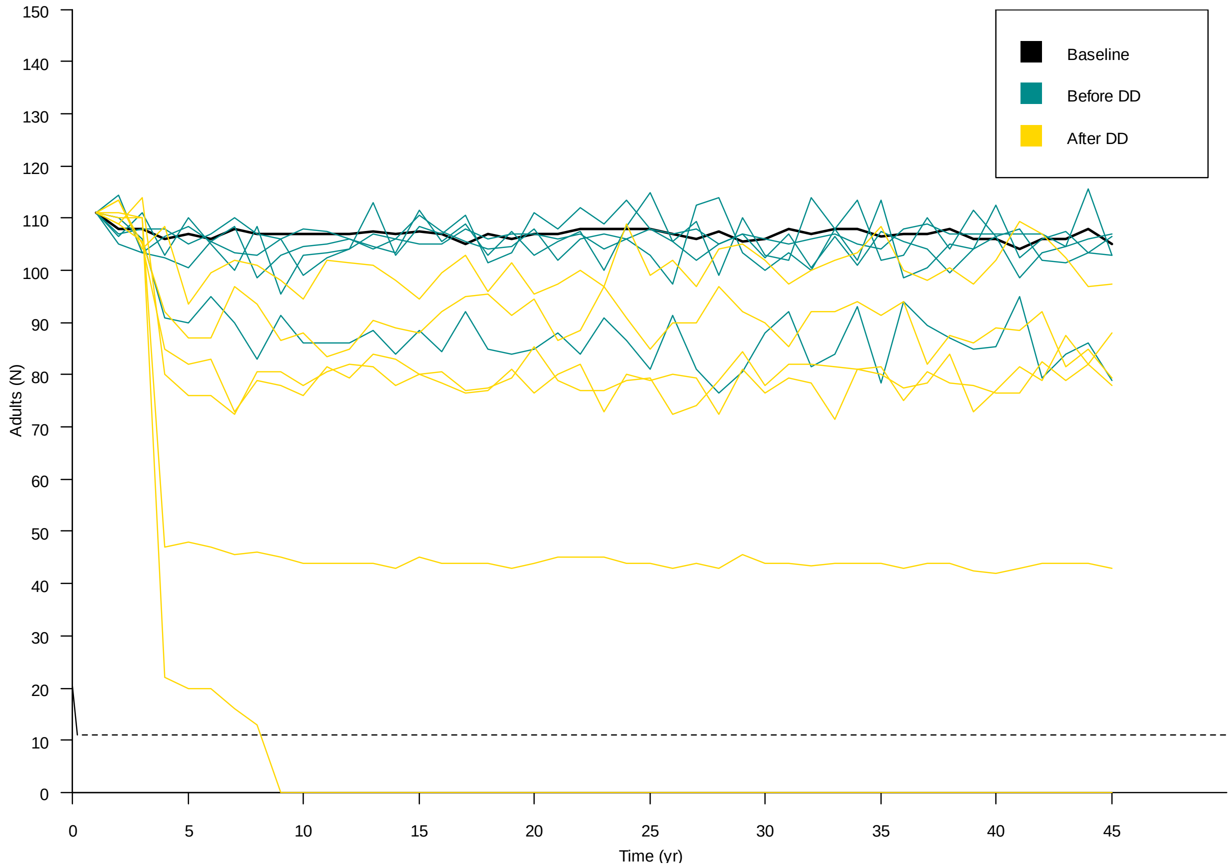

Figure 2. Number of adults over time for the baseline stable population (black line) and all scenarios before (blue) and after (yellow) the density-dependent spring bottleneck. Each line is the median of 1,000 Monte-Carlo simulations. The strength of the density-dependent bottleneck was mild (a=1.3).

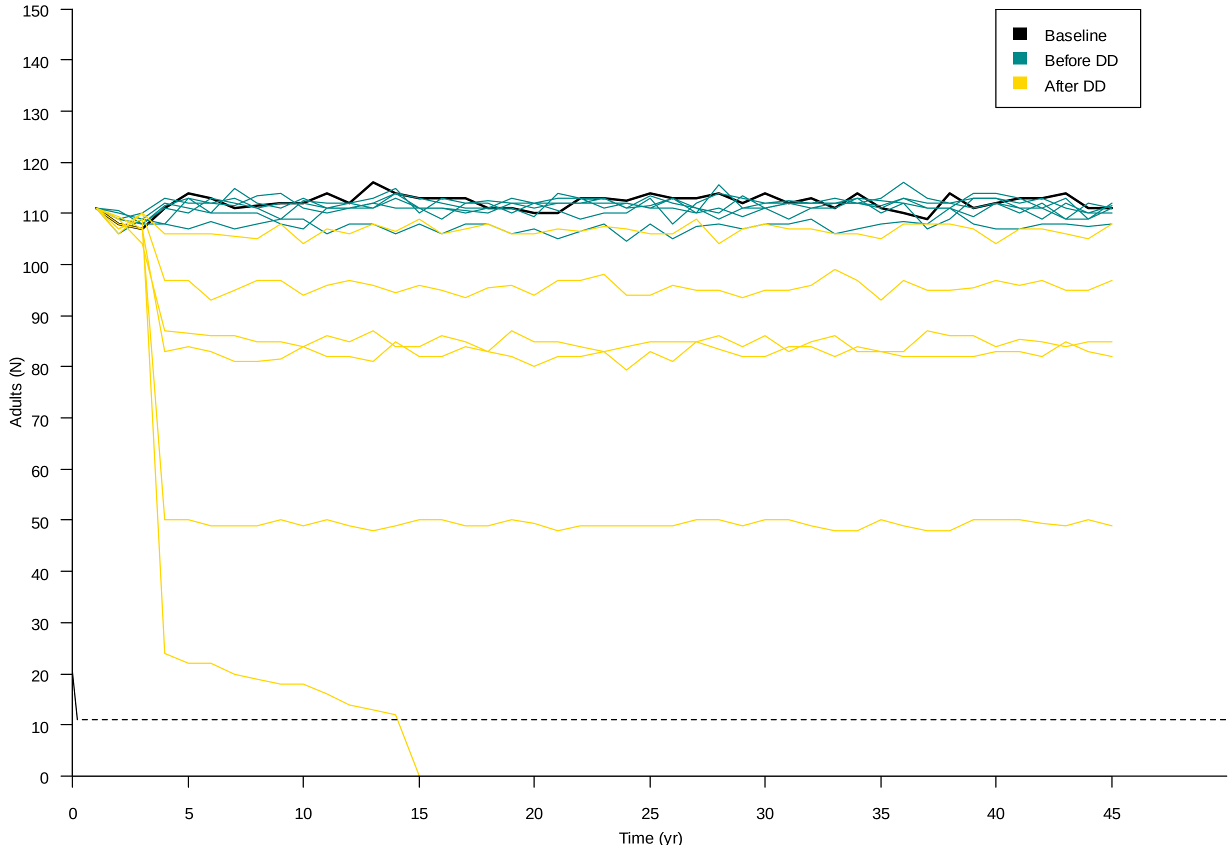

Figure 3. Number of adults over time for the baseline stable population (black line) and all scenarios before (blue) and after (yellow) the density-dependent spring bottleneck. Each line is the median of 1,000 Monte-Carlo simulations. The strength of the density-dependent bottleneck was strong (a=6.8).

Our results suggest that anthropogenic flow fluctuations induced by RoR hydropower may negatively affect the long-term population dynamics of Coho salmon, depending on when and how strong they are. However, inherent population mechanisms such as density-dependent mortality bottlenecks may be able to compensate for the extra mortality induced by human actions, even when mild. We hope that our model can be used as a tool to forecast possible long-term responses of fish populations experiencing increased mortality due to operations of small hydropower projects in regulated rivers.

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A history of flow management on the lower Columbia River downstream of Hugh Keenleyside Dam for spawning rainbow trout (*Oncorhynchus mykiss*): past results and future direction

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Talk Summary
Since the early 1990's, BC Hydro has implemented a flow management strategy downstream of Hugh Keenleyside Dam on the lower Columbia River to protect the majority of Rainbow Trout (*Oncorhynchus mykiss*) spawning sites (redds) in the mainstem from dewatering. The objective of these Rainbow Trout Spawning Protection Flows (RTSPFs) has been to have a stable or increasing hydrograph on the Columbia River from April 1 to June 30 and protects redds during the peak of spawning. Achievement of these flows requires annual negotiation with the US, and there can be a significant Lost Opportunity Cost for power generation with the implementation of these flows.

In 2008 a 10 year study to examine the effects of RTSPFs on was initiated by BC Hydro with the primary techniques being aerial and boat monitoring of spawner and redd abundance in areas of the Columbia River through each spawning year, modelling spawner abundance, and understanding the impacts of flow reductions on redds. Since 2008, RTSPFs have annually resulted in greater than 99% of the redds protected from dewatering (Figure 1). There has also been a roughly 2 fold increase in the number of spawners since the 10 year study began (Figure 2). Although this increase in spawners over the past 10 years has been associated with the implementation of RTSPFs, it cannot be attributed to these flows as they haven't been varied.

During this period of increased spawner abundance, there has also been an observed decrease in growth (Figure 3; fish are getting skinnier) and body condition (Figure 4; fish

are growing slower) that suggests the potential for density dependence and food limitiation. Beverton-Holt stock recruitment analysis of the spawner abundance data from this study, and age 1 recruit data (which is collected from the Large River Indexing Program conducted for BC Hydro by Golder and ONA) suggests that more spawners doesn't equate to more recruits, and that in actual fact the relationship suggests that over 50% of the redds based on current levels can be dewatered with no effect on age 1 recruitment (Figure 5). Roughly 1,500 spawners would be needed to saturate the habitat in the mainstem, and this is suggesting that habitat saturation, density dependence, and possible food limitation are occurring at these high spawner abundance levels and that the implementation of RTSPFs at these levels may not be of biological or population benefit and comes with a significant financial cost.

A Technical Committee consisting of representatives from First Nations, government agencies, and BC Hydro reviewed the data and concluded that the link between the flow management strategy and Rainbow Trout population abundance was as yet unclear. It was agreed to implement an experimental approach, as part of future monitoring, where RTSPFs would be stopped and implemented in alternate years starting in 2019 (e.g., no RTSPF in 2019, RTSPF in 2020 and so on) for a maximum duration of five years, until 2023. Redd dewatering estimates, spawner abundance estimates, age 1 recruitment data, condition data and growth data will be collected through these 5 years to monitor the effects of flow manipulation on the Rainbow Trout population.

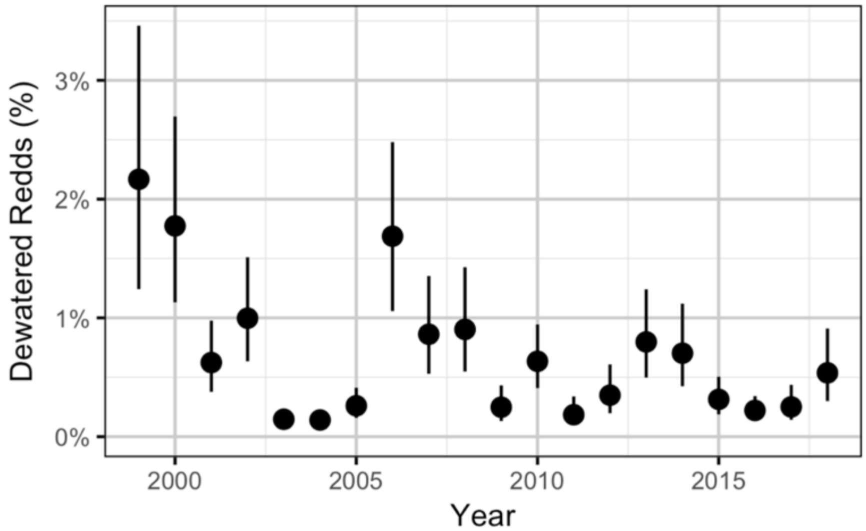

Figure 1. Estimated percentage of dewatered Rainbow Trout (*Onchorhynchus mykiss*) redds in the mainstem Columbia River downstream of Hugh Keenleyside Dam through a period of spawning protection flows.

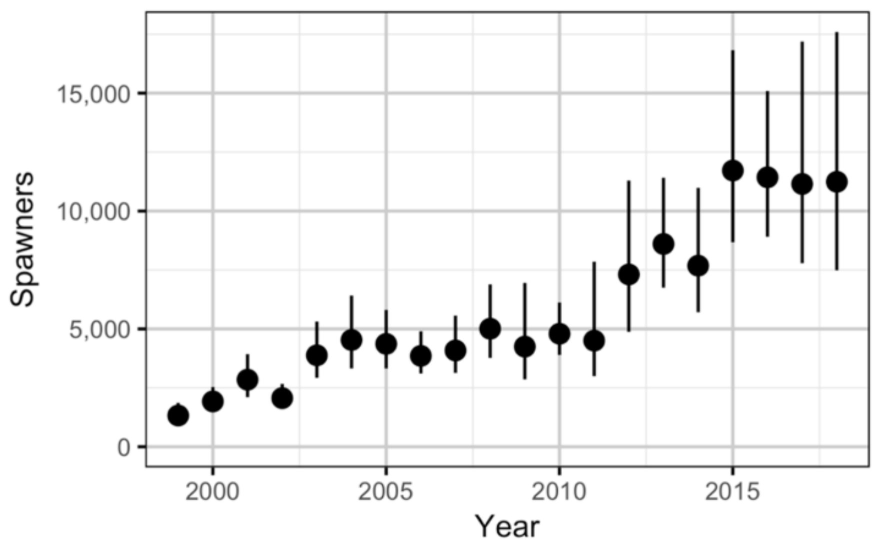

Figure 2. Estimated number of spawning Rainbow Trout (*Onchorhynchus mykiss*) in the mainstem Columbia River downstream of Hugh Keenleyside Dam through a period of spawning protection flows.

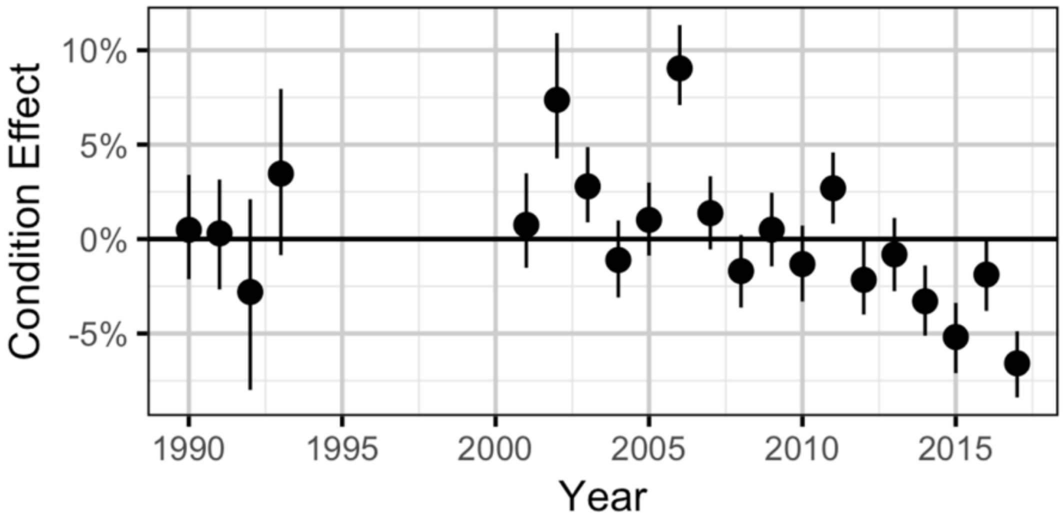

Figure 3. Condition effect of Rainbow Trout (*Onchorhynchus mykiss*) in the mainstem Columbia River downstream of Hugh Keenleyside Dam through a period of spawning protection flows. Declining condition effect suggests fish are getting skinnier.

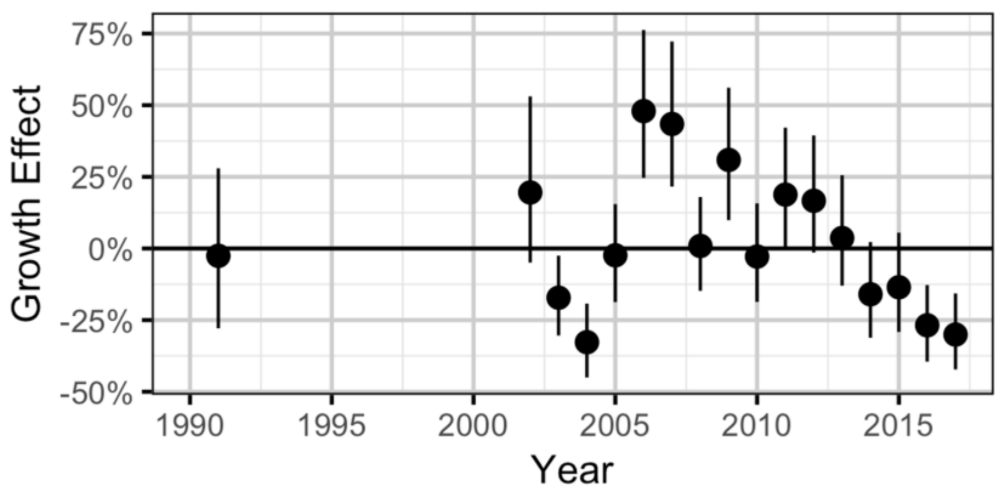

Figure 4. Growth effect of Rainbow Trout (*Onchorhynchus mykiss*) in the mainstem Columbia River downstream of Hugh Keenleyside Dam through a period of spawning protection flows. Declining growth effect suggests fish are growing slower.

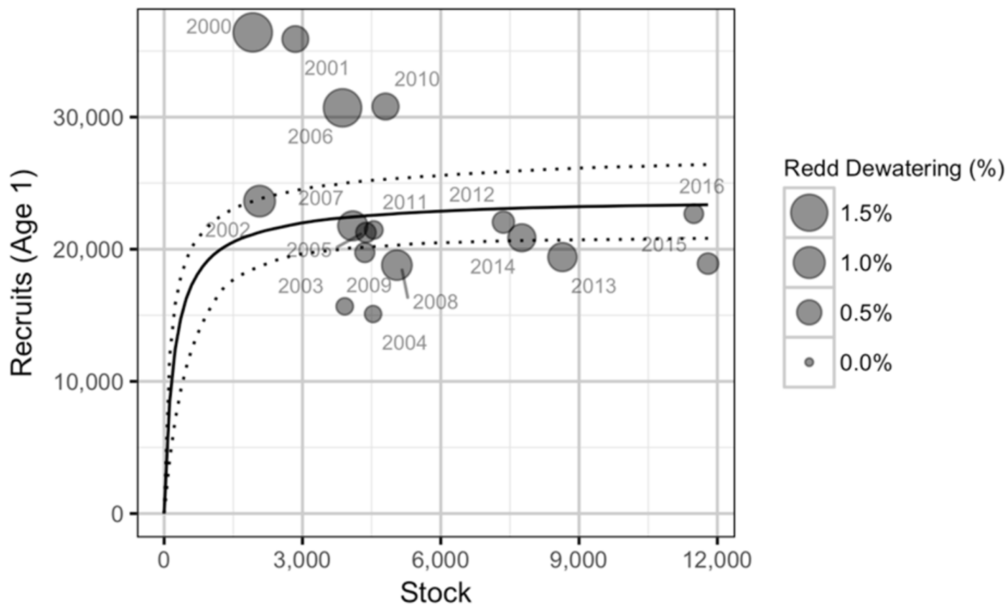

Figure 5. Beverton-Holt stock recruitment relationship of spawner abundance and age 1 recruits for Rainbow Trout (*Onchorhynchus mykiss*) in the mainstem Columbia River downstream of Hugh Keenleyside Dam through a period of spawning protection flows.

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Hydrological dynamics driving potential change in reservoir inflows: A multi-scale approach in one regional landscape

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Introduction

Assumptions of hydrologic stationarity are no longer reliable. In the North Kootenay Lake region of southeastern British Columbia, rising temperatures brought about by increased atmospheric levels of greenhouse gases are being accompanied by extreme climate and hydrologic events, causing loss of life and social/environmental disruption. In 2012, a landslide in the Johnsons Landing area occurred due to record precipitation (Figure 1) followed by sustained heating. It resulted in four deaths and extensive property damage including four destroyed homes. In 2013, a rain-on-snow event brought record daily precipitation (Figure 2) leading to extreme flooding and debris floods in the area. In June 2015, monthly mean temperature was far outside of anything that had been previously recorded (Figure 3). These changing patterns of precipitation and temperature are leading to declines in low-elevation snowpack, increased drought, enhanced debris flows/floods, and other diverse hydrologic and cryospheric adjustments with far-reaching implications for water resource management and monitoring.

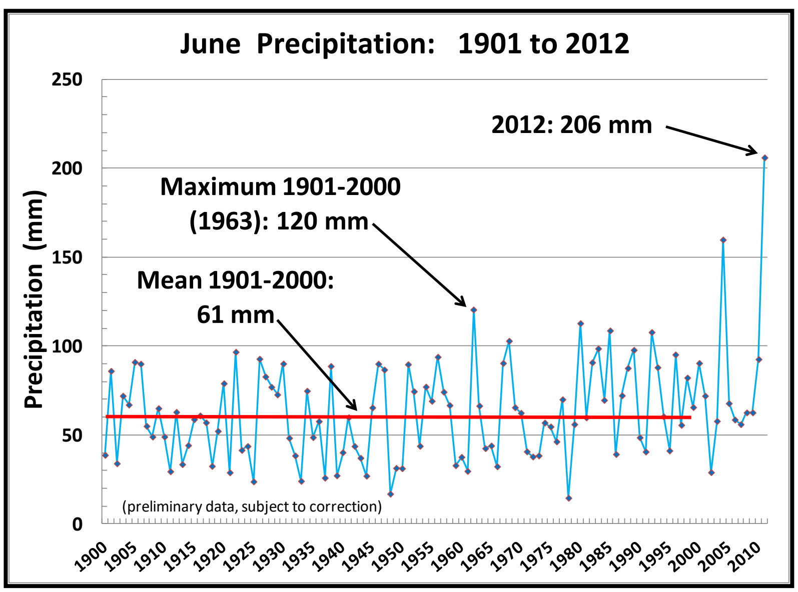


Figure 1. June precipitation as measured at Environment Canada’s Kaslo climate station.

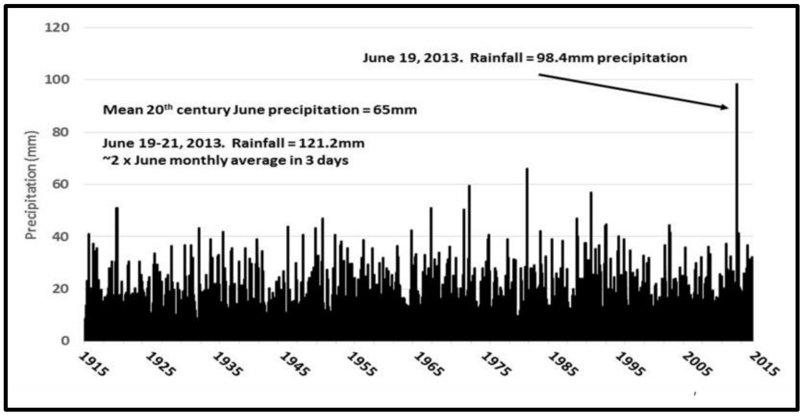


Figure 2. Daily precipitation as measured at Environment Canada's Kaslo climate station.

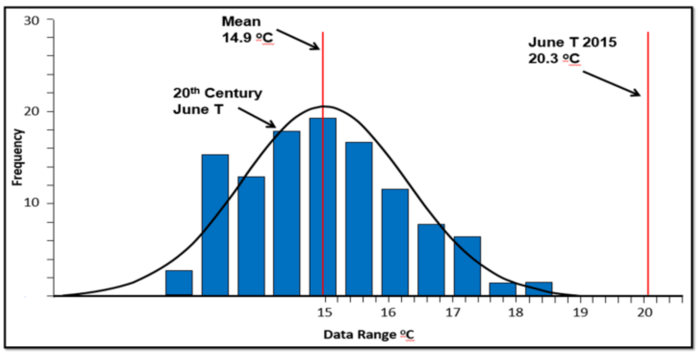


Figure 3. Historic distribution of mean June temperature compared with 2015, as measured at Environment Canada's Kaslo climate station.

In addition to direct community challenges brought about by climate disruption, the changing climate also holds implications for the long-term behaviour of reservoir inflows. There are compelling reasons to understand behavior of tributaries flowing into reservoirs. Information derived from snowpack data and climate/hydrologic modelling is used by hydroelectric utilities in making multimillion-dollar decisions related to inflow forecasting. Reservoir managers must also manage geohazards that may threaten operations, dam structures and even downstream communities. Measures to enhance and restore ecosystem habitats and functions require an understanding of how inflows behave (*e.g.*, flow quantity/timing) particularly in relation to reservoir levels, fish spawning, etc. Inflow behaviours are adjusting to the new climate, however, agency data suitable to characterize changes focus on larger drainages which may be adjusting differently than smaller ones. This paper introduces a non-government integrated regional network of monitoring stations focused on smaller drainages within the north Kootenay Lake area. The North Kootenay Lake Water Monitoring Project (NKLWMP) operates a monitoring network addressing a scale gap associated with the long-term agency networks. This multi-scale and regional approach may be of interest to reservoir managers in light of potential changes occurring in the hydrologic dynamics of reservoir inflows.

Regional Monitoring Networks

NKLWMP's network monitors hydrologic behaviour of watersheds in one regional landscape. Regional landscapes support an approach for generalizing hydrology across discrete sections of landscape. A systematic basis for examining runoff dynamics is enabled by vegetation zonation which is a strong representation of regional climate (Wang *et al*. 2012). Based on this knowledge, regional landscapes have been established as areas of similar elevational sequences of biogeoclimatic units and similar patterns of surface water flow (Utzig 2018). Regional landscapes have been defined by grouping hydrologic regions representing areas of similar streamflow patterns. Multiscale monitoring data are used here to examine site-specific and landscape-level patterns within the regional landscape extending from mid-Arrow Reservoir to Kootenay Lake, as shown in Figure 4. Monitoring networks within this regional landscape can be examined across spatial scales to determine what we know and what is missing in evaluating inflow dynamics.

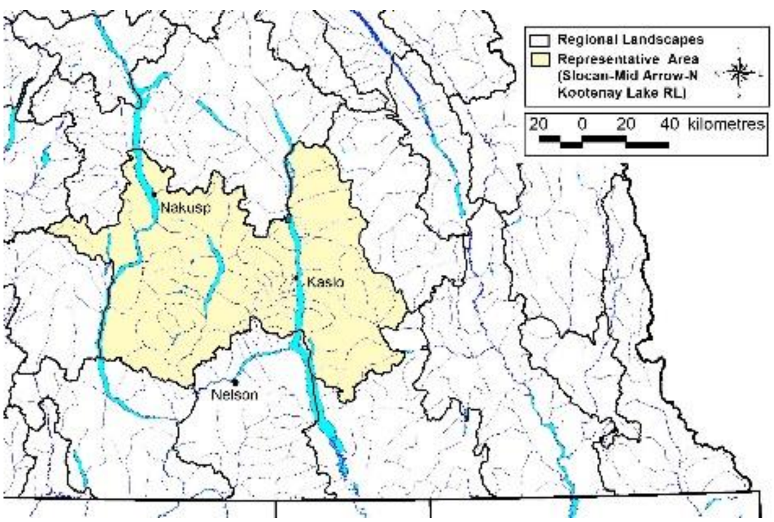


Figure 4. The regional landscape associated with the north Kootenay Lake area.

Hydrology is notoriously variable among mountain ranges and monitoring data are needed to understand and partition the variability. Government agencies provide data from active and discontinued hydrometric stations that now emphasize larger basins (above ~100 km^2) at low elevation (under ~1000 m). Stewardship groups provide additional short-term data for selected streams. A gap in long-term monitoring remains for smaller drainages nested within others or discharging directly into valley-bottom systems. We know that monitoring has generally declined in the Columbia Basin since the 1980s (CBT 2017). This regional landscape has seen a sharp decline in agency monitoring (Figure 5) with only six stations now remaining. Figure 6 illustrates how this decline has disproportionately affected the monitoring of small drainages.

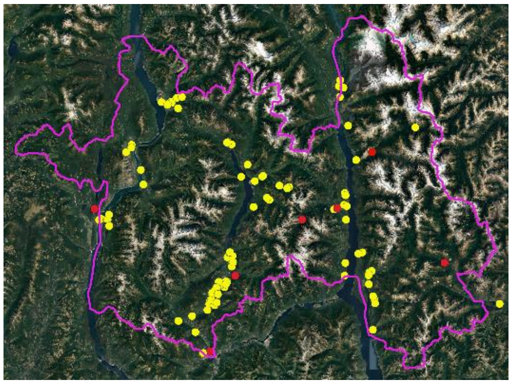


Figure 5. Active (red) and discontinued (yellow) WSC hydrometric stations within the regional landscape outlined.

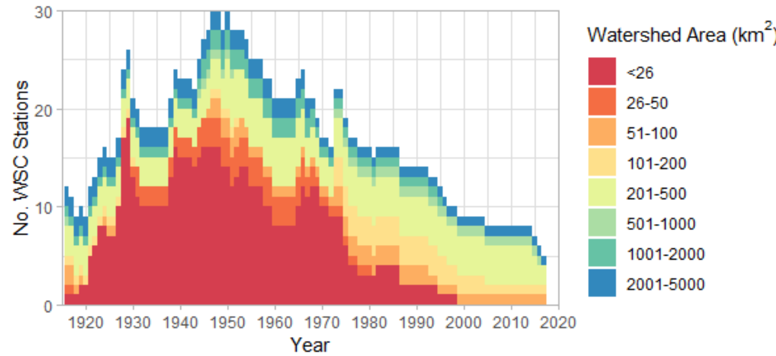


Figure 6. History of monitoring stations within the network operated by the Water Survey of Canada within this regional landscape.

What monitoring remains is at low elevation and for watersheds draining more than 92 km^2, as indicated in Table 1.

Climate and snow accumulation are monitored variously within this regional landscape by Environment and Climate Change Canada (ECCC), the Province of British Columbia, and BC Hydro. Climate stations include six year-round stations operated by ECCC (one is owned by BC Hydro) and a collection of seasonal stations operated by BC Ministry of Transportation and Infrastructure (MoTI) and BC Forests Lands and Natural Resource Operations and Rural Development (FLNRO). The long-term active year-round sites are at low elevations (512-600 m). The seasonal stations include sites at higher elevations operated by MoTI (up to 2518 m) and BC's Fire Management Branch (up to 1608 m). Eight sites are included as part of BC's snow survey network, at elevations ranging from 662 to 1926 m.

Table 1. Elevation and drainage area for six active hydrometric stations within the regional landscape.

Station Name	Elevation (m)	Drainage Area (km^2)
Fry Creek	947	585
Kaslo River	768	442
Keen Creek	1206	92
Lemon Creek	635	181
St Mary River	1177	208
Slocan River	466	3,330

Agency Data

Climate, topography, vegetation, soils and other factors interact in complex ways to yield scale-dependent hydrologic runoff behaviour. Influences related to climate change, climate modes (*e.g.*, El Nino Southern Oscillation) and land use change through time. A large number of factors can be at play, including component behaviours of smaller watersheds within larger ones. Figure 7 shows the long-term pattern of change in annual peak flow for the Slocan River watershed, the coarsest scale available from this regional landscape's hydrometric stations. At this scale, highly diverse factors shape net runoff response making generalizations difficult. Figure 8 illustrates similar data for three stations draining smaller basins – Fry Creek, Kaslo River and Keen Creek. Trends for these systems neither match that of the Slocan watershed nor that of each other, though recently there does appear to be increased variability.

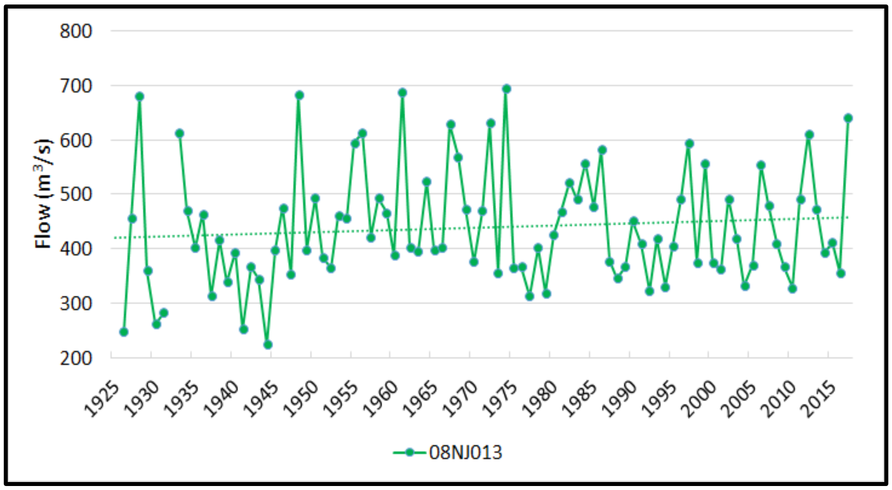


Figure 7. Annual peak flow at WSC Slocan River hydrometric station (1923-2017).

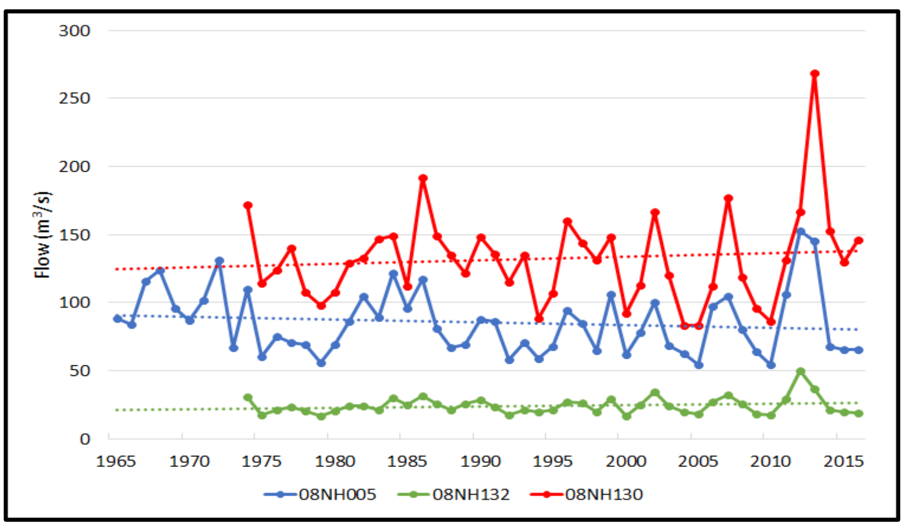


Figure 8. Annual peak flow at WSC hydrometric stations within the regional landscape: Fry Creek (red), Kaslo River (blue) and Keen Creek (green).

These contrasts in streamflow behavior highlight the complexity of the controls on streamflow and the importance of spatial scale in understanding this complexity. It is clear that the behavior of larger systems does not reliably reflect the behavior of the smaller systems of which they are composed. The runoff at the outlet of these large basins is an aggregate of complex processes unlikely to mirror that of small and intermediate watersheds. Without appropriate data to characterize behaviour across scales, it is difficult to generalize and forecast inflows.

A review of the available climate data returns similar interpretations about uncaptured variability of the agency monitoring networks. The year-round climate stations are located only in the valley bottoms and do not represent the distributed climate across the regional landscape. Long-term time-series data available from the snow courses show contrasting behaviour – some, but not all, show slightly downward trends in annual maximum snow accumulation. Generalizations are difficult based on these seven sites alone. As with the hydrometric data, there are signs of increased variability at these snow courses in recent years, perhaps reflecting the extreme events that were presented at the outset of this paper. What climate assumptions would appropriately apply when forecasting runoff from a smaller watershed? The spatial limitations associated with the agency climate and snow data sets present further limitations to the ability to characterize the climate inputs shaping the runoff behaviour of smaller and intermediate watersheds.

North Kootenay Lake Water Monitoring Project

The North Kootenay Lake Water Monitoring Project (NKLWMP) is a community-driven program of action to prepare for climate change. Building on a previous program (started in 2013), NKLWMP monitors a network of hydrometric, snow course and climate stations designed to maximize insights gained from a local monitoring network and taking best advantage of regional information and data sets. Extreme climate and hydrologic events in recent years in the north Kootenay Lake area have had significant impact within large portions of the Regional District of Central Kootenay. These events have catalyzed citizens to take responsibility in preparing for the deepening climate crisis and its associated disruption by generating important and potentially life-saving data for use by planners and decision makers in sectors related to land use, development, forestry, conservation, water supply, emergency preparedness, transportation, agriculture, back-country recreation and more.

Water monitoring under NKLWMP was formalized in 2016 and the program has been strengthened each year. NKLWMP has three objectives:

1. To establish a long-term integrated scientific water, snow and climate monitoring program in the north Kootenay Lake region of British Columbia;

2. To facilitate community engagement and ownership of the NKLWMP monitoring system, including developing community responses to watershed and climate disruption; and
3. To engage funding and knowledge partners and facilitate application by decision makers at all levels of NKLWMP outputs to inform decisions that support climate-change preparedness.

The monitoring network was completed in 2018 and now includes seven hydrometric stations, two snow courses and three meteorological climate stations, providing data of up to six years' duration, reflecting processes within the regional landscape (Carver *et al.* 2018). Table 2 summarizes the elevation and drainage area of the hydrometric stations. They are generally at higher elevations and drain watersheds that are smaller than those of agency networks.

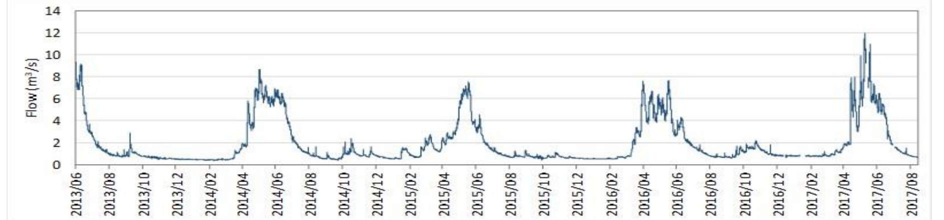
Table 2. Elevation and drainage area for the seven hydrometric stations monitored by NKLWMP.

Station Name	Elevation (m)	Drainage Area (km^2)
Davis Creek	850	63.6
Bjerkness Creek	625	26.7
Carlyle Creek	1530	4.1
Ben Hur Creek	1550	5.6
MacDonald Creek	720	2.2
Gar Creek	570	4.1
Kootenay Joe Creek	890	6.0

Early Observations from NKLWMP Monitoring Sites

Time-series data from the first years of monitoring at NKLWMP hydrometric stations can be examined to identify behaviours for comparison with that of larger watersheds. Table 3 provides preliminary observations related to the timing of the annual peak flow in intermediate-sized watersheds, the influence of aspect on melt timing in high-elevation watersheds and the annual timing of peak flow in a small low-elevation watershed. In each case, although the period of monitoring is limited to about five years, the data suggest behaviour that differs from general expectation based on large drainages.

Table 3. Three practical applications highlighting differences in behaviour between small and large watersheds and highlighting the value of data gathered from smaller watersheds.

<table>
<tr><td rowspan="2">Plots show streamflow at Davis (upper) and Bjerkness (lower) Creek hydrometric stations. These are NKLWMP’s largest drainages and include alpine areas. The timing of the annual peak flow remains consistent (late May and early June) and is not advanced relative to long-term expectations.</td><td>
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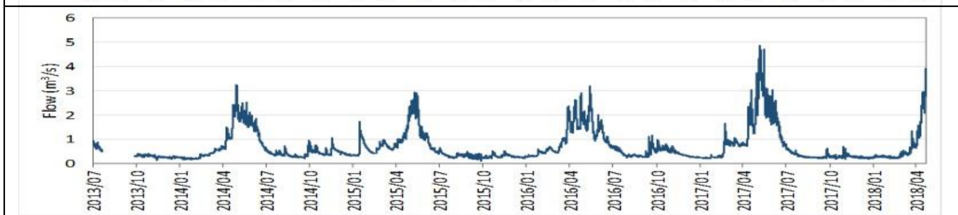
<tr><td>
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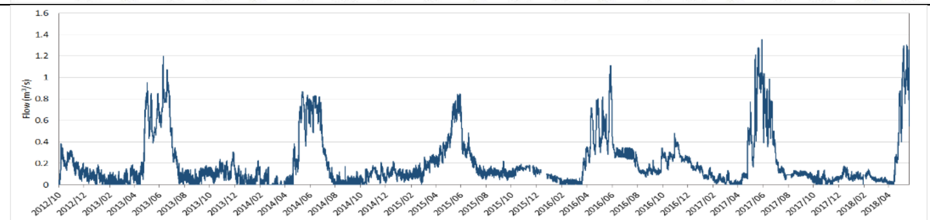
<tr><td rowspan="2">Plots show streamflow at Carlyle (upper) and Ben Hur (lower) Creek hydrometric stations from 2012 through April 30, 2018. These are NKLWMP’s highest-elevation hydrometric stations. Although they drain contrasting north-versus-south aspects, there is no difference in the timing of annual peak flow.</td><td>
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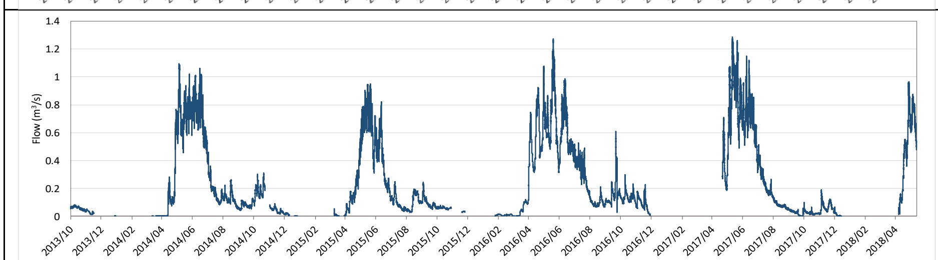
<tr><td>
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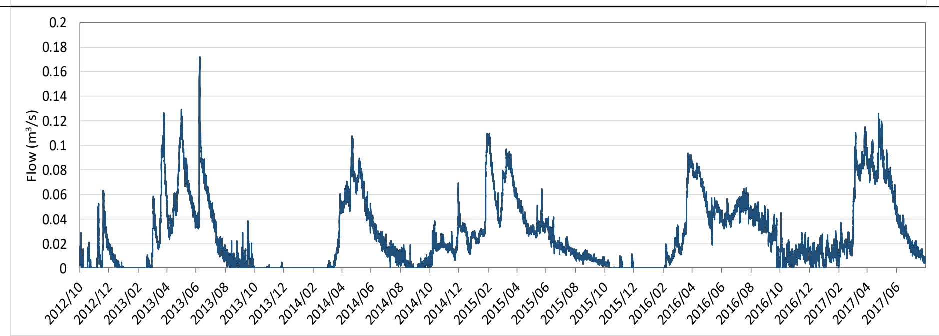
<tr><td>Plot shows streamflow at MacDonald Creek hydrometric station, in a small low-elevation drainage. The annual timing of peak flow is highly variable (February to June), consistent with the variability associated with climate disruption.</td><td>
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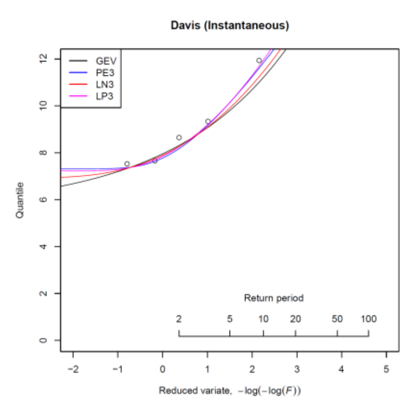
Translating Data into Decisions

Three streamflow metrics that are used in practical hydrologic and engineering applications are shown in Table 4 to illustrate the value of hydrometric data from small- and intermediate-sized watersheds, as collected by NKLWMP. Of particular importance to reservoir and water-resource managers is the ability to quantify the frequency, duration and magnitude of extreme high flow events (Table 4a). Critical infrastructure like dam-site access roads, stream restoration works, and land-use zoning must be designed with extreme high flow resiliency in mind. In addition, understanding extreme low flows is vital for managing reservoir levels in relation to tributary flows for fish spawning needs, making water allocation decisions and for managing water, especially in times of drought (Table 4b). Without access to suitable hydrometric data, environmental flow needs cannot be accurately established, and the ability for water managers to make informed reservoir flow-management decisions or water-allocation decisions becomes severely limited. In the absence of site-specific hydrometric data, regional analyses are employed to extend data from one watershed to another by normalizing the data by its watershed size (Table 4c). This practice is commonly used by practitioners and can provide meaningful results; however, extending data across watersheds that are too different in terms of their size and hydrologic character can induce significant uncertainty in the results. In many regional landscapes, there is simply not enough hydrometric data available for representative watersheds for one to consider performing regional analyses without large margins of uncertainty. The NKLWMP network may provide a foundation of hydrometric data for small- and intermediate-sized watersheds that can be regionalized, cautiously, to obtain hydrologic information for ungauged watersheds of similar size in the regional landscape. Within one regional landscape, however, there can remain significant differences in the hydrologic behaviour of streams of similar sizes, thus highlighting the complexity of watershed hydrology, the limitations of regional analyses and the importance of collecting watershed-specific data.

Table 4. Three practical applications using early NKLWMP data, highlighting potential differences in runoff behaviour between small and large watersheds.

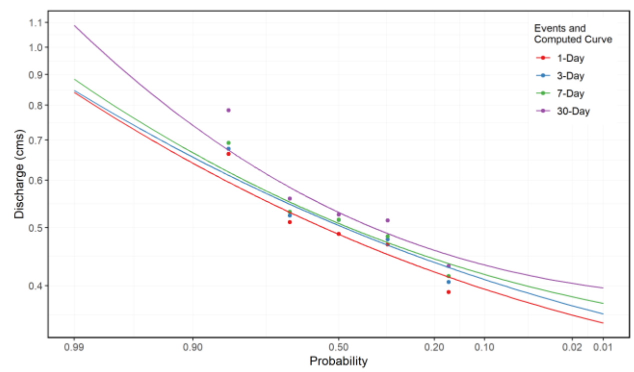
a) Flood Frequency Distribution for Davis Creek

This figure shows a distribution of peak annual instantaneous discharge values for Davis Creek (points) with frequency distributions fitted to the data (lines). The additional NKLWMP data help characterize the risk of flood hazards Davis Creek could impose on the community of Lardeau. Without these added data, understanding this community's vulnerability and/or resiliency to extreme events from this creek would be very limited.



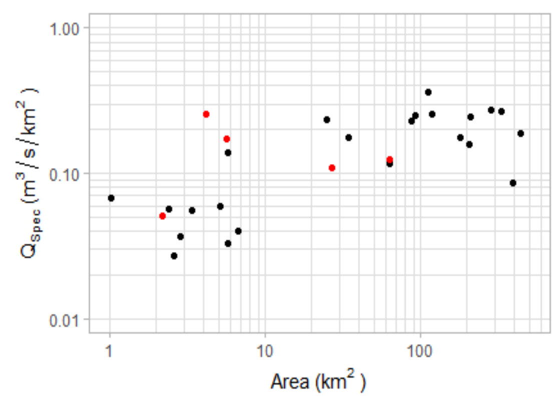
<u>b) Frequency-Duration Distribution of Low-Flow Events for Davis Creek</u>

This figure shows the distribution of extreme low flow events, of various durations, for Davis Creek. These flow metrics are essential for making robust, data-driven, water allocation decisions and in accounting for low-flow conditions in the hydraulic design of stream restoration structures. Without these NKLWMP data, understanding this stream's ecosystem vulnerability and/or resiliency to drought conditions, or the vulnerability of Lardeau's water supply system, would be very limited.



<u>c) Specific Discharge of the NKLWMP stations and the current and historical WSC stations</u>

This figure shows annual peak flows with a two-year return period, at the NKLWMP stations and the WSC stations in the regional landscape. Flow is normalized by watershed area to yield specific discharge. There is significant scatter even between watersheds of similar drainage area. This highlights the variability of watershed behaviour even within the same regional landscape and stresses the importance of collecting watershed-specific hydrologic data.



Discussion

The examination of the initial time-series data from the NKLWMP monitoring network is suggesting that runoff from these smaller basins likely behaves differently to that of large basins. These differences highlight the importance of multi-scale monitoring data when characterizing the behaviour of reservoir inflows from small- and intermediate-sized basins. As climate disruption intensifies, the historic long-term data sets may become increasingly inapplicable for purposes of reservoir forecasting. In fact, the behaviour of smaller drainages may become our best tool to signal what may be coming later in the larger drainages.

Whereas watersheds with areas between 100 and 1,000 km^2 (and over 1,000 km^2) are reasonably well monitored, those with an area of 1-10 and 10-100 km^2 are currently not well monitored in the agency network. These are not all "small" drainages; they require monitoring if managers and forecasters are to be confident about their decisions and outcomes. In addition, data availability in the smaller drainages is also valuable for other purposes related to community well-being and adaptation to climate change. In various respects, maintaining operations at these monitoring sites will be a critical element of adapting across scales and applications to the ongoing changes in climate.

Conclusion

The decline in hydrologic stationarity due to climate disruption introduces doubt about the value of existing long-term data sets in forecasting the behaviour of reservoir inflows. Additionally, active stations within agency networks in the regional landscape associated with the north Kootenay Lake area emphasize large watersheds and low-elevation sites. Selected comparisons provided here of time-series data sets from these stations with those of watersheds for small- and intermediate-sized watersheds have raised questions about the value of data from agency networks for characterizing reservoir inflows and, thus, for informing reservoir operations. Practical engineering calculations applied to these contrasting data sets introduce doubt about the consistency of runoff behaviour across spatial scales. These findings suggest caution in extrapolating projections based on coarse-scale (and older) data which now dominate agency networks. Data from small- and intermediate-sized watersheds appear to be needed when characterizing the full range of reservoir inflows and may indeed also be required to help explain changes in runoff behaviour occurring across scales.

Four implications are suggested by the above conclusion:

1. Neither the agency nor NKLWMP network alone is sufficient to describe the behaviour of runoff from the watersheds within the regional landscape associated with the north Kootenay Lake area.

2. It is important to maintain the combined network to reduce uncertainty associated with non-stationarity.

3. As hydrometric data accumulate at the scale of small- and intermediate-sized drainages, complexity of potential analyses can grow, including better calibrated and validated hydrologic modelling across multiple spatial scales.

4. As the climate changes, and as stationarity decays further, data and modelling outputs will be critical to the success of management objectives that depend on hydrometric data.

As data accumulate from the community-driven North Kootenay Lake Water Monitoring Project, its monitoring mosaic offers an unusual opportunity to examine how smaller and larger basins compare in responding to controls on runoff and a disrupted climate. Whereas clarifying these dynamics may be useful in reservoir management, the improved granularity should also be of value in adaptation efforts of local communities, conservation planners, and resource managers.

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Equipment funding has been provided by Kootenay Savings Credit Union, Nelson and District Credit Union, Fortis BC, and Kootenay Country Store Cooperative. Seasonal equipment loans have been provided by Ministry of Forest Lands and Natural Resource Operations and Regional Development (FLNRO), Selkirk College, and volunteers.

Operational support has been provided by Columbia Power Corporation to contract the Selkirk Geospatial Research Centre to review NKLWMP's data standards and advise on storage and dissemination technologies. FLNRO has assisted with operational aspects of monitoring in the Johnsons Landing landslide area and continues to make its turbidity meter available for analyzing water samples.

Powder Bound Ski Club

Johnsons Landing
Community Association

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Assessing impacts of a new flow regime along the lower Duncan River, British Columbia

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Introduction

The Duncan River flows into Kootenay Lake and was dammed in 1967 as part of the transboundary Columbia River Treaty. The Duncan Dam has no hydroelectric facility therefore allows for greater flexibility for downstream flow management. Following a Water Use Planning (WUP) process, a new environmental flow regime was implemented in 2008 with Alternative S73 (Alt S73) that is intended to benefit black cottonwoods (*Populus trichocarpa* Torrey & Gray) and riparian woodlands, as well as Gerrard rainbow trout and Kokanee salmon. To assess responses to river damming and flow regulation with Alt 73, we undertook field studies from 2009 through 2018 to investigate channel and riparian responses. We applied a paired-comparison study design to contrast hydrology, channel form, bank profiles, surface sediments and vegetation along the regulated reach of the lower Duncan River with the unregulated Lardeau River (the reference reach) which joins the Duncan River downstream of Duncan Dam.

Following damming, substantial accumulation of cobbles, gravels, sands, and large woody debris has occurred along the lower Duncan River. This contrasts with the physical processes downstream from most dams, where alluvial sediments and woody debris are depleted due to trapping in the slack-water reservoir. For the lower Duncan River, extensive sediment and woody debris inputs persist from the free-flowing Lardeau River. The attenuation of high flows from the upper Duncan River has diminished the transport capacity below the Duncan Dam and downstream to Kootenay Lake.

Location

The lower Duncan River is located in the Columbia Mountains region in southeastern British Columbia. It flows south out of the 45 km-long Duncan Reservoir (includes the former Duncan Lake which was 15 km long), which was impounded by the Duncan Dam in 1967. Approximately 300 m downstream from the Dam, the lower Duncan River is joined by the free-flowing Lardeau River and the combined rivers continue south for approximately 11 km to Kootenay Lake, where a broad delta is formed. Midway along, in Segment 4, the lower Duncan River channel is joined by three free-flowing tributaries: Meadow, Hamill and Cooper creeks. Meadow Creek includes an artificial channel producing a low gradient stream, contributing small amounts of sediment and woody debris during spring high water. At their confluence, the Duncan River flows into Meadow Creek creating a back-water effect during high water. This backup of water into the Meadow Creek channel has been documented to occur past the second meander point bar upstream of the confluence since 2009 and earlier by Miles (2002). In contrast to Meadow Creek, Hamill and Cooper creeks are high gradient streams that contribute substantial sediment and large woody debris to the lower Duncan River (Figure 1).

The Lardeau River was selected as the reference reach due to its proximity to the lower Duncan River and its similar channel reaches. The Lardeau River flows out of a nearly parallel watershed with a higher gradient and lower discharge volume compared to the Duncan River. The Lardeau River study reach starts approximately 3 km upstream of the confluence with the lower Duncan River and extends upstream for approximately 11 km (Figure 1).

Figure 1: Location of the lower Duncan River and the lower Lardeau River (Google Maps).

Methods

To monitor the effects of the new flow regime Alt S73 on vegetation colonization dynamics, we used three methods of data collection.

1. Established belt transects with three quadrat sizes to assess plant occurrences and abundance.
   - Large quadrats (50 m^2 area) were used for woody vegetation greater than 2 m tall (referred to as Tree quadrats).
   - Medium quadrats (10 m^2 area) were used for woody vegetation less than or equal to 2 m tall (referred to as Shrub quadrats).
   - Small quadrats (1 m^2 area) were used for graminoids, forbs, moss, ferns, and cottonwood seedlings.

   Transects were permanent and re-established in the same place every year of monitoring.
2. Aerial photography of the lower Duncan and Lardeau reaches (100 m on either side of the channel)
   - Aerial photograph occurred every third year – 2009, 2012, 2015, and 2018.
3. Pre-Alt S73 sampling within delineated sites.
   - A ½ inch increment borer was used to sample black cottonwood trees within random generated 100 m^2 plots in 2016.

Three hypotheses were assessed:

H_{01}: There is no change in black cottonwood establishment or survival resulting from the implementation of Alt S73;

H_{02}: Black cottonwood establishment and survival along the lower Duncan River are not affected by the river flow regime; and

H_{03}: The river flow regime is the primary driver of black cottonwood establishment and survival along the lower Duncan River;

Results

We have provided the detailed results and analyses in yearly reports during the decade long study (Polzin and others, 2010 to 2018), and the following summarizes the findings relative to the specific hypotheses.

H_{01}: There is no change in black cottonwood establishment or survival resulting from the implementation of Alt S73.

The null hypothesis was rejected. There was a significant decline in black cottonwood survival compared to 10 and 20 years previous to Alt S73 during the previous flow regime. There was no data for establishment pre-Alt S73 so it was dropped from the null hypothesis.

Survival pre-Alt S73 data was collected through the extensive sampling and results of tree core data for pre-Alt S73 which gives cottonwood recruitment stems per hectare for pre-Alt S73 flow regime. However, we do not know what the pre-Alt S73 flow regime impact to survival would have been if it was applied from 2008 to 2018. Tree core data for the pre-Alt S73 results confirms that the H_{O1} as written is rejected. We are not comparing the previous flow on the current recruitment area.

An alternate hypothesis would relate to the DDMMON#8-1 study design, with the paired comparison of the regulated lower Duncan versus free flowing Lardeau River reaches. With this comparison, revisions to the null Hypothesis 1 would be:

H_{O1}: There is no difference in black cottonwood establishment or survival between the lower Duncan River with Alt S73 and the free flow Lardeau River.

This hypothesis is testable with DDMON#8-1 and the null hypothesis, H_{O1} is rejected. Generally, the patterns and dynamics of cottonwood seedling establishment and survival were very similar along the Duncan and Lardeau Rivers. This was a favorable outcome because the reference reach of the Lardeau is free flowing and with the natural flow paradigm it would thus be generally assessed as ecologically healthy.

However, there were some significant differences between the two river reaches. With the artificially prolonged high flow of 2012, there was complete mortality of second and third year seedlings and extremely low establishment. There was substantial seedling recruitment in the following three years resulting from the benefit of the extensive, barren colonization surfaces created by the high flow events.

A second difference arose with the drought interval and especially the more severe drought year of 2017. During the drought stress through August, some flow augmentation was provided by release from the Duncan Dam and this increased the survival of established second and third year cottonwood seedlings, relative to the lower flow along the Lardeau River.

Thus, the study indicates that cottonwood seedling establishment and survival were quite similar along the regulated and free flowing river reaches but there were some significant differences in particular years and these were both negative and positive with respect to both establishment and survival.

H$_{02}$: Black cottonwood establishment and survival along the lower Duncan River are not affected by the river flow regime

The H_{02} was rejected as there has been a significant decrease in the establishment and survival of black cottonwood correlated to the river flow regime. Particularly for the 2012 flow regime over the growing season. There have been moderate increases in survival rates compared to the reference reach for some years with low precipitation and high daily temperatures during the summer months. When the regulated flow regime was high enough it offset some drought mortality during dry, hot summers and not so high as to induce inundation mortality. When the regulated flows were low during dry, hot summers, survival was similar along the low Duncan River to the Lardeau River.

H$_{03}$: The river flow regime is the primary driver of black cottonwood establishment and survival along the lower Duncan River.

The results from DDMON#8-1 indicate that rivers are primary drivers of cottonwood establishment and survival but establishment and survival are also substantially influenced by weather. Therefore, H_{03} was accepted recognizing that while the river is the primary driver, weather plays an important influence.

In drier, semi-arid or arid regions such as the American southwest or the Great Plains, there are tighter associations between river flows and cottonwood recruitment. In the wetter Pacific Northwest, rain is more abundant and this can promote seed dispersal and enable seedling establishment even in positions that were not saturated with water from the receding river or from the capillary fringe above the alluvial groundwater table. Rains through the summer provide alternate water sources for riparian cottonwoods, including seedlings. As well, temperature and humidity, and subsequently the dryness or vapor pressure deficient, largely determines the extent of drought stress, which provides a major influence on seedling survival.

Conclusion

Over the study decade, there was extensive interannual variation and seasonal patterns were strongly influenced by rainfall patterns; this contrasts to some observations along rivers in drier regions (Williams and Wolman 1984, Dunne 1988, Debano and Schmidt 1990, Rood and Mahoney 1995, Polzin 1998). We observed that seedling survival was strongly impacted by sediment deposition and scour, emphasizing the importance of fluvial geomorphic processes. Moreover, there was a very close correspondence between the alluvial groundwater level and river stage, demonstrating a high degree of connectivity within the riparian colonization zones. From the decade long study, the results reveal mechanistic relationships between river flow regime, sediment dynamics, seedling colonization, and the persistence of riparian vegetation along the lower Duncan River. The study also revealed that during drought intervals, when weather is especially influential, river flow augmentation can be especially beneficial.

The Duncan River study provides useful insights towards the development of environmental flow regimes for other regulated rivers of the North American Pacific Northwest especially in humid reaches. It may be relevant for semi-arid systems but that was not tested during this study.

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The complicating influences of river regulation on productivity in riverine habitats

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1.0 Introduction

River regulation alters the natural flow regime of a watercourse. It influences the hydraulic regime, channel character, and instream and riparian habitat. These changes in habitat type and quality affect the structure and biodiversity of aquatic communities. This response may lead to a reduction in food resources for fish (e.g. periphyton and benthic invertebrates) and an overall loss of production.

Primary production in regulated rivers is influenced by a complexity of intertwined factors that vary with specific site conditions both within and between rivers, all the while interacting with flows and the dynamic changes induced by their regulation. Discharge modulates the physical characteristics of a watercourse including depth, velocity, substrate composition, and available photosynthetically active radiation (via light attenuation). Flow variability alters these physical characteristics and is dependent upon channel cross section and/or stream morphology. These physical characteristics are dynamic with flow and influence both direct and indirect responses in periphyton and benthic invertebrate production.

Separating the influences of river regulation from natural factors that affect productivity is challenging. Dam operators can only control the rate of discharge (flow), yet discharge itself varies the physical habitats of the river and that variability is specific to a particular channel cross section. This means that flows, in combination with the site-specific river morphology (or channel cross section), ultimately determine the specific habitat conditions present. Therefore, the responses of primary producers to flow require an understanding of more than just how rivers are regulated and ultimately require understanding how productivity varies with specific physical processes in the river to understand how flow alteration may influence or alter production.

Complex models help us better understand river production. They illustrate how discharge is directly linked to the area of productive habitat (via submergence) and is indirectly linked to other important factors that affect productivity like velocity or depth, where these physical factors are cross section dependent. When this broad understanding of factors affecting productivity is applied to different regulated river systems, it becomes apparent that physical parameters vary between rivers and within and between macro reaches of the same river. The physical parameters combined with flow create two distinct zones, including the areas under direct influence of regulation (i.e., varial zone wetted habitats) and areas of permanent submergence which are more affected by the physical habitat conditions, which can also be affected by alterations in flow.

2.0 Data Collection and River Overview

The sampling apparatus used to collect field data for productivity assessments was very similar between each different region sampled (i.e., Peace River[2] & Mid Columbia Revelstoke Flow Management Plan CLBMON15b[3] and Lower Columbia Flow Management Plan CLBMON44[4]). The general artificial sampler design is presented in Figure 1 below, and consists of a heavy anchor to hold in the apparatus in place during high flows, associated sampler lines connected using snap hooks, a large metal frame with Styrofoam mounted on treated plywood with a temperature / light logger for sampling periphyton, and a benthic invertebrate rock basket. Our works have assumed that the artificial sampling substrates do not exert any bias on sampling. However, data does suggest that artificial substrate selection itself may also act as a source of error and potential bias. Specifics are discussed in Schleppe et al (2015) and Olson et al (2015). It is also noted that in some instances, level loggers for water surface elevation, turbidity sensors, or other data collection devices have been attached to the sampling apparatus.

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[2] https://www.sitecproject.com/document-library/fisheries-and-aquatic-reports
https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/northern_interior/peace_river/recreational_access.html

[3] https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/revelstoke-flow.html

[4] https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/lower-columbia-fish.html

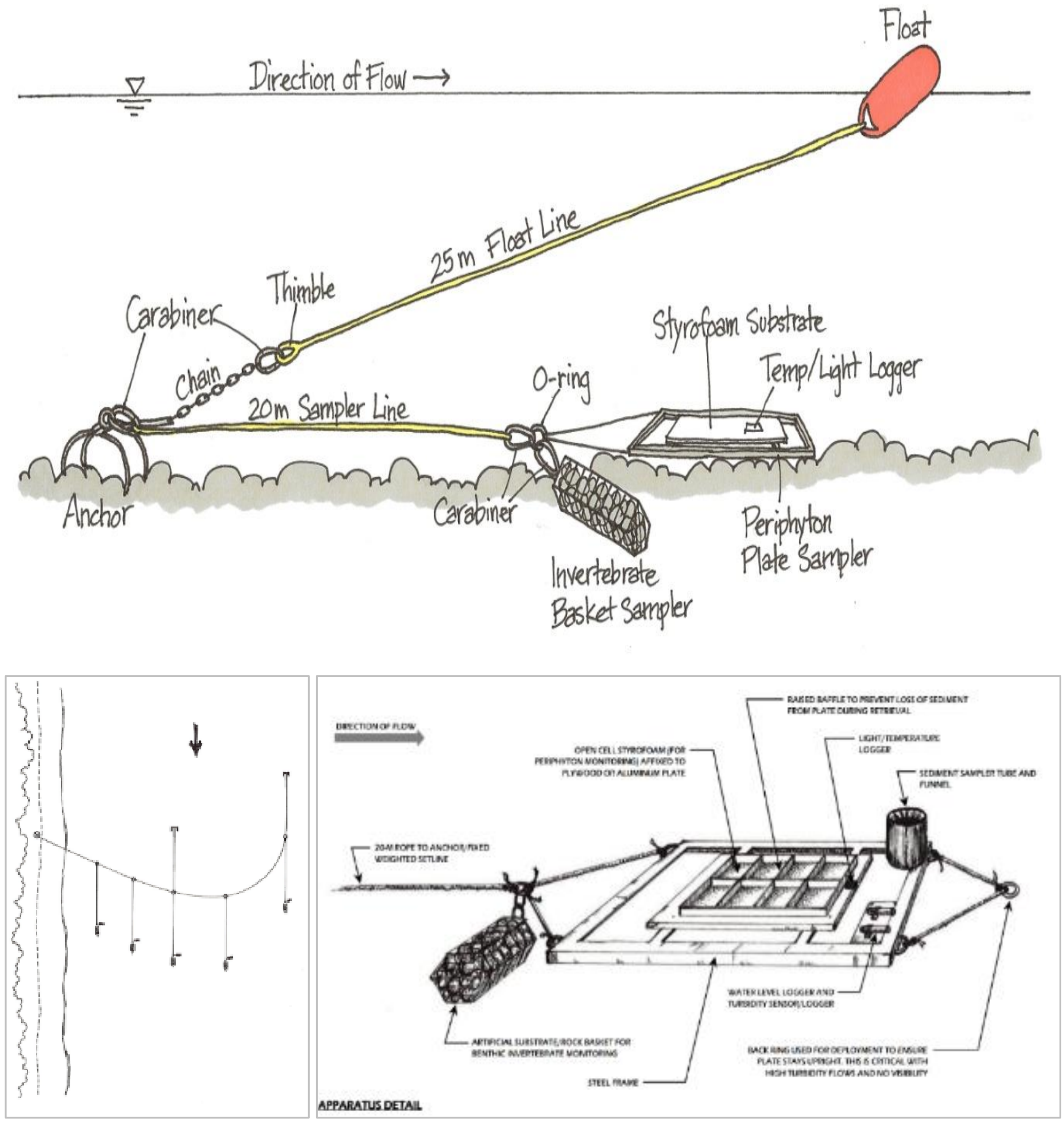

Figure 1: An example of the sampling apparatus used to collect periphyton and invertebrate samples from the Columbia and Peace Rivers.

During operational cycles, river habitats are wetted depending upon whether more or less water is released. The concept is nearly identical to opening or closing a valve such as a garden hose bib. River regulation and facility operation creates an area of the river called the varial zone, which is basically the area between the operating high and low water elevations. Within the varial zone, the area that has been submerged or exposed in the last 60 to 90 days is the area that is currently under direct influence of the regulatory regime. The extent of vertical elevation change originating from river flow regulation depends upon the channel cross section. This means that each river reach (or even areas within a given river reach) will have a different response to changes in flow, where some stretches of river will have larger areas influenced by regulation, and some will have smaller areas.

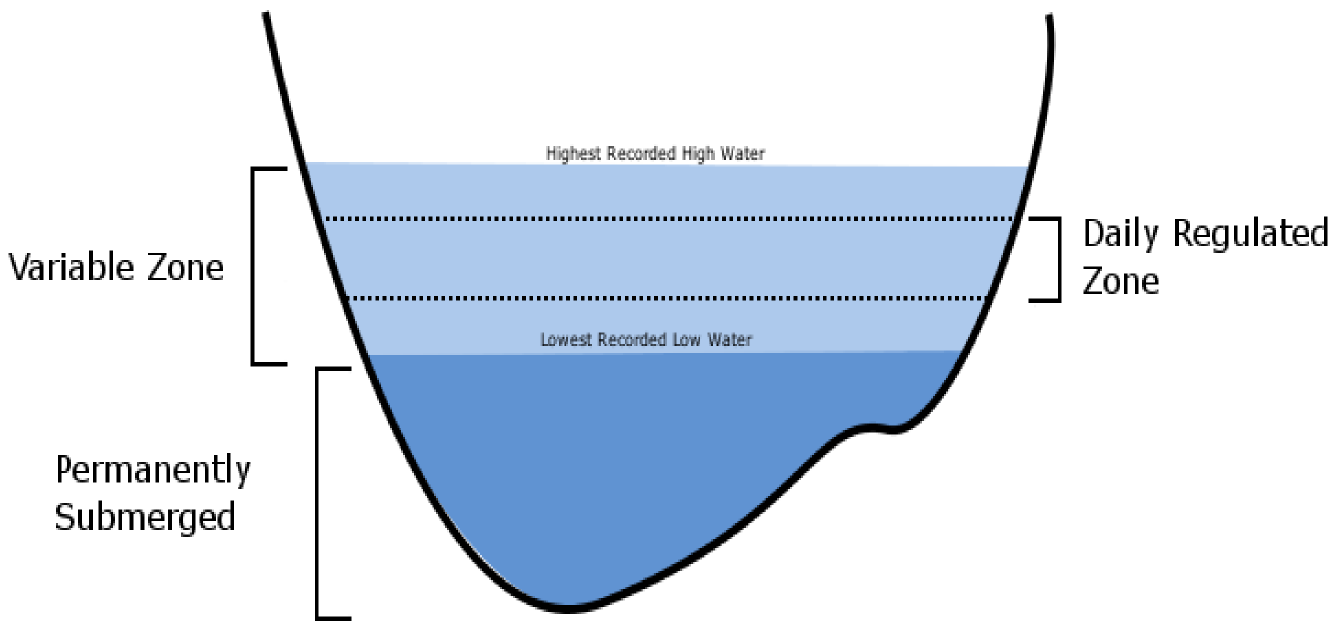

Figure 2: An example of the varial zone areas affected by a regulated river regime.

3.0 Key Physical Factors

It is important to understand that productivity varies with many physical parameters in an unregulated river. For instance, factors such as light (and by association depth), velocity (and subsequent scour and erosion/deposition), and substrates are examples of physical parameters that can influence primary production of both periphyton and invertebrates in a natural river system. Regulation of rivers adds a further physical habitat influence that operates in conjunction or on top of observable natural variation. Separating the influence of natural variation from the impacts of flow alterations associated with river regulation is challenging because flow alterations vary over time. In fact, some hydro facilities alter flows on a near hourly basis creating hourly changes in periphyton and invertebrate habitats because they alter velocity (via changes in channel cross section at different flows), light (via depth), and wetted habitat conditions.

The following is a condensed list of key factors that influence productivity and are associated with changes in flow alteration from river regulation that have been identified as important in the Peace and Columbia systems (i.e., Peace River[5] & Mid Columbia Revelstoke Flow Management Plan CLBMON15b[6] and Lower Columbia Flow Management Plan CLBMON44[7]):

1. Submergence and Depth Patterns (affected by discharge and channel cross section)
2. Light (which is affected by depth and turbidity)
3. Velocity (which is affected by discharge and channel cross section)
4. Substrate Size (which is affected by velocity)
5. Deposition Rates (which is affect by velocity, substrates, and turbidity)
6. And a whole bunch of other factors, which are important, but less influential in a regulated system (e.g., riparian cover, etc.)

3.1 Submergence and Exposure

In permanently submerged areas, the primary factors that affect production within the river are related to physical factors such as substrate size, light intensity, and velocity. The list of physical factors that are potentially influential is quite long, noting that regulation can have a direct or indirect effect on many of them. To generalize, productivity typically increases with increasing substrate size largely because stable substrates experience less abrasion due to the larger substrate sizes and elevation above the bed of the river, and these areas typically experience less deposition (Figure 2). The effects of velocity are variable, with decreasing productivity as velocity increases above a certain threshold and increasing velocity up to a threshold. However, this trend is more complicated than this simple generalization and is dependent upon local channel morphology and species specific responses. Light intensity is also complicated. The data indicate that as light intensity increases, so does productivity, noting again the complex interactions ultimately determine productivity at any permanently submerged location.

In varial zone areas, the most important factor that affects production is submergence (or exposure). Submergence is a direct function of flow regulation, in combination with

[5] https://www.sitecproject.com/document-library/fisheries-and-aquatic-reports
https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/northern_interior/peace_river/recreational_access.html

[6] https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/revelstoke-flow.html

[7] https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/lower-columbia-fish.html

channel morphology. Any increases in flow create larger vertical elevation changes in narrow confined channels when compared to wider, more open channels. Although physical factors are potentially influential, these effects are less important than the submergence time spent within the water. This trend has been found using numerous different variables and datasets that describe submergence, with variables such as total submergence time, total time spent in the water during the day, frequency of 9 and 12 hour submergence events and many factors all identified at one time or another as important. In nearly all cases, the most important predictor of productivity for periphyton and invertebrate abundance and biomass in varial zones areas was submergence when compared to any physical parameter such as light, substrate size, or velocity.

Since submergence is a key factor in varial zone areas, a conceptual understanding of how growth and death occurs is useful. Growth curves have been developed for both the Lower Columbia River and Mid Columbia River, and in each of these cases, the curves developed can be varied by season. It is important to note that many factors affect these growth curves, including patterns of submergence and the time spent in a state of variable daily submergence (see Schleppe et al, 2015; Schleppe et al., 2014). The curves presented here are conceptual, and it is acknowledged that additional data would provide a better estimate.

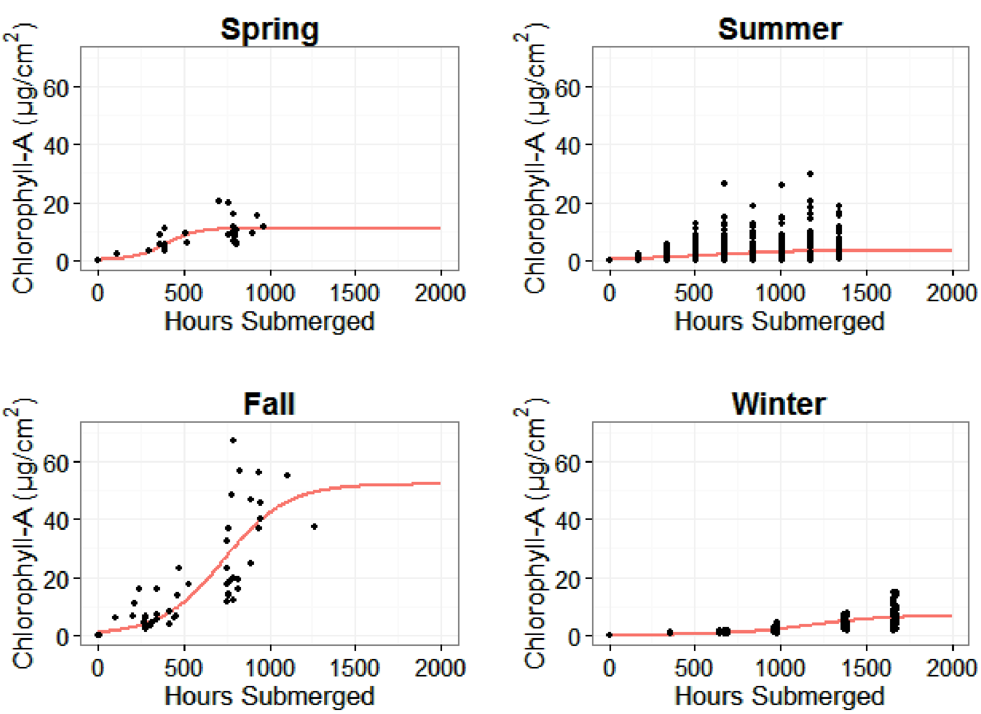

Figure 3: Periphyton chlorophyll A growth curves in the Lower Columbia River in the spring, fall, summer and winter.

A death or exposure curve is also important because it provides a conceptual understanding of how the riverbed drying processes affect survival during a period of exposure. Theoretical exposures curves have not been specifically developed because less data is available for the Columbia system. Existing data published by Stanley et al (2004) is useful to consider for periphyton, when coupled with some assumptions based upon literature reviews, and field exposure data collected. For invertebrates, some simple exposure experiments have been conducted, but do not address the highly variable field conditions that exist, where temperature and weather are always changing. Exposure curves are general for a broad array of species do not account for species specific responses, where there are likely numerous dependent factors such as temperature and weather that influence the responses for any given species. However, the need to simplify exposure scenarios means use of a simple, conceptual response is appropriate to understand reach wide effects for large stretches of river.

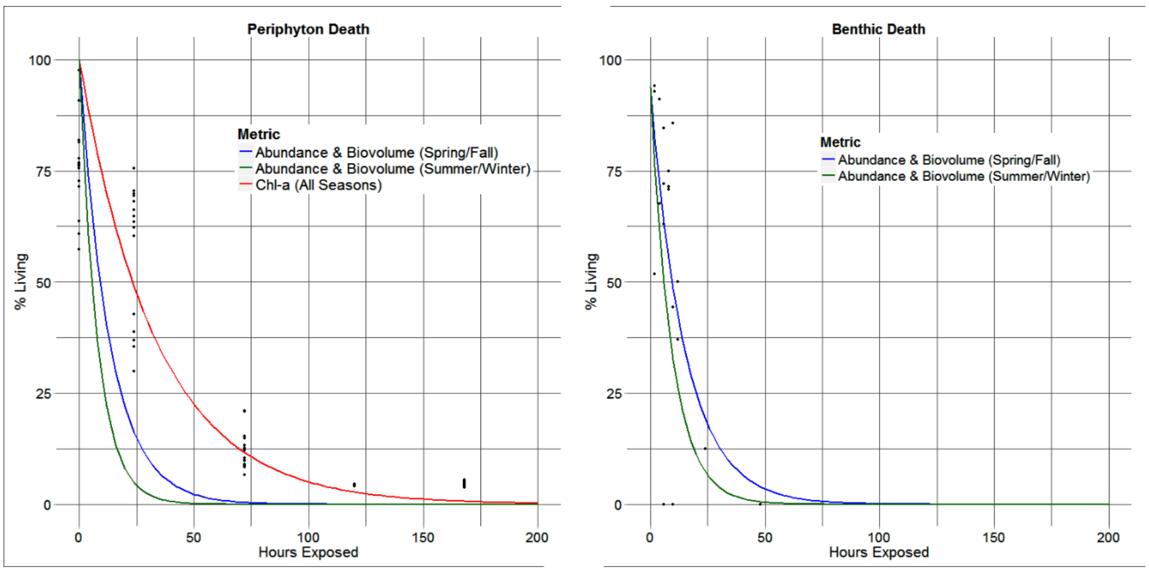

Figure 4: Periphyton and invertebrate death curves. Note that the periphyton death curve is reproduced from Stanley et al (2004).

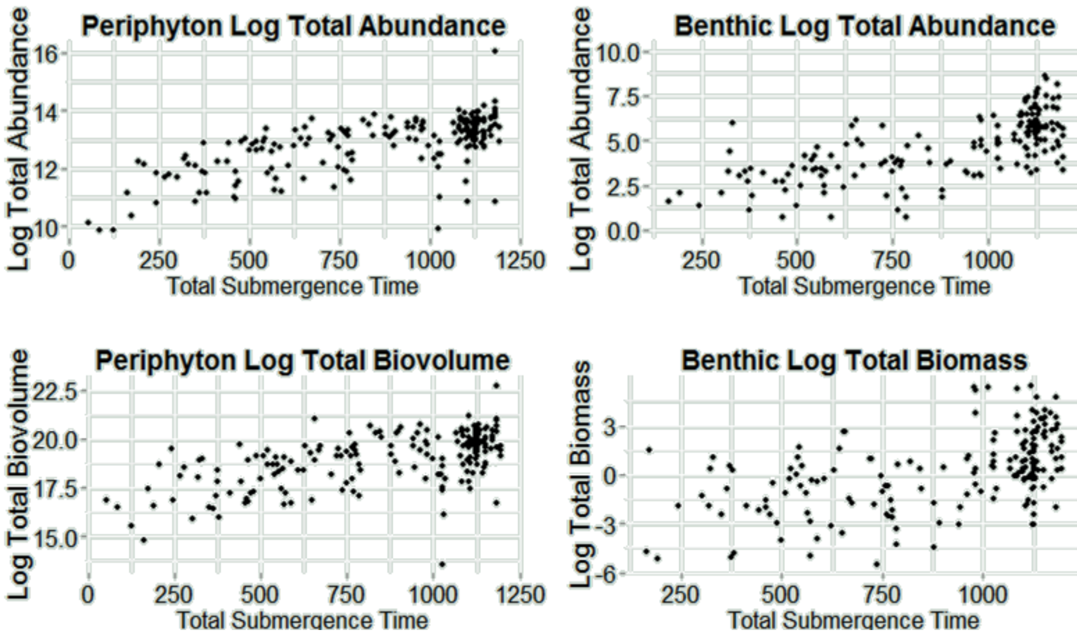

Figure 5: Primary factors, including substrate size and velocity that affect periphyton and invertebrate production. As substrate score increases, so does substrate size.

3.1 Light

Light intensity decreases with depth, where the turbidity of water is also extremely important (Figure 6). The pattern of light attenuation in water is highly predictable, and dependent upon the physical properties of water. In turbid systems, light attenuation increases with increasing turbidity, because it reduces the penetration of light to the riverbed. This reduction in light penetration occurs in the same varial zone areas that are under the influence of river regulation. Thus, it is apparent that new growth and production in turbid rivers can be limited by both light, growth and exposure.

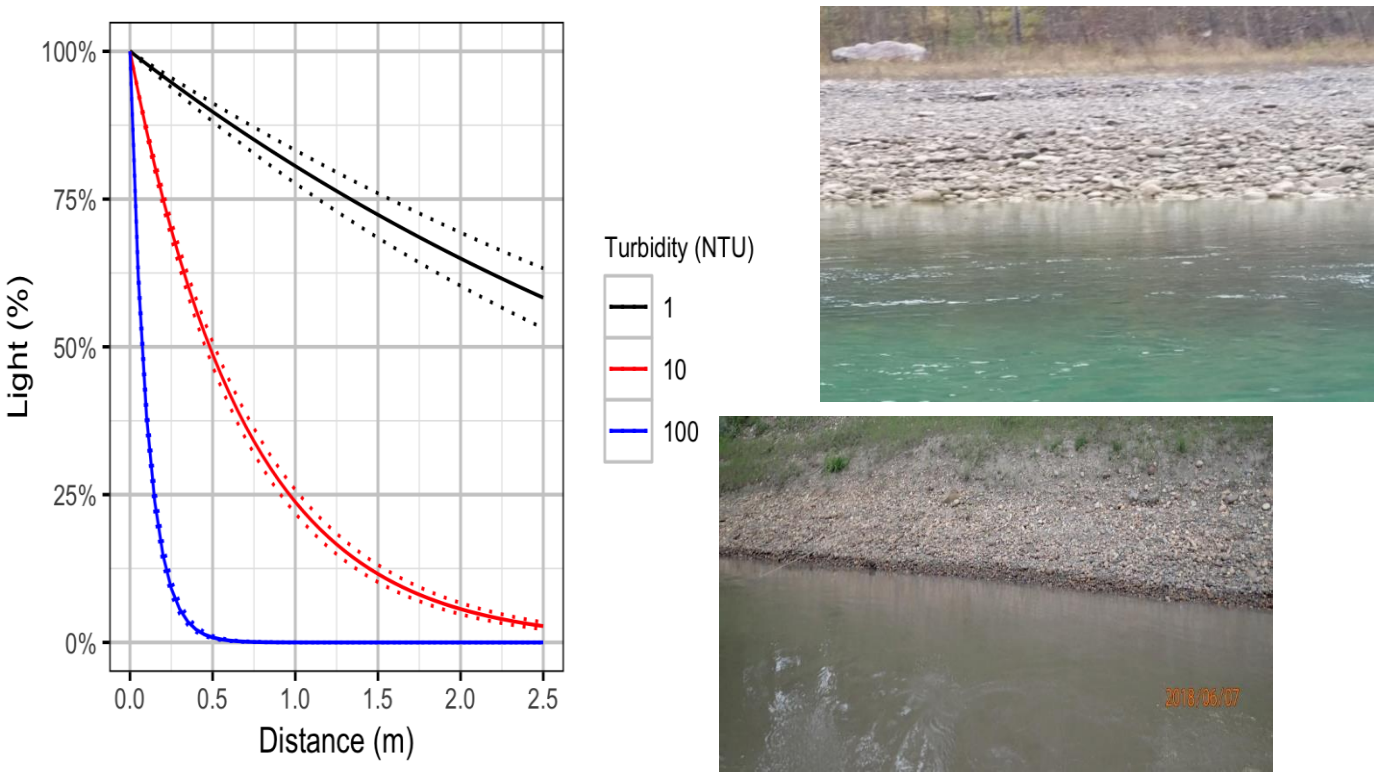

Figure 6: Light intensity, as a percentage under three different turbidity profiles. Photos of the Columbia (Top Photo) and Peace River (Bottom Photo), showing that light intensity in river margins overlaps with the same areas under the influence of river regulation.

Light is extremely important because it provides the energy necessary for production to occur. A lower limit of 10 photons is considered the minimum quantity of light needed to facilitate production (Sigee, 2005). The data from the Peace River provides a good summary of the importance of light, likely because it is a light limited system unlike the Columbia. Productivity was found to increase with the total time spent in locations with over 10 photons. The importance of light is mostly commonly associated with periphyton, although some trends of increasing invertebrate production (abundance) with light were also been observed. Regardless of how strong the relationships observed were, light must be influential because it provides the energy necessary for production to occur.

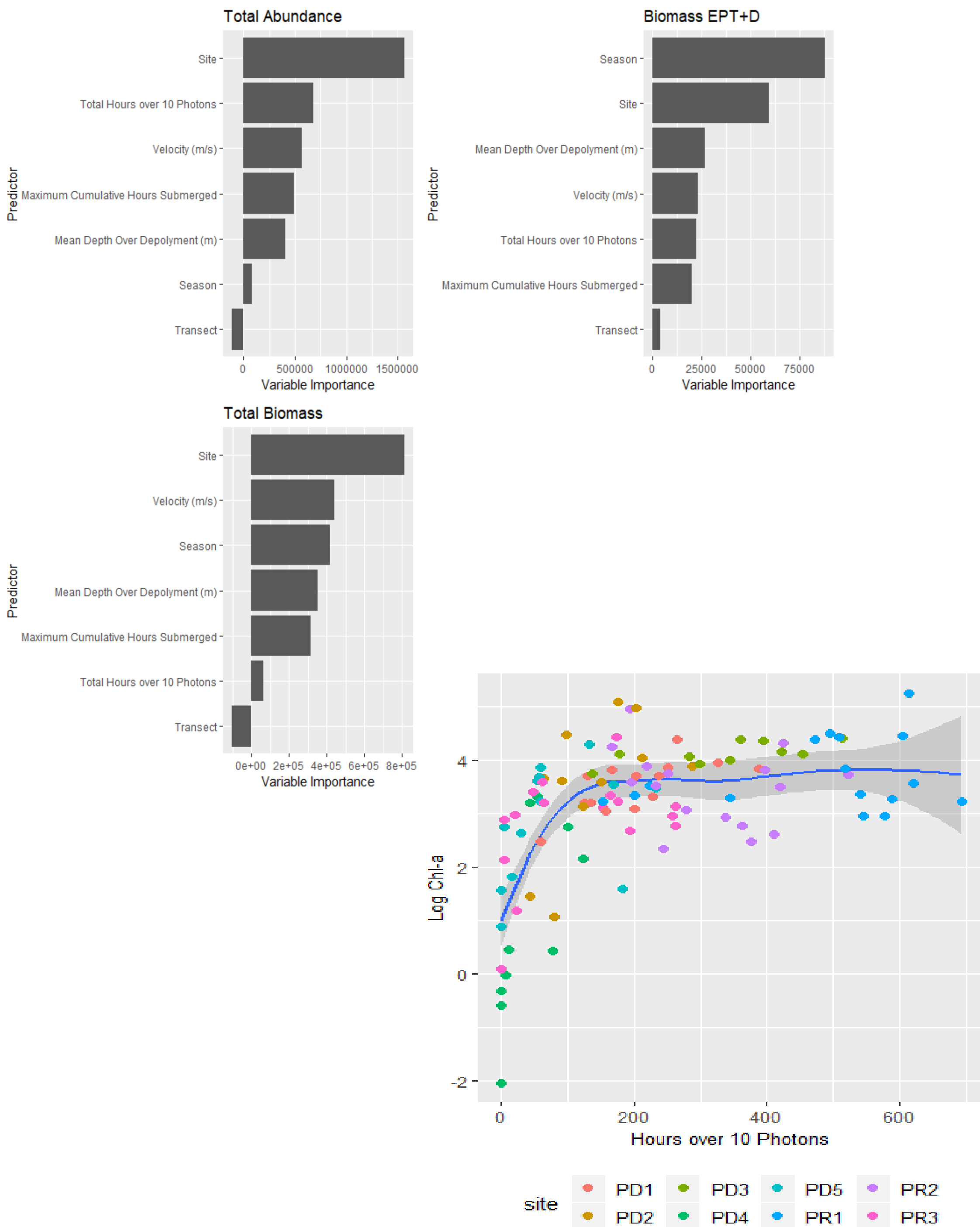

Figure 7: Data from the Peace River highlighting the importance of light to production for invertebrates (top) and the increase in productivity with time spent in at least 10 photons for periphyton.

3.1 Velocity

Velocity is also important because it moves water and provides sources of nutrients and food for both periphyton and invertebrates. While light is more important for periphyton, it is suspected that velocity is more important for invertebrates. The data from the Peace River provide a good summary of the importance of velocity, where productivity increases with the total time spent in areas of moderate velocity greater than 0.5 m/s and less than 1.5 m/s. The full influences of velocity are best understood using bench experiments, which have not been conducted. It is expected that production will increase with velocity beyond a minimum threshold, and at some upper velocity primary production will be reduced because of increased losses associated with scour and abrasion.

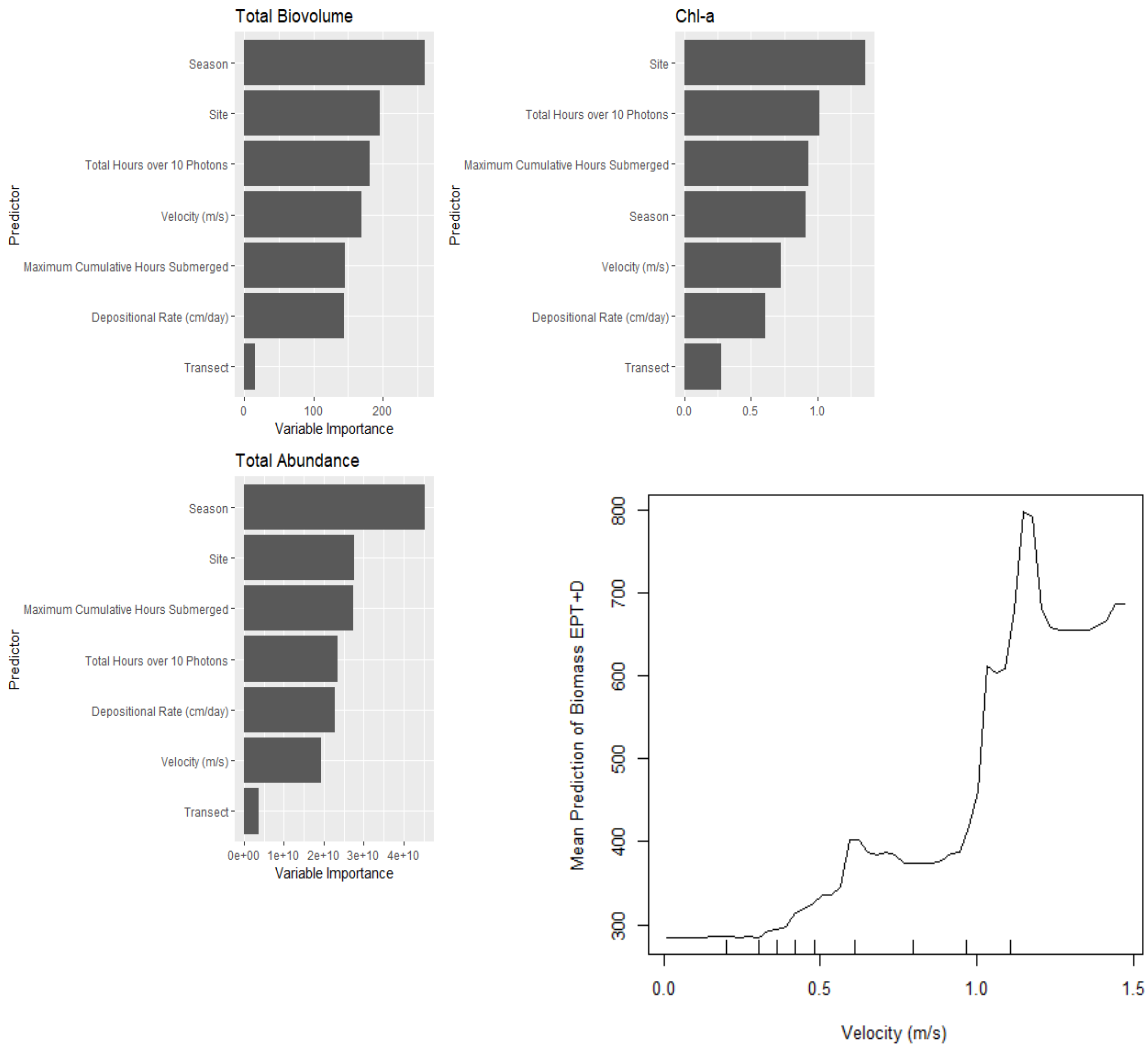

Figure 8: Data from the Peace River highlighting the importance of light to production for invertebrates (top) and the increase in productivity with time spent in at least 10 photons for periphyton.

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Small hydro flow fluctuations & tailed frogs: implications for run-of-river operations

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Introduction

Run-of-river (RoR) hydropower has become increasingly popular as an environmentally friendly alternative for producing electricity. However, RoR may impact stream ecosystems by inducing flow fluctuations below the dams for power generation. These projects work by using a small dam to divert a portion of the river flow through a penstock, down several kilometers to a powerhouse, using the drop in elevation to generate electricity (Figure 1). Flow fluctuations caused by dam operation change the natural flow regime of the stream and could impact organisms that are adapted to natural flows.

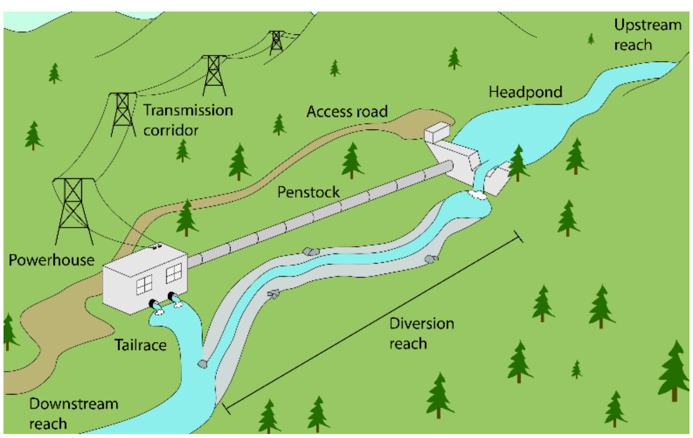

Figure 1. A diagram of a typical run-of-river project in British Columbia.

One of these species is the Coastal tailed frog (*Ascaphus truei*), whose larvae live in small mountainous rivers for four years prior to metamorphosis. This long larval stage prolongs their exposure to any possible in-stream impacts. During these four years, larva scrape biofilm from cobble substrate using specialized suction mouth parts, and drift downstream from the site of oviposition (Wahbe and Bunnell 2001).

After surveys above and below three RoR dams, we found higher *A. truei* densities below dams, compared to above (Figure 2), but the mechanisms responsible for this pattern were as of yet untested. We had three hypotheses that could explain the differences in tadpole densities above and below RoR dams: 1) regulated flow fluctuations below dams that are designed to minimize impacts on salmonids do not protect larval *A. truei*, 2) un-regulated flow fluctuations that occur 24 hours post increases in flow that are assumed to not impact salmonids occur too soon after flow increases and put larvae at further risk to stranding, and 3) the dam and associated upstream headpond act as a barrier to the natural downstream drift of larvae leading to a build-up of larvae above the dam.

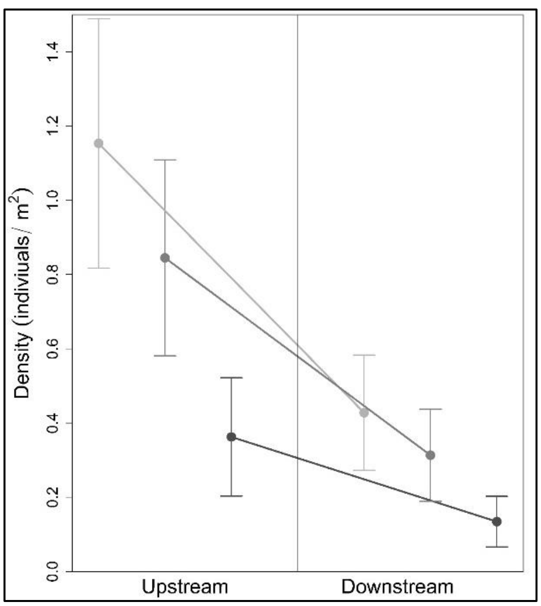

Figure 2. Tadpole density upstream and downstream dams with standard errors (Fire= lightest, Tipella= grey, Stokke= dark grey).

Methods

We preformed experiments testing *A. truei* larval behaviour and ability to avoid stranding during reductions in flow, and their propensity to move into newly wetted areas (NWA) after increases in flow, and subsequently compared the exposure to such un-regulated rapid flow fluctuations above and below dams. Furthermore, we surveyed tadpole density as a function of distance upstream of RoR dams and associated headponds at three RoR streams in southwestern BC (Figure 3) to provide evidence for the dams acting as a barrier to natural downstream drift of larvae.

We tested larval stranding rates using an instream mesocosm that mimicked stream edges (cobble stream bed on a slope) in which larvae were placed at the top (most shallow) side of the mesocosm, and water levels were reduced at three different rates and recorded the proportion of larvae stranded after the trial had elapsed.

Larval colonization of NWA was also tested in an instream sloped mesocosm. During each experimental trial the deepest end of each mesocosm was submerged in flowing water while the most shallow end was kept dry. Larvae were placed in the submerged end, allowed to acclimate to conditions, and the shallow dry end was then submerged in water for 2-24 hours, after which we recorded how many individuals moved into the shallow end (NWA).

To estimate the exposure of stranding due to un-regulated reductions in stream flow after periods of stream flow increase which creates NWA we constructed an algorithm that searched wetted-area hydrographs for three streams at defined stream reaches for a 10% increase in NWA that remained at the increased NWA for 12 hours. Subsequently depth-hydrographs were searched for the following 12 hours for ramping reductions in flow that resulted in a stage change of higher than 2.5cm/hr. We computed the number and the magnitude of events for above and below the dam.

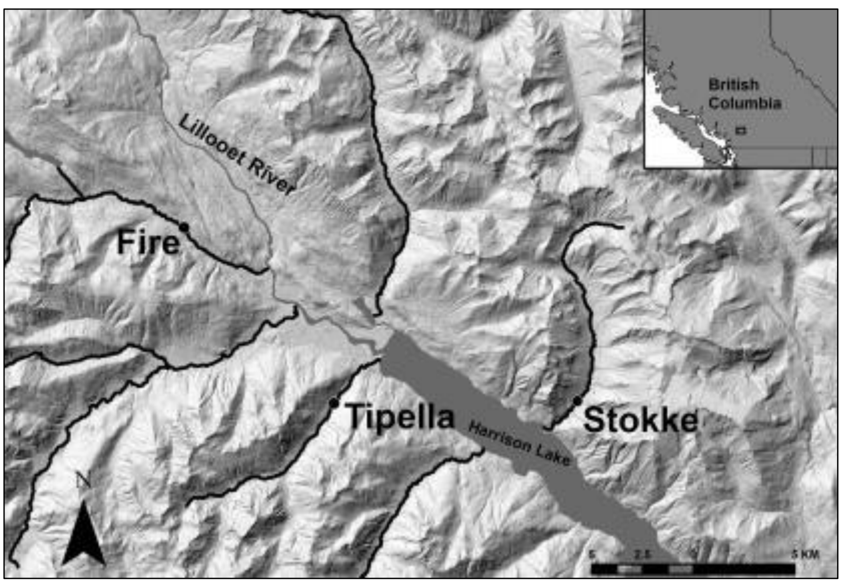

Figure 3. Study area within Lillooet and Harrison Lake drainage in Southwestern British Columbia. Labelled dots represent the three study streams and dams.

To help determine whether RoR dams act as barriers to *A. truei* larvae upstream of headponds, we mapped environmental characteristics associated with *A. truei* larvae upstream of RoR dams. We chose plots that were believed to be high quality habitat, selecting areas of cobble with low embeddedness, shallow to medium depth, and moderate to high flows (Dupuis and Steventon 1999), and selected 5 – 10 survey plots within the headpond-affected reach (range: 70 – 120m upstream). To analyze the data, we modelled larvae density in relation to distance upstream of headpond, the environmental variables collected and stream to account for differences in background density. Lastly, we multiplied our predictions of density from the resulting model with estimates of high-quality habitat area estimated from drone imagery to give an estimate of larval abundance per 10m segment of headpond-affected reach for each stream.

Results

We found that few larvae move into NWA in 2 to 6 hours, but between 12 to 24 hours 10 to 30% of larvae moved into NWA. This is faster than what regulations are based on, which assume that no fish move into NWA within 24 hours after creation (Figure 4) (Innergex, 2012). We estimate that about 30% of tadpoles strand at 5cm/hr, while at 30cm/hr and 60cm/hr 80 to 95% of larvae stranded. Comparing these results to salmonid studies, which average 9% stranding at 5 cm/hr (Bradford et al. 1995; Bradford 1997; Halleraker et al. 2003), we find that *A. truei* larvae are more prone to stranding than salmonids. We found that flow fluctuations that create NWA and then un-regulated flow reductions occur more frequently below dams compared to below, and at higher magnitudes, suggesting that dam operations are responsible for increasing risk of stranding to larvae.

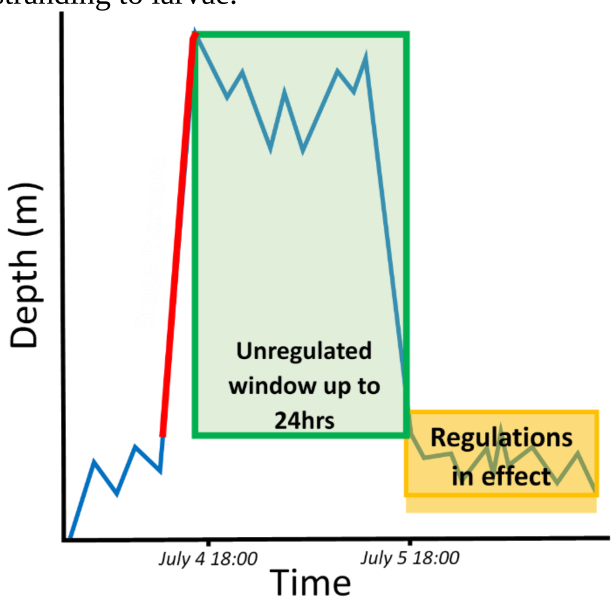

Figure 4. Visual explanation of run-of-river flow regulations where flow fluctuations not limited by regulations within a 24hr window after newly-wetted-area is created.

We found that distance upstream from headpond had a negative effect on larval density, supporting our hypothesis that there is a buildup of larvae at the dam (edge of headpond) and that these structures act as a barrier to larvae. Using estimates of abundance per ten meters we show a shift in larval abundance towards the headpond, lending further support to the idea that the dam is a barrier to larval movement. This higher density of tadpoles could have consequences for survival if it leads to density dependent growth. Furthermore, RoR operations require periodic dredging of the headpond to remove sediment that is transported into the headpond over time. This dredging occurs in the areas we know have the highest larval densities, and likely leads to mortality if no or ineffective larval reclamation is performed.

Conclusion

We found that tadpoles moved into newly wetted areas sooner than salmonids are expected to, and tadpoles had high rates of stranding at flow fluctuation rates considered safe for salmon fry, but increased tadpoles' risk of stranding. Furthermore, our analysis of RoR hydrographs found substantially more intense flow fluctuations below RoR dams compared to natural flows found upstream. We also found evidence that the RoR dams are acting as a barrier to *A. truei* larvae, blocking them from downstream reaches. We believe that both flow fluctuations from the dam and the dam’s role as a barrier to larval movement downstream are responsible for the differences observed in above and below dam *A. truei* larval density.

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Effects of climatic and flow-path modification on water quality in the upper Columbia Basin

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Abstract
The availability and quality of water is arguably one of the most important issues facing our ever- expanding human population. Beyond our own needs, sustainable water resources are essential to the proper functioning of nearly every ecosystem on the planet. A variety of both natural and anthropogenic factors can lead to declines in water quality, including the effects of storms, erosion, landslides, geology, atmospheric contaminants, and land-use. Climate change has the potential to exacerbate all of the above and introduce new and unexpected problems. Here we examine the use of space-for-time substitutions as a tool to examine water quality changes that result from a) climate and habitat change, b) increased fire frequency, and c) glacial recession on water quality and aquatic habitat. We draw from data across southern British Columbia but pay particular attention the Canadian portion of Columbia Basin. The Columbia River Basin incorporates areas from six US states and one Canadian province and supports over 400 dams producing a large portion of the energy needs of the Pacific Northwest, several unique ecosystems, numerous fish species, agriculture, and a growing population. Thus water quality in this regions is of widespread significance for both ecosystem health and human and wildlife consumption and use.

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Incorporating ecosystem function in a renegotiated Columbia River Treaty

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Introduction

The Columbia River Treaty (Treaty) was signed in 1961 between Canada and the United States and ratified in 1964. It authorized the construction of four dams on the Columbia and Kootenay River systems. These dams have devastated aquatic, terrestrial, and wetland/riparian ecosystems of the major valley bottoms of Canada's Columbia River basin. The Duncan Dam was completed on the Duncan River in 1967, creating the Duncan Reservoir. It was followed by completion of the Hugh Keenleyside Dam on the Columbia River in 1968, creating the Arrow Reservoir. Libby Dam on Montana's Kootenai River was completed in 1972, creating the Koocanusa Reservoir which extends into British Columbia. Mica Dam was completed in 1973, creating the Kinbasket Reservoir on the Columbia River. Operations at the three Canadian dams are governed by the Treaty.

The Treaty's two stated purposes are flood-risk management and hydropower production. It does not include measures to protect ecosystem function. Canada was paid \$275 million to build Keenleyside, Duncan, and Mica dams to deliver a required 15.5 million acre-feet (maf) of water storage. (Note: 1 maf is equivalent to 1.23 km^3.) Libby dam has provided an additional 4.98 maf of water storage however unlike the other three dams, its operations are not governed by the Treaty. Under the Treaty, an annual payment called the "Canadian Entitlement" (now valued at \$150-200 million) is paid to Canada to share in the hydropower benefits gained in the US. No payment is associated with Libby Dam and no payments are associated with the loss of ecosystem function that persists in Canada as a result of the Treaty. As of 2014, with ten years' notice Canada or the US can leave the Treaty. Under the Treaty, in 2024 Canada's responsibility for flood control moves from prescribed to "Called Upon" meaning that the US has to first exhaust other options before calling upon Canada to store water. In addition, as long as the Treaty dams exist, even if the Treaty is cancelled altogether, Canada has to provide Called Upon flood control.

Negotiations are currently underway to modify the Treaty. During these negotiations, it is recognized by various parties that ecosystem function needs to be brought into the

Treaty, however, it is far from clear how to do this. The reservoir footprints and regulated flow regimes authorized by the Treaty continue to be destructive to Canadian (and US) ecosystems. Additional incremental activities have added significantly to the Treaty's direct impacts. For example, Mica dam was built higher than the Treaty requires enabling a Non-Treaty Storage Agreement (NTSA) to be established in relation to its reservoir. Additional non-Treaty dams have also been constructed, taking advantage of the regulated flow regimes, creating additional ecosystem impacts.

There is no agreed upon definition of ecosystem function. Ecosystem function can be defined as the collection of biological, chemical and physical processes that support species and biotic communities in aquatic, terrestrial and wetland/riparian realms. Collectively, ecosystem functions yield intact and healthy ecosystems for their own sake and that of their genetic, species and community well-being. Ecosystem function also provides services that benefit human communities. Approaches to bringing back ecosystem function and their accompanying ecosystem services are currently being explored in Canada and the US. Although widely supported in principle, how to design measures to restore Canadian ecosystem function is far from clear due to competing and conflicting economic priorities and environmental outcomes both within Canada and between Canada and the US.

Environmental Consequences of the Treaty

The major valley bottom of Canada's Columbia Basin from the Kinbasket Reservoir and downstream are highly affected by dams and flow regulation. Figure 1 identifies the affected waterbodies, and distinguished in Table 1 on the basis of being Treaty reservoirs, non-Treaty reservoirs, river reaches and other waterbodies. In addition to the Treaty's direct widespread and long-lasting damage to ecosystems of the Upper Columbia Basin, non-Treaty environmental losses have also accrued incrementally through additional development adapted to Treaty installations and the system's regulated flow regimes. The four major dams authorized by the Columbia River Treaty have been followed by construction of the Revelstoke Dam, Pend d'Oreille dams and the 1976 Kootenay Canal Project on the lower Kootenay River. The 1932 Corra Linn Dam, the 1907 Upper Bonnington Falls Dam, the 1925 Lower Bonnington Falls Dam, the 1928 South Slocan Dam, and the 1944 Brilliant Dam pre-date the Treaty. There are also significant sections of rivers and valley bottoms which do not have reservoirs but are affected by these dams. There are four sections in the Kootenay system – the Kootenay River between the US border and Kootenay Lake, the Duncan River below Duncan dam, the lower Kootenay River below the various Kootenay River dams, and Kootenay Lake itself. In the Columbia River valleys, there are three reaches affected: the reach below R evelstoke dam, the reach below Keenleyside dam, and the reach below the Pend d'Oreille dams to that river's mouth with the Columbia River.

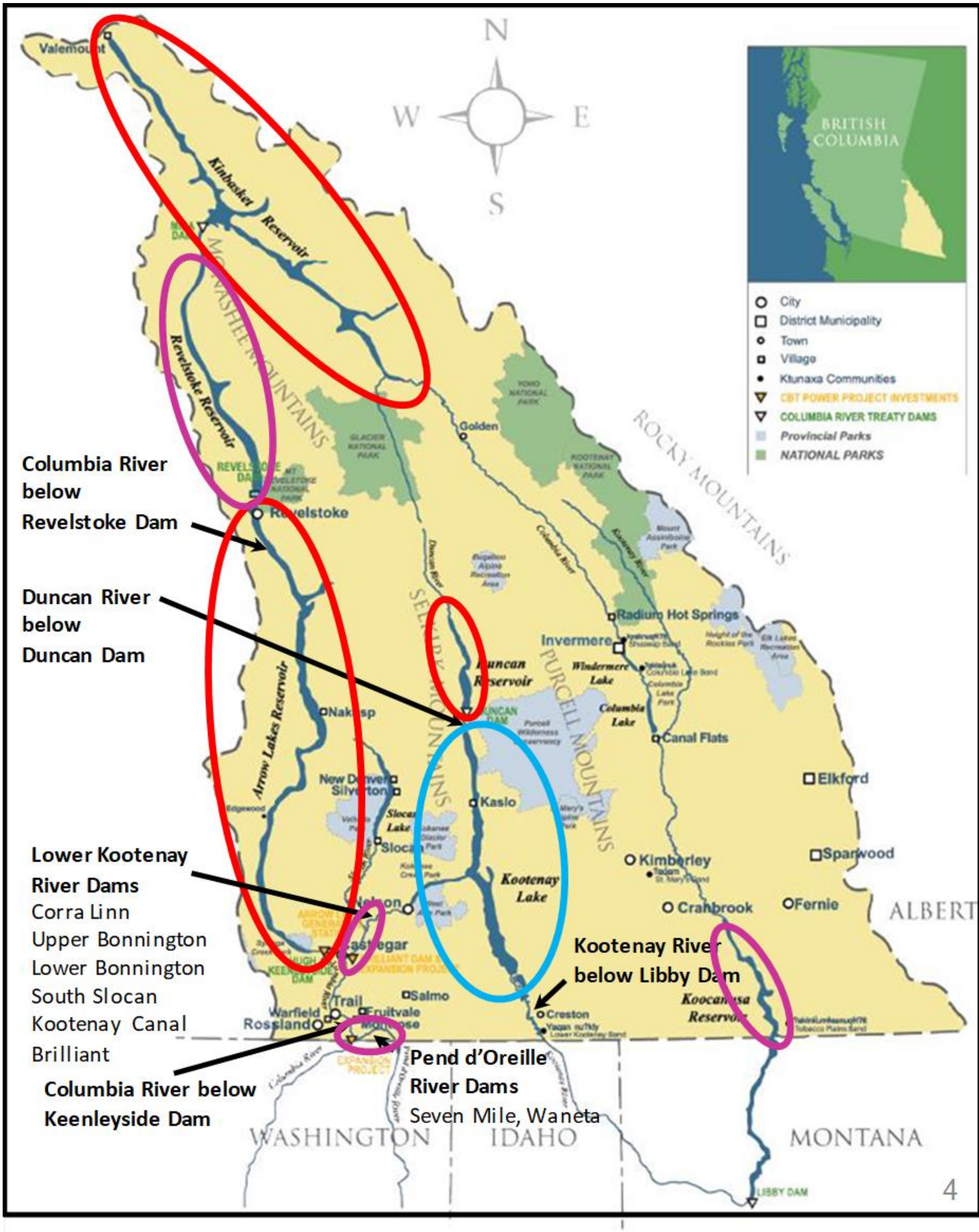

Figure 1. Major valley-bottom waterbodies in the Upper Columbia Basin that have been impacted by dams and flow regulation.

Table 1. Major waterbodies of the Canadian Columbia and Kootenay rivers affected by dams and flow regulation.

Grouping	Affected Components of Valley Bottoms
Treaty reservoirs	Arrow Reservoir (Keenleyside Dam) Kinbasket Reservoir (Mica Dam) Duncan Reservoir (Duncan Dam) Koocanusa Reservoir[1] (Libby Dam)
Non-Treaty reservoirs	Reservoirs along the Lower Kootenay River Revelstoke Reservoir (Revelstoke Dam) Reservoirs along the Pend d'Oreille River behind the Waneta and Seven Mile dams.
River reaches	Upper Kootenay River below Libby Dam Lower Kootenay River below Kootenay Dams Duncan River below Duncan Dam Columbia River below Revelstoke Dam Columbia River below Keenleyside Dam Pend d'Oreille River below Waneta & Seven Mile Dams
Other Waterbody	Kootenay Lake (below Libby & Duncan Dams)

1 Although the Libby Dam was authorized by the Treaty, its operations are outside of the Treaty, distinguishing it from the other three Treaty reservoirs.

A collection of assessments undertaken by the Fish and Wildlife Compensation Program (FWCP) has documented the environmental losses that have accrued due to major dams in the Upper Columbia Basin and including the Treaty dams (Utzig and Schmidt 2011). The impacts result from the combined effects of the reservoir footprints and the regulated flow regime. Impacts in four areas are recognized: habitat, productivity, species, and aquatic fragmentation in the following ecosystem types:

1. Reservoir inundation within the reservoir footprints has resulted in extensive loss of habitat:

   - Terrestrial – upland forest, grasslands, shrublands
   - Wetlands/floodplains – marshes, fens, swamps, riparian
   - Aquatic – lakes, large rivers, low-gradient streams

   The diversity of habitats lost varies markedly from reservoir to reservoir. For example, Arrow Reservoir is associated heavily with lost lake habitat whereas Duncan Reservoir destroyed extensive riparian floodplains and shallow wetlands.

2. Primary productivity has been lost at all reservoirs with the losses associated with the Kinbasket Reservoir exceeding that of all the other reservoirs combined. Lost primary productivity is equivalent to lost carbon sequestration and contributes significantly to climate change.
3. Of the 47 fish species in the Upper Columbia Basin, impacts have been described for 24 species due to habitat loss, habitat fragmentation and flow modification. Of the 289 resident vertebrate wildlife species, impacts have been assessed at all reservoirs. Wetland/riparian-dependent species have been impacted the most and larger reservoirs have resulted in larger impacts.
4. The dams differ in their restrictions on upstream and downstream fish passage. Impacts due to lost passage for salmonid migration were not considered when the Treaty was signed because passage was previously blocked by pre-Treaty US dams.

Although not included in the FWCP assessments, river reaches downstream of the Treaty dams have also degraded ecologically due to the altered flow regimes. These losses include direct flow-regime impacts to channel substrate, channel stability, and life-cycle requirements of fish species. Water quality changes (temperature, nutrients, dissolved oxygen) have further impacted the functions and plant and animal communities of aquatic ecosystems. Riparian function in these reaches has also been affected. Fish passage through these reaches has been variously impaired by the dams both in terms of blockage of upstream passage and lethal effects during downstream travel.

Upper Columbia Basin Environmental Collaborative

The Upper Columbia Basin Environmental Collaborative (UCBEC) proposes that a renegotiated treaty should include a collection of measures to strengthen ecosystem function in the short term as well as measures that enable resource managers and conservation planners to restore ecosystem function incrementally through time. UCBEC is a collaboration between provincial, regional and local organizations giving voice to environmental needs and priorities in the Upper Columbia Basin. UCBEC engages with environmental non-government organizations, indigenous groups (First Nations and US Tribes), and federal, provincial and local governments in pursuit of two ecosystem objectives:

- to improve the function of Canadian ecosystems impacted by dams and reservoirs in the Columbia Basin, in the aquatic, terrestrial, and riparian/wetland realms; and
- to further ecosystem restoration, creation and/or enhancement within, and/or near, all Canadian reservoirs and major river reaches, while recognizing the need to balance efforts among reservoirs and reaches to achieve the greatest net ecological benefits.

UCBEC's core principles include science-based decision making and an openness to collaborate with those who share its ecosystem objectives.

Restoring and Enhancing Ecosystem Function

The type and source of impact from Treaty and non-Treaty developments vary significantly throughout the Basin in relation to each installation, operating regime, and particular geographic and ecological nature of the associated upstream and downstream valleys. While affected waterbodies have unique characteristics, they are also intimately interconnected. Beneficial changes to one may lead to detrimental impacts to another downstream. Those changes that may benefit elements in Canada may not be beneficial for their US counterparts and vice versa. To devise effective solutions, clarity is first needed on the interconnected environmental concerns and their respective causes. Focus in this discussion is on ecosystems and habitats because this is likely to be more cost effective and provide a wider array of benefits than one or multiple singe-species approaches. Proposals are outlined here in two broad areas: 1) governance and funding and 2) flexibility and adaptive management.

The addition of ecosystem function as a third and equal Treaty purpose is required to ensure inclusion of ecosystem considerations alongside the well-established priorities of hydropower and flood-risk management. The addition of this purpose should be mirrored by an increased emphasis on ecosystem function in all water management decisions mandated by the Treaty. Treaty governance should be adjusted to reflect this broadened emphasis by adding scientific expertise on ecosystem function and resilience to all operating entities and incorporating understanding and insights from Traditional ecological knowledge. The role and appropriate rights of First Nations should be recognized. Local and regional trans-boundary participation in decision making should be supported and improved. Increased funding should be provided for restoration and compensation projects.

Another fundamental revision to the Treaty proposed here is to build in greater flexibility into Treaty operations in Canada so that we can learn how to improve ecosystem function by exploring our best ideas and by testing hypotheses. No one will have all the answers upfront. Decades have been spent creating an interconnected system of impacts with little or no priority given to ecosystem function; appropriate adjustments won't be identified and verified overnight. Flexibility would also enable the pursuit of active adaptive management to enable learning by doing. Active adaptive management is a structured, iterative process of learning, monitoring and adapting management in the face of uncertainty. It is proactive and includes testing of new management alternatives to accelerate learning, in contrast to passive adaptive management which emphasizes monitoring of default management approaches leading to a slower pace of innovation.

The primary purposes are to increase understanding of system function, reduce uncertainty over time, and improve future management.

The merits of an intervention will depend on location and what is prioritized. Key is to ensure that ongoing adjustments to operations reflect the monitoring results from active adaptive management. With ecosystem function identified as a third and equal Treaty purpose, outcomes would be evaluated according to all three purposes. Relative costs and benefits across the reservoirs and up and down the system should also be taken into account. Although the proposals here focus on Canadian ecosystems, environmental objectives in Canada should recognize the consequent strengths and drawbacks for US ecosystems and take these into consideration in any transboundary discussions. Adaptive management is not new to the Columbia Basin; however, its application has had varying success (*e.g.*, Cosens and Williams, 2012; US National Research Council, 2004; Taylor *et al*., 1997 and McConnaha and Paquet, 1996).

Discussion

The number of interests and moving parts within the managed Columbia River system is so great that it is difficult to disentangle them to identify specific appropriate improvements that support ecosystem function. What could benefit an ecosystem or a species in one aspect of the system could threaten another elsewhere. Thus, central to the success of this work is to balance impacts through the application of system understanding to achieve improved ecosystem function. Insights into system behavior are available from both Traditional Ecological Knowledge and western science.

Using this more wholistic approach of considering all three purposes, and actively trying out innovations, resource managers can strive to achieve specific Canadian environmental outcomes. For example, we can begin to gain back some land currently lost due to prevailing operational regimes. In addition to gaining back terrestrial habitat, this will also allow restoration of low-gradient streams and rivers previously flooded by reservoirs. The mid-level scenario for Arrow Reservoir (Thomson *et al.* 2017) has been proposed as a viable opportunity to achieve multiple objectives with an overall positive balance sheet and provides an example of the kinds of things that can be tried in other reservoirs. Also, adjustments to the flow regime and to the rule curves can be considered to improve the situation downstream of certain dams, perhaps in support of key species and other habitat issues.

In applying active adaptive management in pursuit of targeted environmental outcomes, indispensable elements for success include:

- wide and meaningful consultation with all stakeholders and knowledge holders,

- clear understanding of decision structure with endorsement and commitment of key decision makers,
- objectives, goals and actions at the appropriate spatial and temporal scales for the problem,
- effective performance measures,
- well-implemented monitoring programs, and
- effective communication of the results to the public and decision makers.

Due consideration of climate disruption and non-stationarity is increasingly essential.

Summary and Conclusions

The Columbia River Treaty authorized the construction of four major dams on the rivers flowing in Canada's Upper Columbia Basin. The three Canadian dams have been subsequently operated under the terms of the Treaty with their associated reservoirs and managed flow regimes. Over fifty years of additional river and floodplain development and incremental water-storage commitments enabled by the Treaty have resulted in a plethora of impacts to habitats, primary production, species and fish passage. Additional pre- and post-Treaty hydropower development has provided further cumulative impacts. Ecosystem function was not a consideration at the time the Treaty was signed. In light of the extensive impacts associated with the Treaty's two primary purposes (hydropower production and flood-risk management), it is recognized by many parties that ecosystem function needs to be brought into a renegotiated Treaty.

This paper has summarized the types of Treaty impacts ongoing within the Upper Columbia Basin and inventoried the reservoirs, river reaches and lake systems where the impacts are occurring. Whereas including ecosystem function as a third and equal purpose is identified as an essential revision to the Treaty to begin to address the extensive damage wrought to ecosystems within the Upper Columbia Basin, the number of interests and moving parts within the managed Columbia River system is so great that it may be challenging to move forward with appropriate improvements in support of ecosystem function.

This paper proposes that a renegotiated Treaty should incorporate increased flexibility in reservoir management to create opportunities to explore innovative adjustments to flow regimes and rule curves. This can be accomplished through active adaptive management, applied by operating entities with new mandated expertise on ecosystem function and ecological resilience. Treaty governance should be adjusted to reflect this broadened emphasis. The role and appropriate rights of First Nations should also be recognized.

This paper reaches four conclusions:

- Opportunity exists to address the accumulation of environmental impacts perpetuated by the Treaty through inclusion of ecosystem function into a renegotiated Treaty.
- Environmental impacts from dams and reservoirs include direct Treaty consequences in addition to incremental impacts due to related activities and legacy impacts from pre-Treaty dams.
- Treaty impacts and causes are highly integrated, requiring flexibility to facilitate learning and innovation in the face of uncertainty. The complexity of the impacts requires application of active adaptive management.
- Adequate funding and appropriate governance mechanisms are needed to ensure effective application of active adaptive management and the appropriate role of First Nations.

It is suggested that Canadian negotiators develop clear internal objectives so they can adapt to countermeasures requested by US negotiators and generate the greatest net ecological benefit for the Basin as a whole.

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This paper is adapted from a Discussion Paper originally prepared by the Upper Columbia Basin Environmental Collaborative (UCBEC) and released on March 21, 2018. We would like to acknowledge input from the entire UCBEC team members for their input into the Discussion Paper. Subsequent feedback about this paper from the public in addition to further input from UCBEC members is being incorporated into a revision of the Discussion Paper and has informed the content of this presentation and proceedings paper. UCBEC members include the Sierra Club of British Columbia, BC Nature, Wildsight, Yellowstone to Yukon Conservation Initiative, North Columbia Environmental Society and Friends of Kootenay Lake Stewardship Society.

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Culturally-informed ecosystem-based management: integration of Indigenous laws

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Mark Thomas, Shuswap Indian Band

Mark Thomas' Presentation

I will be delivering this presentation in a culturally appropriate way; speaking without the aid of a power point or other advanced technology. Bear with me as I have little practice.

I was asked to present on the integration of cultural values into the Columbia River Treaty. I find this difficult as I am culturally illiterate for the most part. You see, my Grandmother experienced the loss of salmon from the Columbia 1st hand and as such realized that our way of life attached to the salmon was to end. She told me "the only way to succeed was to leave my reserve to learn the 'others' way, it's the only way you will survive and prosper." I heeded my Grandmothers words in pursuit of the 'others' knowledge.

Traditional science has always conflicted with western science for reasons unexplained. These conflicting views are odd because the sciences, in my opinion, quite often complement one another. Particularly in ways of management, such as: control burning to propagate or enhance berry patches which decreases fuel load and manipulates succession to select harvesting of aquatic species such as salmon or riparian herbs to ensure species perpetuates for reproduction and/or upstream sustenance. These are only a couple examples among many. Recently the connections are becoming apparent in management practices.

Why do we have oral history stories within our nations? Stories allow us a connection to the land, environment, language and events, to reach back thousands of years throughout our ancestor's existence on this land we call Secwepemcul'ecw. That connection goes beyond the social, and to the emotional. The affectionate connection to Coyote as a trickster allows a common relative theme. Our people left us a legacy that if we connect the dots meticulously, allows us to chart our societies and their connection to the land back in time.

In general, oral teachings are:

1. To encourage behavior conducive of a certain way, such as if you work hard you will benefit or if your lazy you will perish.
2. To provide information on a geographic area or region that would impact the person or people using that area, positively or negatively.
3. To pass down information from knowledge holder to a person of stature, typically of important information that would be of benefit in the future, possibly of neighboring tribal relations, historic dates, etc.

<u>Coyote and the Salmon</u>

Before there were salmon in the streams of Secwepemcul'ecw, they only existed in the lower parts of the Columbia River. The salmon were blocked from migrating upstream because of natural obstacles.

Coyote was a shapeshifter and could transform into any form he wished and often used this ability to persuade others to do his bidding.

Cougar was a great hunter and Coyote wanted an easy meal. One day Coyote and his family attacked Cougar for not sharing any of his fats, meats, or hides. The Big Horn (mountain sheep) learned that Coyote had killed Cougar and became angry and flung rocks at them and Coyote's family was killed.

Coyote fell into the Columbia River and transformed himself into a piece of driftwood that resembled a salmon; he floated downstream until he was caught in women's fishing weirs and dams. Coyote travelled further and further down the River, stopping when he was caught in dams or weirs and transforming himself into a baby so that the women would take care of him. As he travelled downstream, he would break the dams and weirs and the salmon would follow coyote back up the streams.

All the salmon came to Coyote; when he wanted salmon, they would jump on shore to him.

At each place or stream he came to Coyote would stop and ask for a wife. Where Coyote obtained a wife he would stay, and the salmon would follow him to those streams and places.

At one time he wanted to marry Wolverine's daughter, but Wolverine knew Coyote and would not allow him to marry his daughter. Coyote was angry and set a giant stone in the water which prevented the salmon from ascending to Kutenai River country.

When Coyote is angry at Wolverine, he enters the river in Wolverine's village and Coyote sets his penis upright in the river which then turns to rock and prevents salmon from ever migrating up the Kootenay River near Kootenay Falls.

The lessons learned from this story relates to informing us of our reliance on the earth for survival and not the other way around. Without the land and water, we die. Without humans on the earth, the earth and its water and animals would flourish so we must humble ourselves.

This stseptékwll was told to James Teit by Secwepemc storyteller Sexwélecken in 1900, unfortunately only rendered in English as re-told by Teit in his own prose.
The Skeetchestn elders re-translated the story into Secwepemctsin.

<u>Kukwstsétsemc</u> to Daniel Calhoun, Leona Calhoun, Amy Slater, Christine Simon, Garlene Dodson, Doris Gage, Marianne Ignace, Ron Ignace, Julienne Ignace

Cw7it te qelmúcw tsyem-ekwe ne nek̓úl̓ecw te tmicw.
A large number of people lived together in one place, so they say.

Re speqmíc ri7 re kúkwpi7s-ekwe.
Swan was their chief, they say.

Ne kekéw te t̓ecwllúl̓ecw, te nek̓wésq̓t-ekwe me7 re scwesét-kt, te tekenu7s re sk̓welkwélt, tsyemes-ekwe te t̓icwell te qelmucw te sts7émet.stem te Ts̓í7emc. In another far away place, one day's journey away, beyond the snowy mountains lived another group of people, they were called the Deer People.

Yi7éne te tmescécen lu7 re ts̓i7, re teniye, re selcwéyecen, re sxwet̓éy, re yigelécken ell re s7i7llcw.
These people included deer, moose, caribou, mountain goat, mountain sheep and some others.

Re tcets̓-ekwe lu7 re kúkwpi7s.
They say that their chief was Elk.

Ye-ekwe yirí7 k scmentwécws te tsqwétsten te m-sq̓7es.
For a long time they had been enemies.

Kwemtús re sk̓elcmentwécws, t̓ri7 yem wel re kwek̓wiyúsem re s7elk̓wstsíllens They were interfering in each other's business all the time, that's why they had a hard time putting away food.
Tect̓icwell re stk̓wenm7íple7s, ell re tsutsúwet.s.
They each had a different kind of government and different ways of doing things.

Nek̓úsem relralt re sw7ecs, k̓emell nek̓usem ta7 t̓ri7 k sle7s, t̓ri7 yem wel kwemtús re skwek̓wiyusems.
What one group did well the other group did poorly, that is why all of them they always suffered.

Re spipyuy7e tit̓éy̓pens re tmescécen ell re tmescécen tit̓éy̓pens re spipyuy7e t̓ri7 wel qwenqwént re xwexwéytes.
The birds were acting like four-legged animals, and the four-legged animals acted like birds, that is why they were all pitiful.

Re speqmíc qwenmíns es texwentés tkenhé7e re lele7stw7écws, es ta7es cuy̓tsem re sk̓elcmentwécws.
Swan wanted to fix how they could be good to each other, so that they wouldn't interfere in one another's affairs any more.

Re speqmíc necwentés es pálpelt.s re tsqwétsten, t̓ri7 yem wel w7ec re yewsentwécwes.
The swan believed that the people were stubborn that is why they were troublesome and were being a nuisance to one another.

Nek̓u7 te sitq̓t te m-ístkmes, le gat̓tes re swucwt ne skwelk̓wélt, m-melk̓wilcmens re k̓wséltktens re speqmic.
One day in winter when the snow was deep in the mountains, Swan gathered his people together.

Neri7 m-lexéy̓ect.s stem̓i re sptínesems, m-yews re sulltimt.s swéti7 me7 nes es tsxlitens re tcets̓, swéti7 t̓ri7 re sxilems me7 éyentem cw7it te sxíxlem.
And he told them what he had thought, and then asked who would go to invite Elk to come, and whoever would do that would be paid lots of dentalium.

Tsúntem te sk̓elép, “Re ntsétswe7 me7 néns-ken.” M-yews re sllecwentés re s7ícenst.s te stemstítem̓t.s, tskerniy̓ te sillts̓u7úw̓i, ell xwexwéyt re sxixlems ell re mémles.

Coyote said, "I will go." Then he put on his fancy clothes, his embroidered moccassins, all his dentalia and his necklaces.

Le estk̓lucwes m-qwetséts re sk̓elép, k̓émell ta7ks qwenens̓ es k̓wétems ne xgat̓t te s̓wucwt. T̓ri7 yem m-tentyénmens re c7istkten wel tskwtek̓ re skék̓w7es le xqilltes re k̓wséltktens.
Coyote left at sundown, but he did not want to walk in the deep snow. That's why he kept circling the underground house until sunrise when his relatives woke up.

M-séwentem te speqmic, "kénem me7e ta7 ke7 sqwetséts ey?"
Swan asked him, "How come you have not left yet?"

M-éytsentem te sk̓elép, "m-etsxmimen t̓ucw ens cwiwselc, t̓ri7 wel ta7 ey ken sqwetséts te sqeltus. E r7ales me7 qwetséts-wen.
Coyote answered, "I was practicing running, that's why I haven't left for the mountains yet. I will leave tonight.

M-r7ales tspíqwstem le qwetsétses te k̓wséltktens wel re m-legúp.
In the evening the relatives watched him until he was out of sight.

Ta7 k sq̓7es̓ m-xp̓qenwéns̓es k sgat̓t7uys re swucwt, cwelpilc m-tspelq̓ilcwes, m-stsilcwes ne k̓wellk̓émts re xnicw ne c̓kemqíns re c7istkten .
It was not long until he found the snow too deep, so he turned around and went back, and he lay down under the ladder on the roof of the underground house.

Le xqilltes re qelmucw m-wiktem te xexe7 re s7itcs re sk̓elép, m-xúq̓leqses. M-séwentmes te speqmic, "kénem mé7e ta7 ke7 sqwetséts ey?"
When the people woke up they saw that coyote was fast asleep and snoring. Swan asked him, "why didn't you leave yet?"

M-tsúntem te sk̓elép, "m-etsxmímen ens cwiwselc, t̓ri7 yem wel cetsétsus-ken." E r7áleses me7 qwetséts-wen.
Coyote told him, "I was practicing running, and that's why I got tired. I will leave tonight.

Re speqmic m-séwens re k̓wseltkens sweti7 me̓7 exték es qwetséts.s. Xwexwéy̓t re stsetsut, y̓iri7 re sku7pecen tikwemtus re skuk̓uwétems ne skwelk̓welt, ne gat̓t te swucwt, t̓ri7 yem me7 exték es qwetséts.s.
Swan asked his relatives who would be the fittest one to go. They all said that the porcupine always walked in the snowy mountains in the deep snow, that's why he would be the fittest one.

T̓ri7 yem m-twinél̓esmentem re sku7pecen es qwetséts.
Thus, they depended on Porcupine to go.

t̓qwentés re silltsu7uw̓is ne sitest wel re m-cwén̓wen, m-yews re syexs te qwets.
He sewed his moccassins

Le-tsek̓ul̓ecwes re tmicw m-qwetsétses.
He left at the break of dawn.

M-wiktmes te sk̓elép m-tulíl̓mentem, tsuntmes, "yumell re ntsétswe7 ta7 ks xenwéw̓en ens qwetséts, tkenhé7e me7 xillt.s yi7ene te qwenqwént, te kenkint, te ctsetsscécen te k̓wséltkten-kt es t̓7eks ne gat̓t te swucwt?
When Coyote saw him, he laughed at him and said, "If even I could not make it, how can this pitiful, slow and shortlegged relative of ours make through the deep snow?"

E r7aleses m-kitsc re sku7pecen re tcets re tsitcws, xexé7 re stlel̓s, stsmuxmux-ekwe te scúyent ell te swucwt.
In the evening, Porcupine arrived at Elk̓s house, he was very exhausted and covered in ice and snow.

Le qw7étses re skú7pecen, m-kectés re tcets te stélt̓ snems re speqmic es tsxlitens re tcets met re k̓wséltkens. M-yews re sulltimcwes te stiten̓c ell te t̓éq̓cen̓ es t̓qwentés re silltsu7uw̓is.
After Porcupine had warmed himself, he gave Elk the message from Swan and asked for sinew and an awl to sew his moccasins.

Le-wi7es re stel̓tsnem̓s, m-tsuntem te tcets, "Pexyéwt me7 tégwentp-kucw re ntsétswe7 met ren k̓wseseltkten ne tmicw-emp."
When he was finished delivered, Elk told him, "tomorrow me and my people will visit you
in your country.

M-pelq̓ilc re sku7pecen ne tmicws, m-lexéy̓ect.ses re speqmic stem̓i lu7 re stél̓tsnem̓s re tcets.
Porcupine returned to his country, and then he told Swan what Elk̓s message was.

Le yigapes re tcets met re k̓wséltktens m-tsecwmintem, m-yews re smetéms.
When Elk and his relatives arrived they were warmly greeted and feasted.

Le wi7es re s7illens m-xit̓elc well re speqmic met re k̓wséltktens ne sxetéqs re tcets̓.
After they finished eating, Swan and his relatives knelt before Elk.

Re speqmic m-tslexemcit.s xwexwéyt re stem re stslexméms, ell m-lexéy̓ect.s tkenhe7e m-tsets̓eclemen̓twécwes, T̓ri7 yem m-kectéses re tcets̓ xwexwéyt re texpqenwéllens ell re m-tk̓wenm7iplemenses.
Swan shared his wisdom with them and told them how they could fix one another. This is how he gave Elk all his knowledge and his advice.

M-yews re tcets̓ met re k̓wseltktens m-xit̓elc ne sxetéqs re speqmíc ell re tcets̓ m-kectés xwexwéyt re sptinesems ell re tk̓wenm7ipe7s.
yiri7 re sxepqenwellentwécws ell t̓qwews p̓7ecws re sle7s re sxenwéllens es tsetséts.s es yucwmentwecws.
Then Elk and his relatives knelt before Swan and Elk shared all his thoughts and his advice. And this is how they learned from one another, and they were able to look after one another.

M-yews re p̓7ecws re sle7s re sw7ecs, m- le7stwécw wel me7 yews, m-ta7es cuy̓tsem re sts̓niqentwécws.
Then they lived much better, they were good to one another from then on, and they stopped fighting.

Yiri7 re tkwenm7íplemen̓twecwes wel me7 tekwemíte7.
These are the laws they gave to one another.

Re skú7pecen m-kwenwén̓ses te cwesqlew̓ te sxixlem. M-yews re skucwsentem te sk̓elép.
And Porcupine became rich with dentalia and was much envied by Coyote.

Yiri7 re stsecwtéps!
This is the end.

These stories remind you of the dangers of being to rambunctious or flashy and that simplicity is often the best way to achieve things. Slow, steady and carefully thought out is better than fast and careless.

Coyote is used in many Secwepemc teachings and is nearly always an instigator ending up in a predicament that would test his ethics or abilities. This can be used as a euphemism for our lives and the pace at which we frantically go to achieve our objectives we desire. It teaches us of the patience and understanding we require of others in our space and the need to understand their position or abilities around your objective.

There are many transitional lessons to be learned from First Nation oral histories, that would often compliment Western Science objectives. This is true for Traditional Science and its ability to take lessons from Western Science. Oral teachings are meant to be the tools required for understanding the natural world and its inner workings, Western Science is intended to do the same. Like the swan people and the deer people; working together makes us much more useful to one another, in life and in practice.

The Columbia River Process requires the patience and careful thought processes to achieve the greatest benefit to the Columbia Basins many resources. Fast and furious will end disastrously. This can also ne relayed in the terms of "Adaptive Management" and is a key component of learning the ecosystem component impacts of CRT operations.

The CRT Operations will benefit from the lessons of the Coyote and the Salmon in learning that without people the River would prosper perpetually, along with all of its natural components. We must humble ourselves to its powers, rather than trying to control the River and build out in flood prone areas. A lesson to learn from the Coyote and Porcupine could read: Some areas will not have salmon restored as quickly as desired and may require many studies to determine best management decisions to do so. This should not pose any stalls in the process because of lack of energy or resources.

Kuksetemc

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Bill Green's Presentation Summary

Three nations are working together in the process of renegotiating the CRT. This is an important and unprecedented level of collaboration. Some important Indigenous Nations laws and principles are guiding this collaboration: (This will very briefly recap some of the laws/principles described by Mark)

- Water is sacred and the life blood of the earth

- The restoration of salmon, as identified in the coyote story, is of core importance to the three Nations. This includes work to restore fish passage
- From Salmon Boy: salmon responsible for taking care of humans; reciprocity – humans responsible for taking care of salmon
- Importance of humility; be patient and attentive to non-human life
- Qwengqwent (Secwepemc): recognizing the significance and power of land, resources and non-humans in relationship with people
- "All our relations", refers to the interconnection amongst humans – not just to each other – but with the land, water, four-legged, winged ones, etc.
- Reciprocal relationship between humans and the land/water.
- Parallel Ktunaxa concept of "Akxamis qapi qapsin": This Ktunaxa concept is about everything that keeps us alive as a living thing, from water and rocks to the sky and the language we speak and feelings we feel. It is about how we find balance in our lives. It is also about the connections between all living things, including people and the land
- **Yucweminmen** (Secwepemc)**:** The over-harvesting or usage of our water results in the reduction of life. This speaks to our responsibility to care for the water and to our right as Secwepemc to govern the resources within Secwepemcul'ecw.

Consideration of these and other Indigenous Nations laws and principles leads to shared Indigenous Nations principles and goals for CRT modernization:

1. Ecosystem function is made a co-equal purpose of a renewed CRT, equal in importance to hydro power and flood control.
2. The re-negotiation of the CRT must be accompanied by coordinated, joint and adequately funded efforts to address restoration of salmon to the upper Columbia.
3. Indigenous Nations will exercise their stewardship responsibilities for water throughout the CRT renewal process and in implementing a renewed CRT.

It is also fundamental that Indigenous cultural values and use are inextricably linked to ecosystem values.
Indigenous laws and principles also lead the three nations to agree on the following four priority themes for addressing ecosystem function in a renewed Columbia River Treaty:

1. **Ecosystem productivity**: Restore and, where appropriate, enhance primary, secondary and tertiary productivity in aquatic (riverine and reservoir), riparian, floodplain, wetland and upland ecosystems.

   Underlying Indigenous laws/principles

   - From Akxamis qapi qapsin (Ktunaxa: everything that keeps us alive as a living thing;
   - From yucweminmen (Secwepemc)**:** The over-harvesting or usage of our water results in the reduction of life.

Shared objectives from previous work with US tribes:

a. Avoid deep drafts and provide more stable reservoir elevations to improve resident fish production and to provide better protection of historical and ceremonial needs and tribal cultural resources;

b. Adequate reservoir water residence times to support ecosystem productivity during the growth season;

Some next steps

- Compile and synthesize existing information on ecosystem productivity in the Canadian Columbia Basin;
- Develop and refine a reservoir residence time (or alternate) and riverine productivity performance measures

2. **Floodplain, riparian and wetland ecosystem restoration**. (CRT dams and reservoirs caused the largest losses to these ecosystem types).

Underlying Indigenous laws/principles

- interconnection amongst humans – not just to each other – but with the land, water, four-legged, winged ones, etc.
- Akxamis qapi qapsin (Ktunaxa…includes the connections between ALL living things, including people and the land

Shared objectives from previous work with US tribes:

a. Treaty storage reservoirs operated with infrequent (high flow years only) inundation of the uppermost reservoir elevations to promote re-development of floodplain, wetland and riparian ecosystems;

b. Reconnect and reestablish floodplain habitat to allow for groundwater recharge and restoration of important habitat for riparian dependent plant and wildlife species;

Some next steps

- Using best available information, develop different operational scenarios and model the corresponding predicted outcomes over time for vegetation (indicator species, community types, and seral stages) and wildlife species of interest
- Compile indigenous knowledge and traditional use information about these (floodplain, riparian, and wetland) ecosystems
- For all CRT reservoirs, fill gaps in habitat mapping and determine, at a minimum, “no decline” targets and ideally enhancement targets for terrestrial/riparian vegetation and wetlands as restoration isn’t feasible.

3. **Riverine and reservoir ecosystem restoration**.

Underlying Indigenous law/principles

- Water is sacred and the life blood of the earth
- Yucweminmen (Secwepemc)**:** our responsibility to care for the water

Shared objectives from previous work with US tribes:

- A partially restored spring and early summer peaking hydrograph to improve resident and anadromous fish survival and wildlife habitat and help restore tribal First Foods

Some key concepts

- Manage flows to achieve geo-fluvial processes that mimic normative/pre-dam erosion and sediment transport rates
- Restore normative pre-dam water flow regimes in riverine reaches
- Maintain access to, and connectivity between, mainstem, reservoir and tributary habitats
- Increase the availability of functional free-flowing riverine mainstem habitats

4. **Restoration of anadromous salmon**

Underlying Indigenous law/principles

- The restoration of salmon (as identified in the coyote story) is of core importance to the three Nations. This includes work to restore fish passage
- From Salmon Boy: salmon responsible for taking care of humans; reciprocity – humans are responsible for taking care of salmon

Shared objectives from previous work with US tribes:

- Develop and implement structural modifications to dams to improve and restore fish passage and ensure reintroduction to Canadian spawning grounds and other blocked areas

Some key concepts:

- Manage flows to maximize anadromous species survival and condition at all life stages
- Restore diverse, productive, harvestable populations of anadromous salmon throughout their historical (pre-dam) range in the upper Columbia River in BC.

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- Global Affairs Canada

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Northern pike in the lower Columbia and Pend d'Oreille rivers – 2018 Update

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Introduction

Northern Pike (*Esox lucius*), a fish endemic to northern regions of Canada, are a recent non-native species invader of the Columbia River system in both Canada and the United States. Northern Pike (NP) are a slow-water, predatory species whose preferred habitat includes shallow lakes, marshes and backwater sloughs with extensive instream cover (McPhail 2007). NP have the potential to significantly impact sportfish populations and the recovery of species listed under the Species-at-Risk Act (SARA) in the Columbia River through competition, predation and the introduction of disease (Baxter and Neufeld 2015).

Northern Pike were first detected in the U.S. Columbia River in 2007 and in the Canadian Columbia River in 2009 (Lee et al. 2010; Baxter and Neufeld 2015). The species was thought to have then traveled via the Clark Fork River into Lake Pend d'Oreille, into the Pend d'Oreille River and downstream into the Columbia River (Bailey 2016). The Pend d'Oreille River enters the Columbia River near Trail, BC just upstream of the international border (Figure 1). However, a recent genetic evaluation suggests NP were likely introduced directly to the Pend d'Oreille River by illegal human transport (Carim et al. 2018).

Since the initial detection, strategies to inventory and suppress the non-native predator have included a gill-net suppression program, changes to daily angling quota (unlimited), angler incentive/awareness programs, acoustic telemetry, otolith geochemistry, environmental DNA detection (eDNA), habitat reduction, and juvenile detection programs (Amec Foster Wheeler 2017). In response to the conservation concerns that Northern Pike pose to the Lower Columbia River, an annual gill-net suppression program ran from 2014 to 2017 that removed 323 Northern Pike (Baxter and Lawrence 2018). This program continued in 2018 and was expanded to include the Pend d'Oreille River where formal suppression efforts have not been undertaken previously. The following summarizes the methods and outcomes of the 2018 program (Wood 2019).

Study Areas

The Lower Columbia River study area includes the 58 km long section of the Columbia River between Hugh. L. Keenlyside (HLK) Dam and the U.S. border (Figure 1). It also includes the approximate 2.8 km section of the Lower Kootenay River between Brilliant Dam and the confluence with the LCR.

The Canadian section of the Pend d'Oreille River extends into Canada from the U.S. for approximately 25 km before it reaches a confluence with the Columbia River downstream of Waneta Dam, just upstream of where the Lower Columbia River enters the U.S. (Figure 1). The Pend d'Oreille study area includes two separate reservoirs: Waneta Reservoir upstream of Waneta Dam to Seven Mile Dam (9 km long), and, Seven Mile Reservoir upstream of Seven Mile Dam to the U.S. border (15 km long, Figure 1). Seven Mile Reservoir continues for approximately 2 km upstream of the U.S./Canada border until it reaches Boundary Dam (Figure 1).

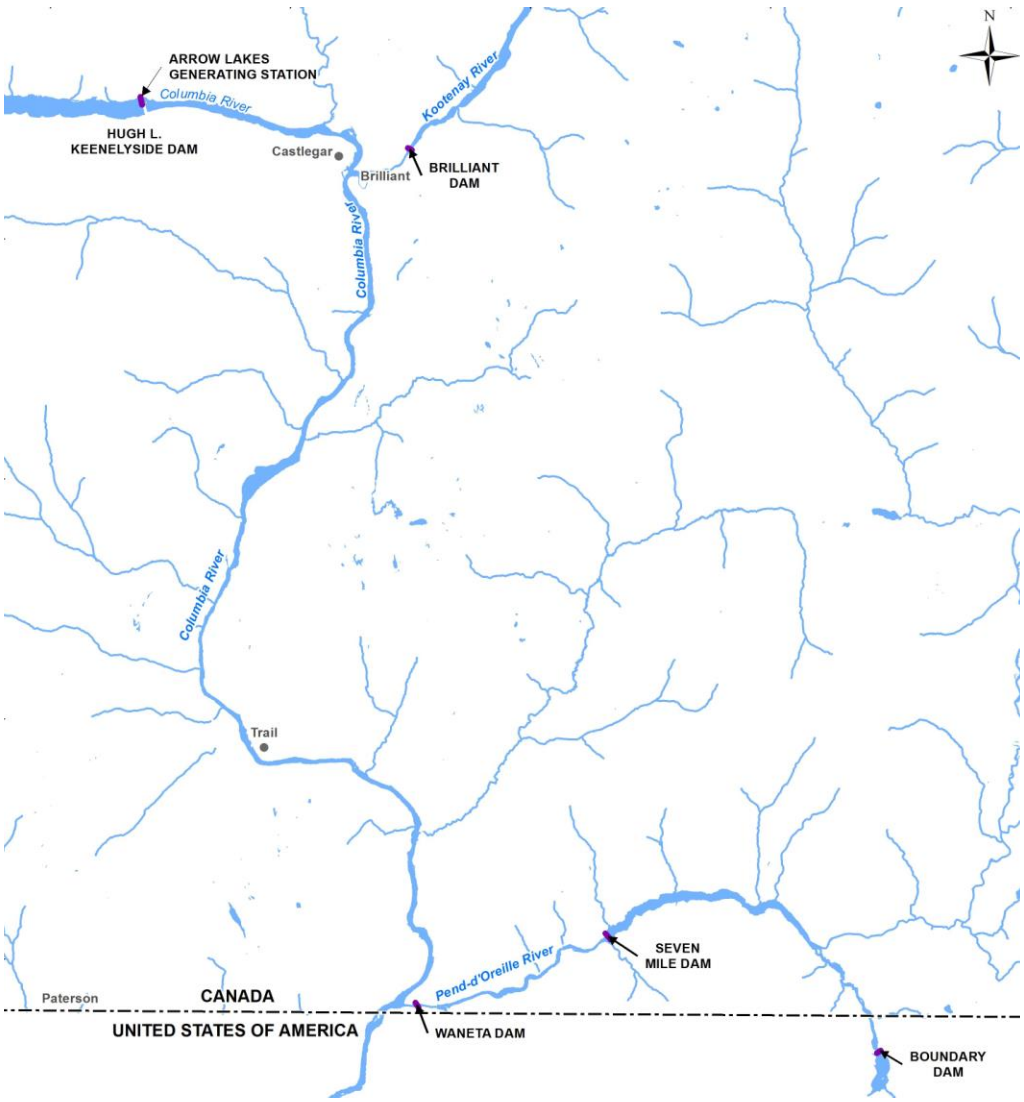

Figure 1: Overview of Lower Columbia and Pend d'Oreille rivers.

Methods

Desktop reviews of pre-existing data for the Lower Columbia River and its tributaries as well as for the Pend d'Oreille River were conducted prior to conducting suppression surveys to determine potential locations of suitable Northern Pike habitat. Suppression methods used in 2018 included gill-netting, boat electrofishing and angling.

Spring index gill-netting (SPIN) was completed during the Northern Pike spawning period in both study areas. The goal of spring index gill-netting programs is to remove as many NP as possible prior to their spawning period using a consistent level of effort to allow comparison with previous and future SPIN assessments. Monofilament gill-nets with the same specifications as those that have been found to be the most effective for removal of various Northern Pike age cohorts during previous suppression efforts were used (e.g. Baxter and Neufeld 2015). Gill-nets were set in suitable NP spawning habitat in shallow bays with aquatic vegetation and woody debris. Gill-nets were also set in areas within these areas known to limit bycatch of salmonids and White Sturgeon (*Acipenser transmontanus*). Gill-nets were set for a maximum of 4 hours, or checked within a 4 hour period, to reduce bycatch mortality of native and SARA-listed species such as White Sturgeon. Supplemental gill netting surveys were also conducted in the late summer and fall in 2018 in the Lower Columbia River.

Daytime boat electrofishing surveys were conducted in the LCR in the late summer/fall to target removal of the juvenile age class. Boat electrofishing had not previously been used in the Lower Columbia River as a suppression technique but was recommended because it has been used successfully in Lake Roosevelt. The boat electrofishing unit was powered-on and maneuvered slowly in an upstream direction through shallow, vegetated shoreline areas. All stunned fish were quickly netted out of the river and into a recovery tub on the boat deck that had been filled with fresh river water.

Angling was conducted opportunistically during the SPIN surveys.

Results

In the Lower Columbia River study area, a total of 27 Northern Pike including 7 females and 20 males were removed in 2018. Twenty-two Northern Pike (NP) were removed during 525.3 hours of gill-netting resulting in an overall catch-per-unit-effort (CPUE) of 0.04 NP/net hour. Five Northern Pike were removed during 19,867 seconds of boat electrofishing resulting in an overall CPUE of 0.9 NP/electrofishing hour. No Northern Pike were captured by angling in 2018. Catch-rates during the annual May SPIN surveys are used to track the status of Northern Pike in the Lower Columbia River and in 2018 the CPUE during SPIN surveys was 0.05 NP/net hour, higher than the 2017 SPIN CPUE (0.04 NP/net hour) but substantially lower than during the initial SPIN program in 2014 (0.44 NP/net hour). In total, 510 fish were caught as bycatch in the Lower Columbia River study area in 2018 of which 243 fish were captured during gill-net surveys (79.4% were released alive) and 267 fish were captured during boat electrofishing surveys

(97.8% were released alive). Two White Sturgeon were captured as bycatch in 2018 during fall gill-netting surveys and were released alive and unharmed.

In the Pend d'Oreille River study area, a total of 15 Northern Pike including 5 females and 10 males were removed in 2018. The 15 Northern Pike were removed during 308.4 hours of gill-netting resulting in an overall CPUE of 0.05 NP/net hour. No Northern Pike were captured by angling in 2018. In total, 163 fish were caught as bycatch in the Pend d'Oreille River study area in 2018 of which 123 were released alive (75.5%). Unpredictable water level fluctuations and turbidity created challenging sampling conditions in the Pend d'Oreille River in 2018.

Recommendations

Ongoing, effective annual suppression is recommended to maintain the low catch rates observed in 2018. In the Columbia River study area, this includes SPIN surveys in May, gill-net surveys in potential Northern Pike habitat areas downstream of Trail, BC and surveys that target juvenile Northern Pike in the late summer/fall. In the Pend d'Oreille River study area, this includes SPIN surveys in April and surveys that target juvenile Northern Pike in the late summer/fall both in Seven Mile and Waneta reservoirs.

Acknowledgements

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Stock assessment and monitoring of burbot in Lake Roosevelt on the Columbia River in Washington

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Introduction

Burbot (*Lota lota*) are often overlooked by fisheries management plans in regulated rivers. In Lake Roosevelt Reservoir on the Columbia River in Washington State, USA, there is no targeted annual monitoring for Burbot, but this species is commonly captured incidentally during annual gill-net surveys designed to monitor the Walleye (*Sander vitreus*) population. Since 2013, data from Walleye surveys has been used for stock assessment of Burbot in the reservoir. The objective is to use stock assessment indices for Burbot to assess inter-annual trends and the status of the population. Stock assessment indices that were evaluated were relative abundance, mortality, recruitment, population size and age structure, body condition, sex ratio and reproductive development, and size selectivity. Statistical power was calculated for all the indices of interest. The power analyses were used to identify which of these indices lacked sufficient data to identify trends over time.

Methods

1. Study area and field sampling

Lake Roosevelt Reservoir is a large reservoir on the Columbia River located between the Canada-USA border and Grand Coulee Dam in northeast Washington, USA. The Washington Department of Fish and Wildlife, Spokane Tribe of Indians, and Colville Confederated Tribes have collectively monitored Walleye populations in Lake Roosevelt Reservoir using the Fall Walleye Index Netting (FWIN) surveys since 2002. The FWIN methodology was developed in Ontario, Canada as a standardized way to monitor Walleye population indices using gill-nets (Morgan 2000). Detailed methodology and sampling procedures for the FWIN in Lake Roosevelt Reservoir are provided in Schmuck (2017).

In Lake Roosevelt Reservoir, the survey consists of 150 gill-nets fished overnight at randomly selected areas in habitats with a depth of 2 to 30 m depth and a bottom slope gradient less than or equal to 45 degrees. Gill-nets were multi-paneled with mesh sizes of 2.54, 3.81, 5.08, 6.35, 7.62, 10.16, 12.7, and 15.24 cm. All captured Burbot were identified to species and measured for total length (mm) and weight (g). Gonads were extracted to determine sex and stage of maturity and then weighed (g). Sagittal otoliths were removed and used for age determination.

2. Data Analysis

Catch-per-unit-effort (CPUE; #Burbot/net/24 hr) was used as an index of relative abundance and was analyzed using a generalized linear model (GLM) assuming a negative binomial distribution. Year was the predictor variable of primary interest, to assess variation in relative abundance over time. Gill-net depth was included in the model as a predictor variable. The proportion of positive catch was also used as an index of relative abundance and was calculated as the proportion of gill-net sets that captured at least one Burbot each year. Proportion of positive catch was compared among years using a logistic regression that included year and gill-net depth as predictor variables.

Annual survival was estimated using catch curve regressions, which are linear regressions of the natural logarithm of the number of Burbot caught versus their age. The regression slope represents the instantaneous total mortality and its exponential is the annual survival rate. Catch curves were calculated for each spawning year (cohort), each sampling year, and for all years combined.

Annual recruitment of Burbot was assessed using two different approaches as a recruitment index: 1) the CPUE of age-2 Burbot and 2) the residuals from catch curves. The CPUE of age-2 Burbot was analyzed using the same negative binomial models as CPUE. Catch curves from individual sampling years assume constant recruitment over time. Therefore, the residuals from catch curve regressions may reflect variation in recruitment among years and were used as a quantitative index of year-class strength (Maceina 2004).

Population size and age structure were assessed using various methods including length-at-age and proportional size distribution (PSD). PSD is the proportion of Burbot in each of five length categories (Fisher et al. 1996) and is intended as a method to assess population size structure relative to fishing opportunity. Differences in PSD among years were assessed using ordinal logistic regression. Body condition was analyzed using weight-length regression and relative weight. Relative weight was calculated by dividing the weight of each Burbot by its standard weight, which is the expected weight for a Burbot of a particular length, calculated following Abrahamse (2009).

To assess potential size-related biases in the Burbot catch data, size selectivity models were fit to the length-frequency and mesh size data following the methods of Millar and

Holst (1997). These models were used to estimate the predicted probability of retention in the gill-nets for different lengths of Burbot.

The statistical power to detect annual differences in Burbot population indices was calculated for most analyses. Standard power analysis software and methods usually assume a normal distribution and were not appropriate for most of the analyses conducted. The power to detect statistically significant effects was estimated using simulation methods like those of Seavy et al. (2005). The general approach was to simulate data based on the variability in the observed data and then to re-run the models that were used for analysis using the simulated data. The data simulation and analysis were repeated typically 1,000 times, and the proportion of repetitions where yearly differences were statistically significant was interpreted as the power. The power to detect statistically significant yearly differences was estimated for various sample sizes or effect sizes of interest.

Results

Catch-per-unit-effort (CPUE; #Burbot/net/24 hr) suggested increasing Burbot abundance from 2005 (0.9/net) to 2011 (3.0/net), stable abundance from 2012 to 2016 (1.7–2.2/net), and a small decrease in abundance between 2016 and 2017 (1.3/net; left panel; Figure1). There was a significant difference in log incidence rates (i.e., CPUE on the logarithmic link scale) between the reference year, which was 2017, and 2008, 2010–2014 and 2016. All these years had higher estimates of incidence rates when compared to 2017, with differences ranging from 38% (2012 and 2014) to 139% (2011). The greatest predicted CPUE occurred at a gill-net depth of 36 m. The proportion of positive catch suggested a similar trend in relative abundance, with increasing catch from 2003 to 2010, stable catch from 2011 to 2016, and a decrease in catch in 2017 (right panel; Figure1).

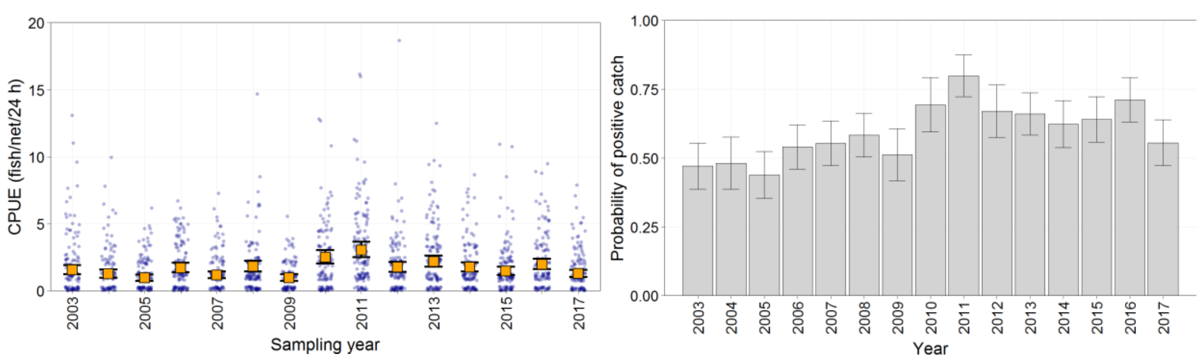

Figure 1. Indices of relative abundance for Burbot in Lake Roosevelt Reservoir. Left panel shows catch-per-unit-effort including observed (blue) and model-predicted values (orange) at the average gill-net depth of 20 m. Right panel shows the predicted probability of positive catch. Error bars are 95% confidence intervals.

The overall estimate of annual survival based on catch curve analysis was 57%, but estimates varied between 62% and 87% for brood years between 1997 and 2012. CPUE of age-2 Burbot, an indicator of annual recruitment, suggested relatively strong recruitment in 2003, 2006, 2010–2011, and 2015–2016 (left panel; Figure 2). The residuals from catch curve regressions suggested similar trends in recruitment, with high values of the recruitment index in the 2001, 2004, 2008–2009, and 2013–2014 brood years (right panel; Figure 2). The 2015 recruitment was the lowest in all years since 2003, with a majority (96%) of nets catching zero age-2 Burbot in 2017.

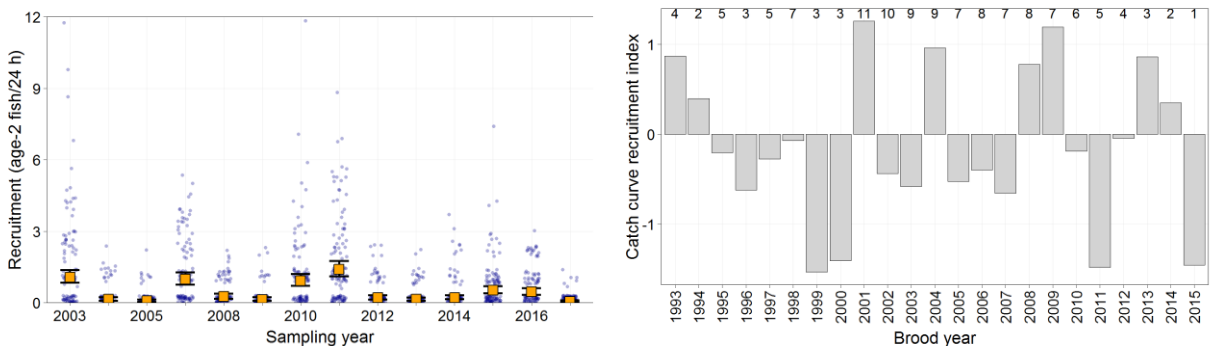

Figure 2. Indices of annual recruitment of age-2 Burbot. Left panel shows observed (blue) and model-predicted values (orange) of catch-per-unit effort of age-2 Burbot by sampling year at the average gill-net depth of 20 m. Right panel shows mean values of residuals from annual catch curves, which are interpreted as an index of recruitment.

Weight-length analyses indicated some significant differences in regression slopes between years. However, predicted weight at the mean total length of 47 cm ranged from a minimum of 0.58 kg in 2003 to a maximum of 0.63 kg in 2017, indicating relatively small differences (50 g or less) in mean weight of an average sized Burbot across years. Mean annual relative weight ranged from 81.4 (2014) to 89.8 (2016). Overall, these indicators of body condition did not suggest any long-term trends during the monitoring period.

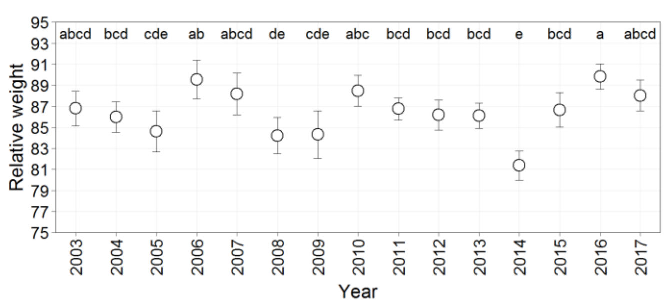

Figure 3. Relative weight of Burbot in Lake Roosevelt Reservoir by year, 2003–2017. Values are means with 95% confidence intervals. Years that do not share letters are significantly different (based on Tukey's HSD test).

Differences in length-at-age for age-1 to age-3 Burbot were small and not statistically significant. Mean length-at-age suggested rapid growth of juveniles, with a mean length of 436 mm at age-2. Proportional size distribution analyses showed that the majority of Burbot captured were in the preferred (>530 mm) and quality (>380 mm) length categories. Burbot in the stock (>200 mm) category comprised less than 10% of the catch, and memorable category Burbot (>670 mm) were less than 2% of catch in all years. Increases in the percentage of Burbot in the preferred category in 2009 and in 2017 indicate increasing body size and older age structure of the population in those years (Figure 4).

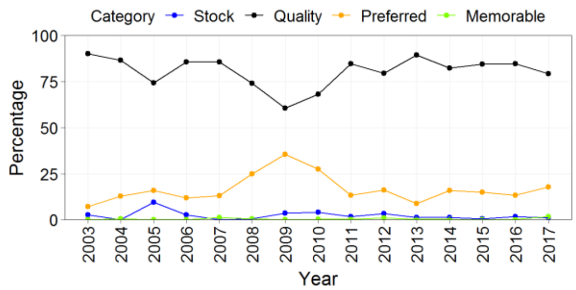

Figure 4. Percentage of Burbot captured in Lake Roosevelt Reservoir in each of the five proportional size distribution categories.

The majority of the Burbot catch was in gill-net mesh sizes ranging from 51 to 102 mm, with very low catch in the 25, 38, 127, and 152 mm mesh sizes. The 102 mm mesh caught larger Burbot than the 76 mm mesh size, but there was no evidence that smaller mesh sizes (38–64 mm) captured smaller Burbot, and sample sizes were too small to demonstrate size selectivity for many of the mesh sizes (38, 51, and 127 mm). The predicted retention curve suggested the greatest retention for Burbot with total lengths of approximately 350 mm, with retention dropping to 51-53% for Burbot between 600 and 700 mm. However, selectivity curves had poor fit with the data, likely because of the lack of observed size selectivity in the smallest and largest mesh sizes. Therefore, the retention curves were not used to correct length-frequency data before other stock assessment analyses.

Power analyses using simulation modelling suggested good statistical power for small effect sizes (<15%) for metrics of body condition, such as relative weight (left panel; Figure5), but that indices of abundance, such as proportion positive catch (right panel; Figure 5) needed to increase by 50–100% to achieve 80% power at the observed sample size of 150 gill-nets.

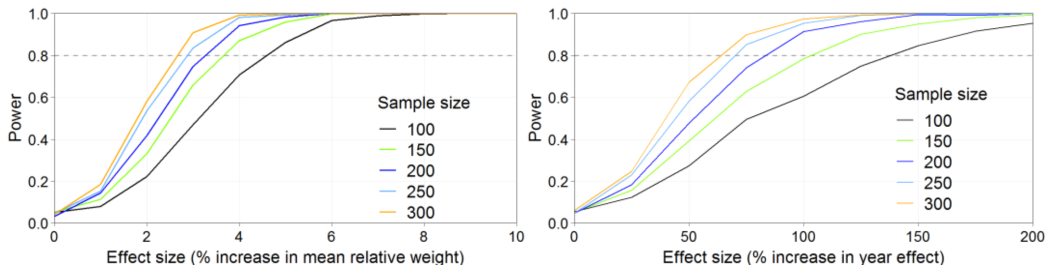

Figure 5. Estimated statistical power to detect significant differences between years in Burbot population indices. Left panel shows power for relative weight and right panel shows power for the proportion of positive catch. Sample size refers to the number of captured Burbot for relative weight but the number of gill-nets for proportion of positive catch.

Discussion

Many populations of Burbot worldwide are healthy or recovering whereas others are declining, endangered, or extirpated (Stapanian et al. 2010). Based on the FWIN data, the Lake Roosevelt Reservoir Burbot population appears to have increased from 2003 to 2011 and remained stable from 2012 to 2016, with a small but statistically significant decrease in 2017. As reported for populations of Burbot elsewhere in North America, abundance of Burbot in Lake Roosevelt Reservoir appears to be driven by periodic years of higher recruitment.

Annual estimates of survival ranged from 62% to 87% between brood years. In comparison, catch curve estimates of survival for Burbot were 43% to 60% in the Wind River watershed in Wyoming (Hubert et al. 2008), 67% for age 6-18 Burbot in Lake Erie (Stapanian and Madenjian 2007), and 43% for Burbot in Lake Superior (Schram 2000). Therefore, survival of Burbot in Lake Roosevelt Reservoir appears to be similar to or greater than estimates for populations elsewhere in North America.

The mean relative weight values for Lake Roosevelt Reservoir Burbot from 2003 to 2017 (range: 81–90) were less than 100, suggesting poorer condition compared to the median values across their range (Abrahamse 2009), but greater condition than the objective relative weight suggested for reservoirs (80±5; Fisher et al. 1996). Body condition indices did not suggest any long-term trends during the study period. Mean length-at-age was much larger in Lake Roosevelt Reservoir (436 mm at age-2) than most other populations (~150 to 425mm; Golder 2019), which could be related to good growing conditions or possible errors (underestimates) in the age data.

Size selectivity models were used to assess potential size-related biases in the FWIN catch data. These models were not used to correct the data prior to stock assessment because of poor fit that was attributed to small sample sizes and lack of size selectivity in many of the gill-net mesh sizes.

The analyses support the idea that FWIN data are adequate to monitor inter-annual trends and provide the basis for standardized stock assessment of Burbot in Lake Roosevelt Reservoir. Overall, the analyses indicated a relatively stable population of Burbot in Lake Roosevelt Reservoir. These analyses are necessary for managers to understand the status of Burbot populations in Lake Roosevelt Reservoir and could be used to evaluate potential effects of management strategies or exploitation in the future. Analyses planned for upcoming years include: 1) assessment of whether limnology variables including primary productivity, zooplankton density, and reservoir drawdown help explain the observed variability in recruitment; and 2) validation of ageing techniques.

Acknowledgements

FWIN survey crews were from the Washington Department of Fish and Wildlife (WDFW), Spokane Tribe of Indians (STOI), and Colville Confederated Tribes (CCT). Marc Divens, WDFW, provided the original FWIN data set to CCT for formatting. Charlee Capaul, CCT, formatted the data. Burbot ageing was conducted by Lucinda Morrow and Andrew Claiborne, WDFW.

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Exploring ecosystem enhancement in a stable Arrow Lakes reservoir operation

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Conference presentation based on the report:
Thomson, A., G. Utzig, B. Green and N. Kapell. 2018. Arrow Lakes Reservoir Mid-Elevation Scenarios: Scoping Evaluation. Prepared for the Province of British Columbia and BC Hydro and Power Authority. 109 pgs. plus appendices.

The Columbia River Treaty (CRT) between Canada and the United States largely dictates how the three treaty reservoirs – Arrow Lakes Reservoir, Duncan Reservoir and Kinbasket Reservoir – are operated. Since treaty ratification in 1964 and the subsequent construction of the hydro electricity generating facilities associated with the three reservoirs, reservoir operation follows a predictable annual pattern of drawdown in the early spring, rapid infilling to full or near-full pool during the freshet period, and slow drawdown over the summer to early winter period. The pattern is designed to facilitate the two main treaty objectives – flood control and hydro electricity generation – and is highly controlled to allow integration into the larger hydroelectricity generation system in the Columbia River watershed.

The renegotiation of the CRT currently underway offers the possibility of modifying CRT facility operations to include or further address objectives other than flood control and power generation. Adding a third objective – ecosystem-based function – to the CRT is being considered and studied by several parties involved in the negotiations. One of the ecosystem-based function options under consideration – maintaining a stable water level operation in the Arrow Lakes Reservoir – was detailed in the above report and briefly presented in the CMI Regulated Rivers ll conference. The concept involves changing the ALR from a storage reservoir - where spring runoff is stored and released slowly over the fall and winter months - into a run-of-river operation where flows are passed through the reservoir largely unimpeded during years where the forecasted risk of flood damage is low. The reservoir water elevation would remain at a constant and stable elevation as opposed to the pre-dam hydrograph which fluctuated with the spring freshet. During forecasted high water years, the reservoir would be used to store excess water to reduce flood risk and the reservoir water elevation would rise and fall over a defined period.

The Arrow Lakes Reservoir (ALR) is located between Revelstoke and Castlegar, is impounded by the Hugh Keenleyside (HLK) dam and stores up to 8.76 km^3 of water. Upon being commissioned, the HLK flooded two lakes – the Upper and Lower Arrow Lakes – the Narrows, an area between the two lakes, and the Upper Columbia Reach, the riverine section between the town of Arrowhead and Revelstoke. Before the HLK was constructed in the late 1960s, the two lakes typically fluctuated 21 ft on average between winter and the peak of freshet in mid June. Under current operations, the reservoir can annually fluctuate up to 66 ft but typically fluctuates 40-50 ft.

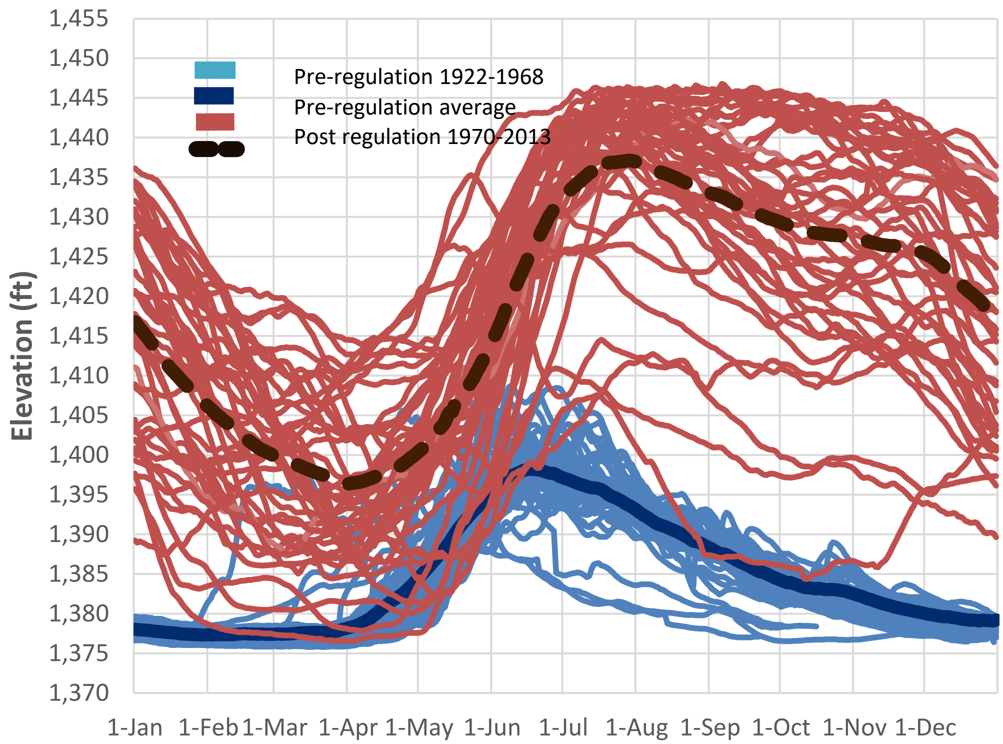

Figure 1: Hydrograph of the Arrow Lakes pre and post regulation.

The hydrograph (Figure 1) of the pre and post regulation illustrates three key distinctions between the two periods:

- The fluctuation between winter and summer elevations is greater during the post impoundment period leading to an expansive drawdown zone exposed to wave erosion;
- The difference or deviation in water levels between years is significantly greater in the post impoundment period;
- In some years the water level remains high throughout the summer vegetation growing period in the post impoundment period.

These changes have resulted in a drawdown zone that is largely devoid of vegetation, a common attribute of reservoirs.

The authors of the Arrow report hypothesise a stabilised water elevation concept will allow the development and maintenance of a permanent, diverse and vigorous vegetated zone (including trees, shrubs and herbs, as upland, riparian and wetland ecosystems) above a defined elevation of the reservoir at which the water level is stabilised. It is further hypothesized that the frequency and duration of vegetation inundation determines vegetation species composition and diversity and survival probability.

In order to assess the potential benefits of modifying the ALR operational regime to restore vegetation in the drawdown zone, the known elevation of different vegetation species and seral stages around Upper Arrow Lake was combined with flooding and inundation frequency data at various water elevations. A lengthy hydrometric dataset, historical photographs, topographical surveys and hand drawn maps completed in the 1940s and 50s that included vegetation cover were invaluable in determining spatial extent and the elevation at which mature vegetation was historically sustained pre-impoundment.

Based on this analysis, mature vegetation will likely establish over a number of decades and become permanent in the upper sections of the drawdown zone if the flooding frequency in this zone is limited to 1 in 7 years on average and inundation duration does not exceed 35 days (Figure 2).

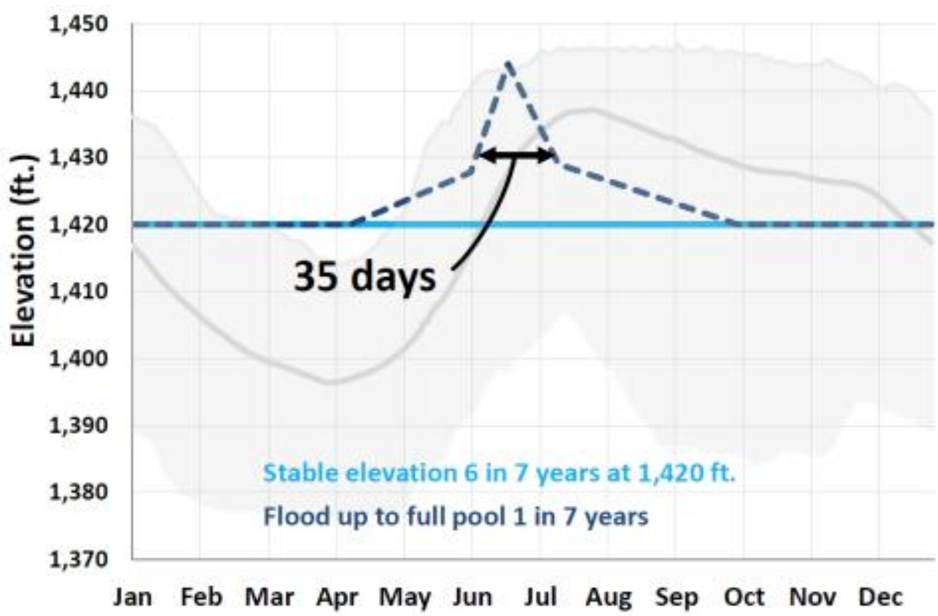

Figure 2: Scenario where water elevation is stabilised at 1,420 ft 6 in 7 years and in 1 in 7 years the reservoir fills to full pool. Maximum inundation period at 1,430 ft is 35 days.

The ecological values that were assessed under this scenario included vegetation, terrestrial wildlife and habitats, fisheries and aquatic resources. Most of the results are either positive or mixed/uncertain when compared to the current ALR operational regime. The successful establishment of riparian vegetation is seen to heavily influence several values in a positive direction, such as wildlife (ungulates and birds) and fish access into tributaries. Vegetated reservoir banks and shorelines are less prone to wind and wave erosion. Terrestrial wildlife habitats would increase, notably ungulate winter range because of improved riparian vegetation. Tributary stream banks are expected to stabilize with mature vegetation establishment which would aid fish access to upstream spawning habitats. Bird nest flooding, a concern in the Revelstoke Reach and other parts of the reservoir, will decrease for nests above the base constant elevation in non-flood years. Herptiles, shorebirds and waterbirds should have better access to wetlands and ponds above the base constant elevation in non-flood years.

Although there are positive attributes, analysis of some values found mixed or uncertain outcomes when compared to the existing ALR operational regime. At the scoping level it is very difficult to evaluate the combined effects of multiple potential changes on fish related values. For all scenarios examined, most fish related values are uncertain (could be either positive or negative) or mixed, in particular pelagic primary and secondary productivity, kokanee biomass, and aquatic productivity values in the Revelstoke Reach. Additional research that includes ALR ecosystem modelling, seasonal analysis of fish population life history requirements in the Revelstoke Reach for current operations and the scenario, and a comprehensive assessment of risks to current fish stocks and aquatic ecosystems associated with the scenario is required. However, burbot spawning and incubation success will unlikely be affected by the scenario. Lastly under a stabilised water elevation regime, invasive vegetation species may become established without aggressive intervention or careful implementation.

An additional scenario - Scenario 3 - was developed after the report was finalised. Scenario 3 objectives are to:

- Maintain and/or enhance the potential benefits identified for the scenario presented above;
- Establish a seasonal pattern of reservoir levels closer to the natural seasonal pattern present in Upper Arrow Lake prior to dam construction; and,
- Allow for flexibility in reservoir management to increase downstream benefits and/or decrease potential downstream negative impacts (e.g. flow increases for fish passage, decreases for flood control).

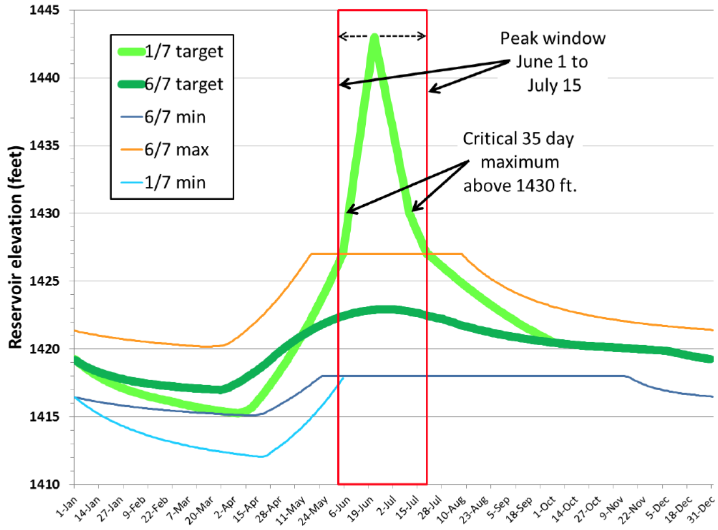

Figure 3: Scenario 3

Scenario 3 maintains the basic structure of the previous scenario: a relatively stable mid-elevation reservoir level in 6 out of 7 years centered on 1,420 ft., and a 1 in 7 year allowance for raising the level to full pool for major flood years. The primary changes associated with Scenario 3 are:

- defining an allowable range and seasonal pattern of elevation variation during the non-flood years (6 of 7 years; between the "6/7 min" and "6/7 max" lines in Figure 3), and
- allowing increased drawdown during predicted flood years (on average 1 of 7 years; light blue line in Figure 3 defines the drawdown extent and period).

Additional details concerning Scenario 3 are included in an appendix in the Thomson (2018) report available online at the website below.

Acknowledgements

The report upon which the conference presentation and this summary paper is based was initiated and funded by the BC Ministry of Energy and Mines and with guidance from Kathy Eichenberger, Executive Director of the BC Columbia River Treaty Review, and Heather Matthews of BC Hydro. The report authors include Alan Thomson, Mountain Station Consultants; Greg Utzig, Kootenai Nature Investigations; Bill Green, Ktunaxa Nation Council; and Nicole Kapell, Ktunaxa Nation Council.

The report is available online at:
https://engage.gov.bc.ca/columbiarivertreaty/review/technical-studies/

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Okanagan fish/water management tool (FWMT) "Fish-friendly flows" (Balancing fisheries, flood control and water allocation benefits)

Presenter: **Dawn Machin,** Fisheries Biologist – Okanagan Nation Alliance

The Canadian Okanagan Basin Technical Working Group (COBTWG) formed in 1996 to address salmon stock and habitat restoration issues in the basin. Members include the Okanagan Nation Alliance, the Canadian Department of Fisheries and Oceans, and the BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development. The COBTWG acknowledged challenges faced by water and fisheries managers including: variation in seasonal flow, competing objectives and communication barriers. This group identified possible solutions to address salmon restoration in the basin, and the project that was identified as having the biggest potential was the Okanagan Fish-Water Management Tool (FWMT). The COBTWG partnered with Douglas County PUD for the development of the FWMT.

The Okanagan basin is managed via a series of dams to balance between flooding, agriculture and urban water supply, fisheries, and other interests. The FWMT is an online, decision-support tool used by fisheries and water managers to balance competing water resource use, which utilizes six linked biophysical models (water supply – based on inflow forecasts, water management rules, water temperature, kokanee egg-to-fry emergence, Rocky Mountain Ridged Mussel, and Sockeye submodels) to predict the outcomes of water management scenarios (weekly releases). The FWMT allows an operations team of fish and water managers to "game" in real-time with various water storage or release options and weigh the associated risks and benefits of each prior to key decision points that may be separated by days to weeks. The FWMT predictions and the potential impacts of scenarios are discussed by water and fisheries managers, and decisions regarding water releases are implemented by the regulating agency. Improved communications between fisheries and water managers has led to greater compliance with recommended flows, in particular, fish-friendly lake levels and flows reduce negative impacts to fish populations.

For more information:

Kim D. Hyatt, Clint A. D. Alexander & Margot 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 / Revue canadienne des ressources hydriques**, 40:1, 87-110, DOI: 10.1080/07011784.2014.985510
http://dx.doi.org/10.1080/07011784.2014.985510

For an informational video about the success of the FWMT:
http://www.douglaspud.org/your-pud/district-videos

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Columbia Basin aquatic invasive species partnerships and collaboration

Presenter: **Khaylish Fraser**, Central Kootenay Invasive Species Society, Nelson, BC
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Aquatic invasive species (AIS) include non-native fish, animal, and plant species that have been introduced into an aquatic ecosystem where they have not been found historically. Once introduced, AIS such as fragrant water lily (*Nymphaea odorata*), zebra mussels (*Dreissena polymorpha*) and spiny waterflea (*Bythotrephes longimanus*) can spread aggressively and rapidly due to a lack of natural controls. This can result in harmful consequences for native species found in aquatic ecosystems, by radically altering habitat and rendering it inhospitable (Environment Canada, 2004). AIS have been implicated in vast reductions or the outright extinction of indigenous fish populations, devastating local fisheries (Therriault, Weise, Higgins, Guo, & Duhaime, 2013). The risk of AIS introductions to British Columbian waters is escalating rapidly, due to a number of anthropogenic factors, including but not limited to, water-based recreation/tourism, illegal dumping of horticultural and aquarium species, and increased global trade (Levine & D'Antonio, 2003; Hulme, 2009). Local citizens prioritized invasive species as one of the key ecosystem concerns during the Columbia Basin Trust (CBT) strategic planning process in 2013.

In 2014, the Columbia Basin Trust and the four regional invasive species organizations (RISOs) operating within the CBT's area of operation in the Canadian Columbia Basin (Central Kootenay Invasive Species Society, East Kootenay Invasive Species Council, Columbia-Shuswap Invasive Species Society, Northwest Invasive Plant Council) partnered to develop or expand their current aquatic invasive species programs to address the ecologic, social, and economic impacts that AIS pose to the Columbia Basin.

This partnership resulted in a regional AIS program, whose primary focus is to promote a proactive, strategic, collaborative, and coordinated approach to AIS prevention, response, and management. To guide this program, a framework was developed by an *ad hoc* committee composed of provincial, First Nation, state, and regional representatives. The framework focuses resources where they are most effective within a 5-year time frame (2015-2020). This program is designed to reflect shared goals and priorities, as such, the five focal areas that were decided upon by the aforementioned committee are 1) Coordination and Collaboration; 2) Education and Outreach; 3) Watercraft Inspection and Decontamination; 4) Monitoring and Research; and 5) Response and Management. Under each of these program areas, many goals and action items have been identified.

Since the inception of this program, the four RISOs have increased regional education, outreach, and monitoring for AIS such as, but not limited to, zebra and quagga mussels in the Columbia Basin. The four RISOs work closely to deliver these programs within the Columbia Basin and in a number of regulated rivers (particularly throughout the Columbia River system), using a variety of communication mediums, in-person boat launch outreach, lake monitoring, and advocating for policy changes at the federal and provincial level. Future challenges for this program include determining how to continue delivering extensive and comprehensive AIS programs if long-term, sustainable funding is not available. The four RISOs continually work on fund development strategies, but securing funds for education and coordination is challenging. Our key recommendation is to ensure continued and consistent monitoring for AIS with coordinated funding from relevant stakeholders.

More information on the Canadian Columbia Basin Regional Aquatic Invasive Species Program, and its' guiding framework are available at: https://ckiss.ca/about/protecting-our-lakes-and-rivers/

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Therriault, T., Weise, A., Higgins, S., Guo, Y., & Duhaime, J. 2013. Canadian Science Advisory Secretariat (CSAS). http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm

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Overview of hydroelectric impacts to aquatic and terrestrial ecosystems in the Columbia Region and some restoration/compensation strategies

Presenter: **Eva Schindler**, BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Nelson, BC
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Eva Schindler is a resource manager with BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. Eva works with her teams on ecosystem restoration, compensation projects, and habitat related items throughout the Columbia Region.

Eva delivered the keynote talk for the conference, giving an overview of hydroelectric impacts to aquatic and terrestrial ecosystems in the Columbia Region and restoration/compensation strategies used to mitigate the impacts.

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Significance, thresholds and decision making

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Introduction

Our understanding of nature is incomplete. And always will be. Yet we must act. How are we to take rational actions in the face of uncertainty? Or to put the question in more concrete terms – how should we use data to inform actions?

Statistical Models

As schematically depicted in Figure 1, statistical inference provides a well-defined pathway from data to uncertainty (in the form of posterior probability distributions).

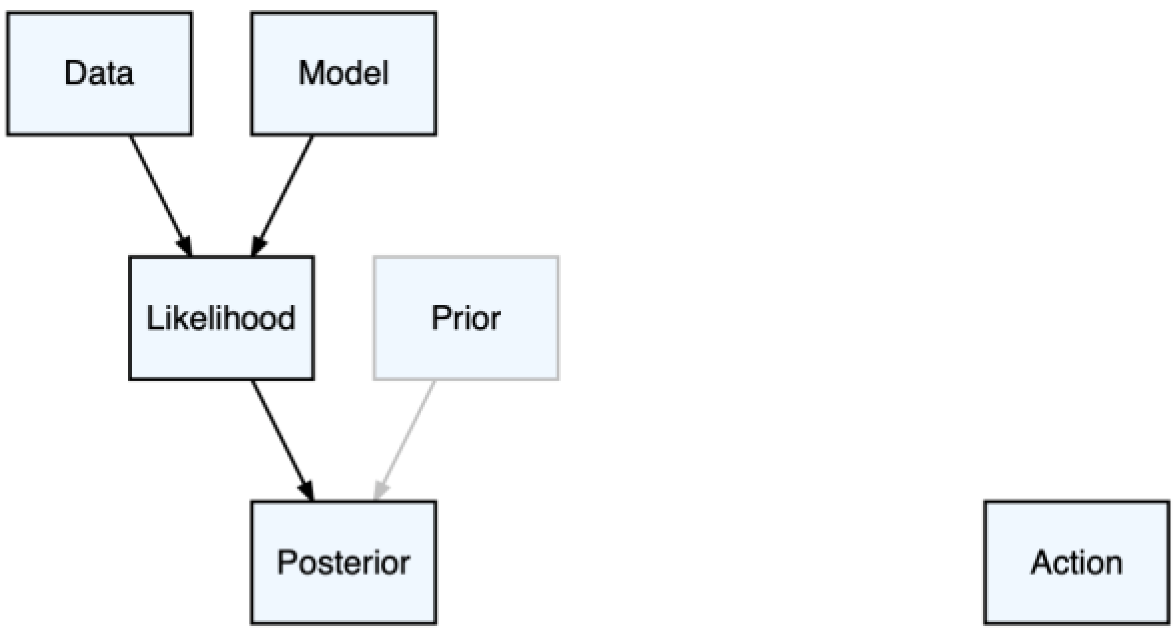

Figure 1. Statistical inference .

The likelihood is the probability of the data given the model parameter values. The posterior probability distributions, which fully capture the uncertainty in the parameter values, are produced by updating any prior information using the likelihood.

Significance

In impact assessments, the most common approach is to convert the posterior probabilities into 95% confidence intervals that are then categorized as being significant if they exclude no effect from the range of possible values. Unless the parameter representing the impact of concern is significant a project is approved. The pathway from uncertainty to action using significance testing is represented in Figure 2.

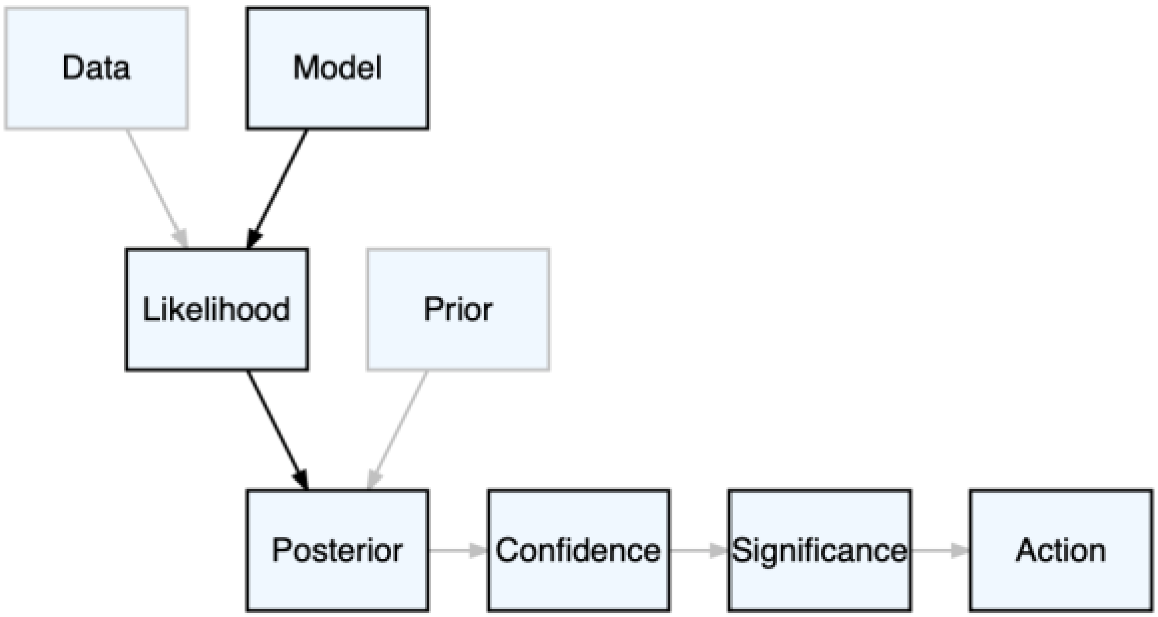

Figure 2. Significance testing. .

The Problem

A problem with significance testing is that substantial uncertainty results in an insignificant result and project approval even if there is a reasonable chance the impact is strongly negative. This violates the precautionary principle and disincentivizes data collection.

Power Analysis

Power analysis calculates the amount of data required to have a reasonable chance of a significant result with an impact above a particular threshold. It enforces data collection.

Prior Information

Incorporation of existing knowledge that an impact is likely to be a particular magnitude, incentivizes data collection if the proponent considers the actual impact to be substantially smaller. Otherwise negative impacts are considered to be as existing knowledge suggests.

Precautionary Principle

The precautionary principle is upheld if a project is not approved unless the estimated effect is significantly less than an acceptable threshold

However significance testing is still a poor framework for decision-making because it ignores most of the information in the posterior probability distribution and doesn't consider the costs and benefits of the project.

Statistical Decision Theory

Statistical decision theory allows the user to choose the option that maximizes the expected net benefit given the uncertainty. It requires a loss function, which can be challenging to develop, but ensures the criteria used to make a decision are explicit and that the decision is optimal (Figure 3). The loss function represents the relative value of each possible outcome.

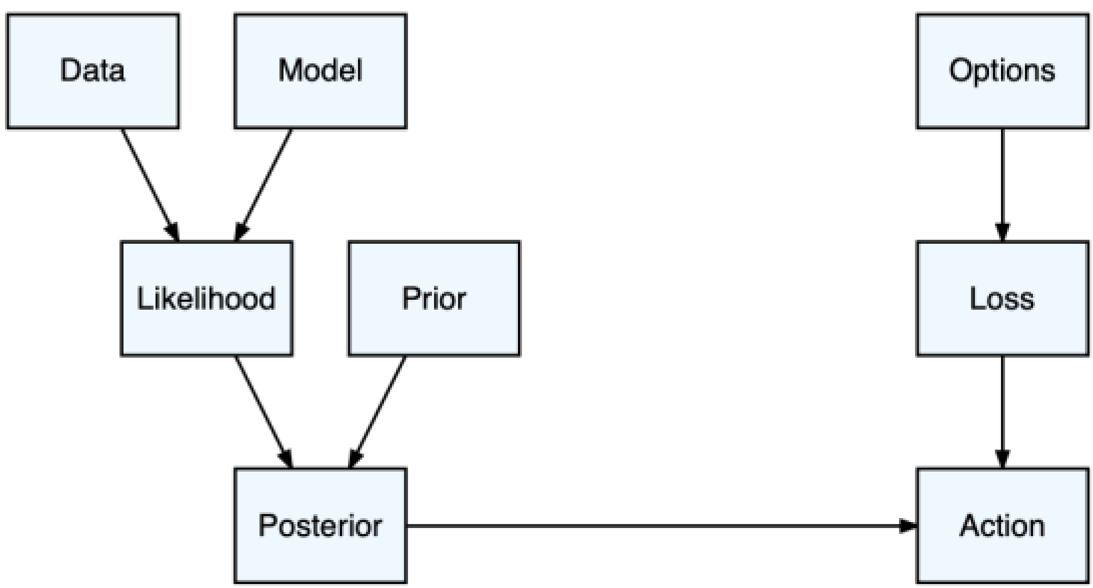

Figure 3. Statistical decision theory. .

Biodiversity Crisis

The UN's Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) 2019 report warns that as many as 1 million species are now at risk of extinction. If we are to better manage our planet it is essential that we abandon significance as a decision-making tool in environmental impact assessments.

Further Reading

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Long-term fish community monitoring for the Kwoiek Creek hydroelectric project: a look at the preliminary results

Presenter: **Rob Hoogendoorn**, Senior Biologist, Associated Environmental Consultants Inc., Vancouver, BC
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INTRODUCTION

Run-of-river (ROR) hydroelectric projects divert water from a portion of a stream to generate electricity. The reduction of flow in the stream between the project's intake and powerhouse (ie. the diversion reach) may have an effect on fish and fish habitat.

Kwoiek Creek Resources Limited Partnership (KCRLP) operates a ROR hydroelectric facility (the Project) on the lower reaches of Kwoiek Creek located on the west side of the Fraser River across from the community of Kanaka Bar and north of Boston Bar, BC. KCRLP is a joint partnership between the Kanaka Bar Indian Band and Innergex Renewable Energy Inc.

The Project was commissioned in October 2013. The facility diverts up to 13.5 m^3/s of the Kwoiek Creek flow at the intake and conveys the diverted flow 7.2 km through a buried penstock to the powerhouse. A minimum instream flow of 0.55 m^3/s is always released past the intake into the diversion reach, though this discharge increases substantially during freshet and rain events. The mean annual and 1-in-10-year peak instantaneous discharge at the intake are estimated at 7.9 m^3/s and 168 m^3/s respectively (Knight Piesold 2008). At the powerhouse, the diverted flow is returned to the creek via the powerhouse tailrace, which is 0.2 km upstream of the Fraser River.

Fish species documented in Kwoiek Creek include Rainbow Trout (*Oncorhynchus mykiss*), Bull Trout (*Salvelinus confluentus*), and Coho Salmon (*O. kisutch*). Coho Salmon are present only below the Canadian Pacific Railway crossing approximately 400 m from the confluence of Kwoiek Creek with the Fraser River, whereas Rainbow Trout and Bull Trout have greater distribution in Kwoiek Creek and are present throughout all stream reaches in the vicinity of the Project (Summit Environmental Consultants Inc. 2013a, b, 2014a).

As a requirement of environmental approvals, ROR projects are required to implement a Long-term Monitoring Plan (LTMP) for the first operational years. The LTMP includes monitoring a suite of biological and physical characteristics (components), of which a key component is the fish community. For the Kwoiek Creek hydroelectric facility, KCRLP is required to conduct an LTMP for the first 10 years after commencing operations, with fish abundance monitoring to be conducted during Years 1, 2, 3, 5, 7, and 10 of operation (Summit Environmental Consultants Inc. 2013a).

The purpose of the monitoring is to confirm the predictions made in the Environmental Assessment (EA). DFO developed protocols to standardize the monitoring programs for new hydroelectric projects, incorporating before/after control/impact (BACI) experimental designs, where appropriate (Lewis et.al. 2013).

The EA completed for the Project concluded that the primary potential effect on fish populations is through the direct linkage between fish populations and physical habitat. Anticipated losses of physical habitat resulting from the Project included footprint losses due to impacts of new infrastructure and flow reduction losses due to diverted flows for power generation (Focus Environmental Inc. 2008). Fish habitat compensation was included in the EA to provide a net balance of habitat and consisted of a compensation channel built off of the upstream (control) reach of Kwoiek Creek and consisting of series of nine constructed pools and channels. As a result, the EA concluded that there were no residual effects of the Project anticipated on fish populations.

Fish community monitoring completed to date as part of the LTMP consists of two years of baseline and four years of operational sampling. A summary of the results of the fish abundance monitoring component of the LTMP completed up to 2018 (Year 5 of operational monitoring) is provided including preliminary statistical analyses.

METHODS

Fish abundance monitoring was completed during each sampling year during low flows in late summer (mid to late September). Monitoring consisted of fish sampling at 10 fixed sites: five in the upstream control reach and five in the diversion reach. Monitoring included assessing site habitat features, assessing microhabitat characteristics along a representative transect, and photo documentation.

Fish were sampled using multiple-pass electrofishing at enclosed sites as a primary method. Sites were enclosed with mesh stopnets to prevent fish immigration and emigration during multiple-pass electrofishing.

Fish data collection included length and weight measurements of each fish captured, and scale sample collection from a subsample of the Rainbow Trout captured.

Fish data analyses included age class determination, assessment of relative health, density, and biomass. To determine Rainbow Trout age class, scale samples were processed using procedures similar to those described in Minard and Dye (1997). Scales were examined by an experienced reader using a Bell & Howell SR-VII microfiche reader, and an age was assigned for each fish in the subsample. Unaged fish were assigned ages using mixed distribution fitting methods according to MacDonald and Pitcher (1979) and using the package 'mixdist' version 0.5-4 in the R version 3.3.0 software application (R Core Team 2016) using MacDonald and Du (2011). These methods assign ages to individuals based on the length-frequency distribution of all fish collected.

To assess relative health and condition of fish in the upstream (control) and diversion reaches of Kwoiek Creek, the relationship of fork length to weight was examined. Condition factor (K) was calculated and used as an indicator of the general health of fish. Fish population estimates were performed in R version 3.3.0 (R Core Team 2016) and were calculated for each site using the Carle and Strub (1978) method in the package 'FSA' version 0.8.7 (Ogle 2016). The software uses fish removal data from each sampling pass to calculate the population size (or total number of fish) that would have been captured if sampling continued until no fish remained at the site. A density estimate was derived for each age class based on the population estimate for that class and the area of the sampling site. Biomass estimates were calculated for Rainbow Trout at each channel site. A biomass estimate was derived for each age class based on individual fish weights in each class and the area of the sampling site. Values for density and biomass were standardized to 100 m^2.

A BACI ANOVA analysis was completed using a regression model with period (before/after) and reach (control/impact) as fixed effects, and site and year as random effects (Schwarz 2015). All analyses were conducted using R version 3.3.0 (R Core Team 2016) and applying a confidence interval of α=0.05. Prior to statistical analysis, biomass and density data were transformed using the ln (x+1) to normalize the data and avoid potential negative skew effect of zero values in the dataset. In the interpretation of ANOVA results, the interaction of reach and period was used as the statistic of interest. This is because the interaction indicates that an effect of period/time depends on reach or vise versa (indicating a potential Project effect). The study was focussed on identifying changes to fish density and biomass over time, observed in the diversion reach but not in the control reach.

Power was calculated using a BACI power analysis program developed in R (Schwarz 2015), which was set to detect a 50% decline in fish metrics in the impact reach after accounting for observed changes in the control reach.

RESULTS

After four years of operational monitoring (Years 1, 2, 3 and 5), total density of fish increased in the diversion reach relative to the baseline condition (Figure 1). This increase was also noted in the control reach, potentially indicating a natural effect. High variability in fish density occurred in baseline and operational sampling years. The density of individual age classes of Rainbow Trout was also highly variable between baseline and operational years and between reaches (Figure 2).

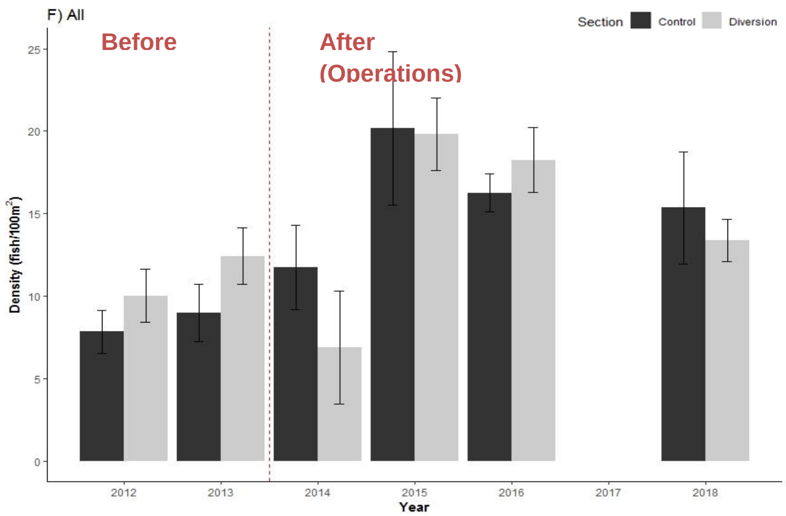

FIGURE 1. Density by year (baseline and operation) for all fish captured in Kwoiek Creek.

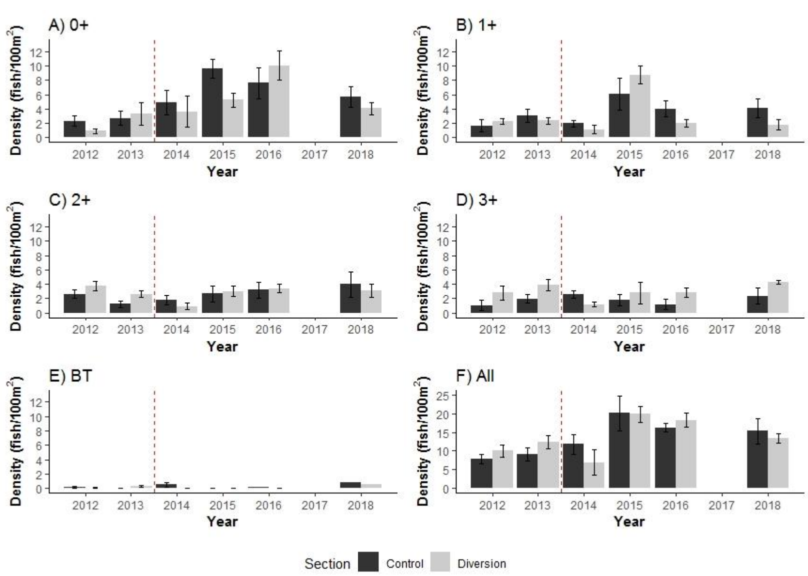

FIGURE 2. Density by year (baseline and operation) for Rainbow Trout by age class, for all Bull Trout, and for all fish captured in Kwoiek Creek.

Fish biomass in the diversion reach during operational sampling was generally similar relative to baseline conditions, which was also observed in the control reach (Figure 3). Similar to density, high variability in fish biomass occurred in baseline and operational sampling years. The biomass of individual age classes of Rainbow Trout was also highly variable between baseline and operational years and between reaches (Figure 2).

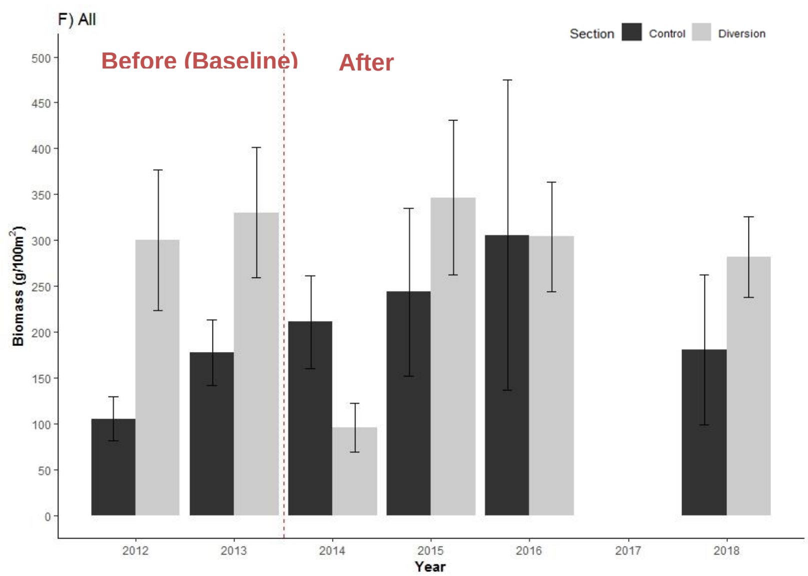

FIGURE 3. Biomass by year (baseline and operation) for all fish captured in Kwoiek Creek.

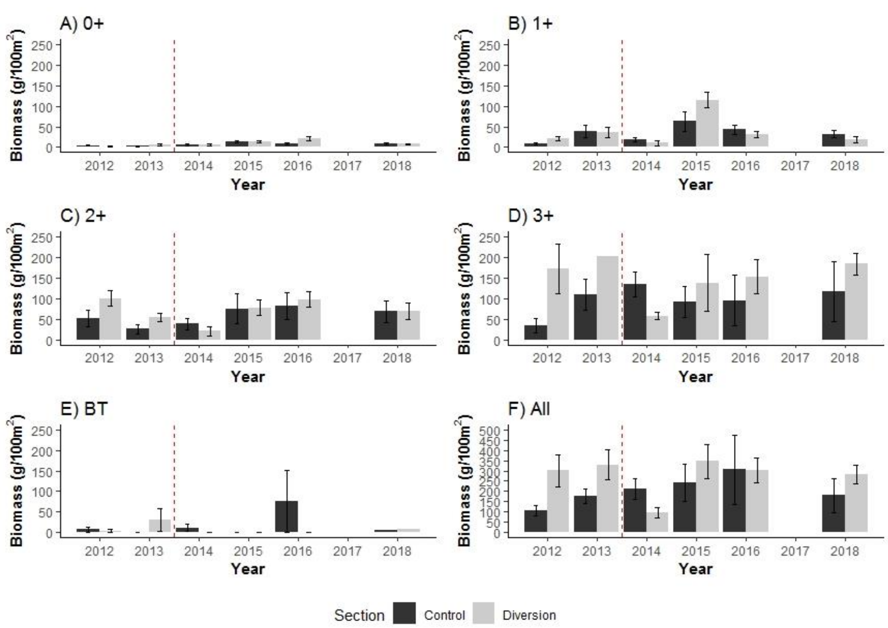

FIGURE 4. Biomass by year (baseline and operation) for Rainbow Trout by age class, for all Bull Trout, and for all fish captured in Kwoiek Creek.

None of the BACI interaction terms were statistically significant ($p<0.05$) and power of the tests were low (power<0.8); therefore, we were not able to detect a significant Project effect. The DFO protocol outlined 50% as the change that the study was designed to detect. The observed changes in total density and biomass were <50%. Although absolute total fish density increased in the diversion reach, a higher increase occurred in the control reach; thus, the relative change in fish density was negative (a decrease of 25%, $p=0.09$, power=0.56). BACI ANOVA analysis of the relative fish density monitoring results to date indicate decreases at all ages. BACI ANOVA analysis results also indicate decreases in relative fish biomass in older fish (parr 2+ and adult fish), but an increase in juveniles (fry and parr 1+), resulting in an overall decrease of 35% in biomass relative to the control reach ($p=0.17$, power=0.74).

Results of the fish habitat compensation channel may be confounding interpretation of the fish abundance monitoring program results. The compensation channel has been very successful at providing functional fish habitat, with relative fish abundance in the channel well exceeding baseline levels in the diversion reach. Movement of fish out of the compensation channel into the control reach may occur, which could be increasing density of fish in the control reach. This potential influence may affect the assessment of the fish monitoring program overall.

SUMMARY

Based on the results of the monitoring program to date, there are no statistically significant negative changes to the fish population in Kwoiek Creek as a result of the Project. Total fish density appears to have increased and overall fish biomass has stayed similar in both the diversion and control reaches during operational years relative to the pre-Project baseline. The 2018 results represent Year 5 of operational monitoring for the Project. The next fish abundance and behaviour monitoring is scheduled for Year 7 of operations (2020). A detailed assessment of all baseline and operational monitoring years will be completed at the end of the monitoring program (i.e., after Year 10 of operations [2023]). The remaining years of monitoring may assist in understanding responses by fish populations. Analysis of other physical and biological data from other monitoring program components (e.g. water temperature, fish compensation channel) may also assist in understanding the mechanism for observed changes. Results of fish compensation channel monitoring should be considered as part of the interpretation of the fish abundance monitoring results and the overall potential Project effects.

ACKNOWLEDGEMENTS

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Twenty years of learning: factors affecting the success of nutrient additions for restoring fish populations and the recreational fishery in Arrow Lakes reservoir

Presenter: **Steve Arndt**, M.Sc., BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Nelson, BC
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Summary

Last year (2018) marked the 20th year of nutrient additions in Arrow Lakes Reservoir (ALR). This presentation reviews the results thus far and some factors that influence the success of the program. ALR is a large reservoir (230 km long, ≈300 km^2 in late growing season). It hosts the second largest recreational fishery in Kootenay Region with annual effort usually > 15,000 angler-days and a harvest from 8 to 12 tonnes (Arndt 2018). The reservoir is impacted by a dam and power plant at the downstream end, and 2 dams with reservoirs and power plants upstream.

There are two ongoing compensation methods for ALR fish. Hill Creek spawning channel (built 1981) provides spawning habitat for Kokanee and Rainbow Trout, and the nutrient program (begun 1999) adds limiting nutrients (phosphorus, nitrogen) to the pelagic zone to compensate for nutrient losses in upstream reservoirs (Bassett et al. 2018). The nutrient program is expected to enhance phytoplankton production, which are consumed by zooplankton, which are consumed by Kokanee and mysid shrimp. Kokanee are intended to provide both a recreational fishery, and adequate food for the apex predators Bull and Rainbow trout, which are also important components of the fishery.

Phosphorus additions were held at 52.8 tonnes for the first five years, after which they varied from 14.5 to 49.5 tonnes based on lower trophic level indicators and water quality considerations. A lesser (and varying) amount of phosphorus also enters from the Columbia River and tributaries. Kokanee fry production at the spawning channel has varied from 114,000 to 20 million since 1999. Data sources for the presentation include: an angler survey, hydroacoustic/trawl Kokanee abundance and size estimates, spawning channel Kokanee data, reservoir-wide Kokanee spawner counts, outflow measured at the outlet, and phosphorus inputs added by the nutrient program.

Results thus far show a strong positive response in fish metrics in some years, but a high degree of variability at the Kokanee (spawner returns, survival, growth, production, biomass) and piscivore (Bull Trout and Rainbow Trout condition and size) trophic levels, and in the recreational fishery (catch, harvest, fishing effort). Preliminary analyses suggest at least three key factors influence the success of the program. The **amount of phosphorus added**, as expected, has a positive effect on Kokanee survival and production, and this transfers up the food web to predator condition factor, an important indicator of their feeding success (Fig. 1). Increasing phosphorus increases

production at the Kokanee and apex predator trophic levels, with predator condition being most closely related to the abundance of the older (larger) ages of Kokanee.

However, **Kokanee density** has a strong influence on Kokanee survival, growth, and production; as density increases (measured as number of Kokanee, or as in-lake biomass), rates of survival and growth decrease. This leads to declines in spawner returns and Kokanee production, and a lower efficiency of nutrient transfer if the reservoir carrying capacity is exceeded (Fig. 2). **Higher flows** during the growing season also have a negative effect on both Kokanee production and predator feeding and condition (Fig. 3). Operations that increase flows through the reservoir (especially through the growing season) will reduce pelagic fish production and be detrimental to the recreational fishery. More detailed analyses on flow timing and magnitude in relation to fish metrics would be beneficial for determining the most flow sensitive time periods for pelagic fish production.

Next steps will include a multivariate analysis to quantify the relative importance of the three factors above and determine how they interact. There may also be other factors such as temperature or other climate variables that should be added to the metrics. And secondly, it will be important to use an active adaptive management approach where variables under our control are deliberately modified to test for ways of optimizing benefits to the reservoir. This process has been started by maintaining consistent spawning channel fry production and phosphorus addition targets over the last four years, and should be continued with thoughtful modifications into the future.

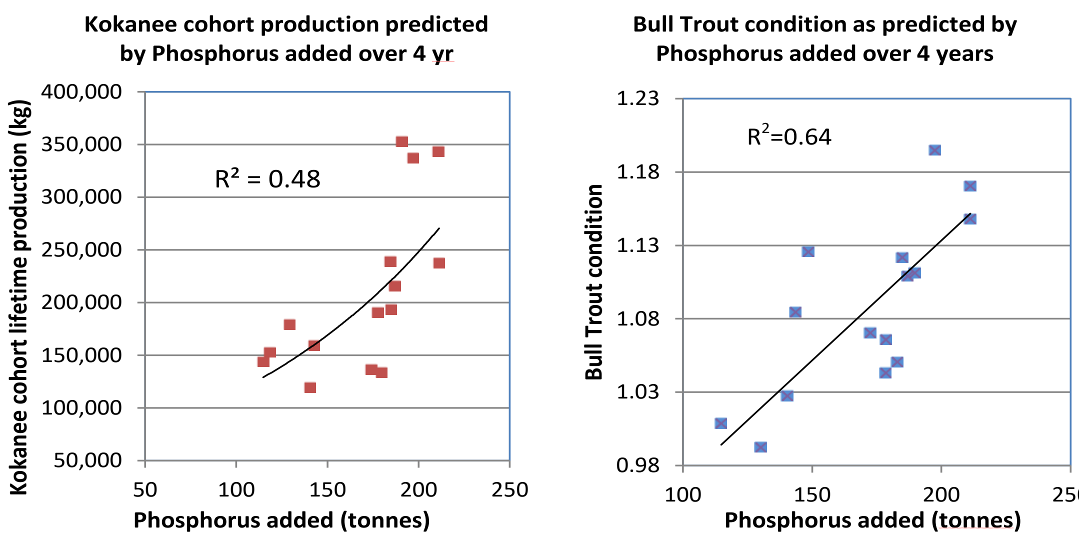

Figure 1. Examples of the positive relationship between phosphorus and fish metrics. Left panel shows that Kokanee production (weight of Kokanee produced over a single cohort's lifetime) increases as phosphorous additions increase over their lifetime. Right panel shows a positive relationship between Bull Trout relative condition (K_n; an indicator of feeding success), and cumulative phosphorus added over the four years of a Kokanee life cycle.

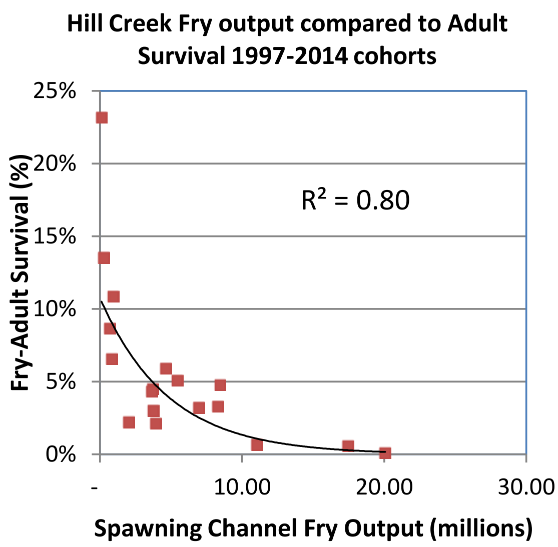

Figure 2. An example of the influence of Kokanee density on survival. Left panel shows a decline in survival from fry to adult as spawning channel fry production increases. Right panel uses the same data to predict returning adults from fry output.

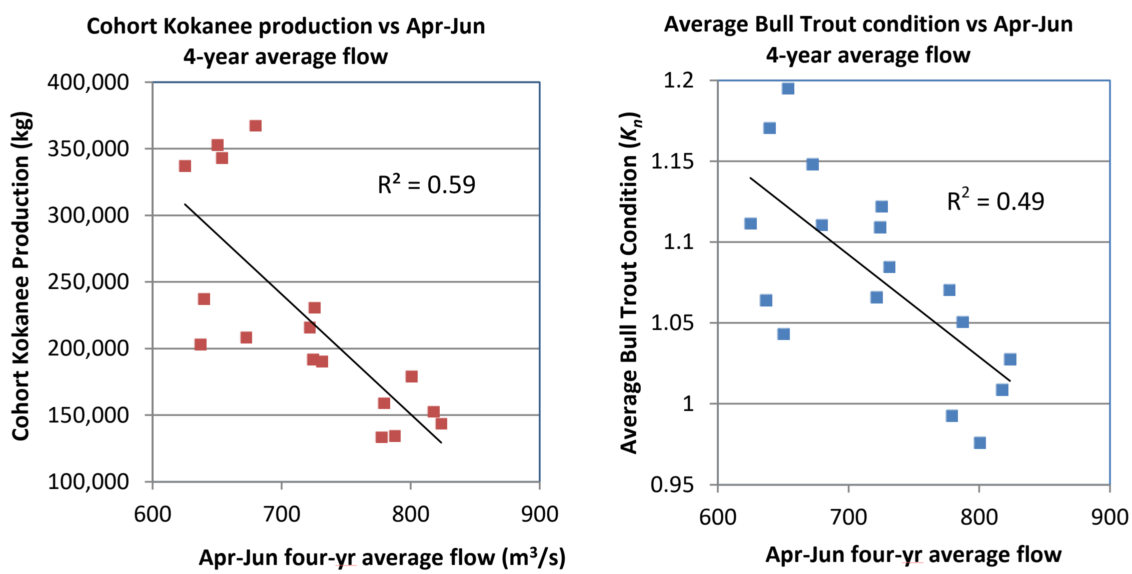

Figure 3. Examples of the negative influence of flow on fish populations. Left panel shows a decline in Kokanee production with increasing flow, and right panel a decline in Bull Trout condition with increasing flow.

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Monitoring white sturgeon (*Acipenser transmontanus*) spawning in the middle Columbia River below Revelstoke Dam

Presenter: **Louise Porto,** MSc., R.P.Bio., Associate Fisheries Biologist
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Introduction

Upper Columbia River White Sturgeon (*Acipenser transmontanus*) are listed under the federal Species At Risk Act (SARA; 2006) as endangered because levels of natural recruitment have been too low to sustain the population. A small component of the population resides in the Middle Columbia River, an area between Revelstoke Dam (REV) and Hugh L. Keenleyside Dam (HLK) in British Columbia. This population component is comprised of approximately 52 adults and has been documented to spawn intermittently downstream of REV near the City of Revelstoke since 1999. REV, completed in 1983, is a daily peaking facility that responds to hourly power demands. The effect of hydropeaking operations at REV is a constant variation in flow rates at the White Sturgeon spawning area coupled with the backwatering effect in Arrow Lakes Reservoir (ALR) from HLK as far upstream as REV, which generally occurs before and during the White Sturgeon spawning period. Spawn monitoring has been conducted under BC Hydro’s Water Use Planning program (2007-2018) to assess spawning activity, timing, and duration in order to determine primary incubation areas, assess stranding risk, and identify potential modifications to protect or enhance spawning and incubation below REV.

Study Area

The study area was located between REV (Km 234) and the Illecillewaet River (223.5), near the City of Revelstoke (Figure 1). From 2012 to 2018 the study area was located between Km 227.4 and 227.1, which incorporated the area where all White Sturgeon eggs have been captured since 1999 (Figure 1). Revelstoke Dam is located at Km 235 (Figure1).

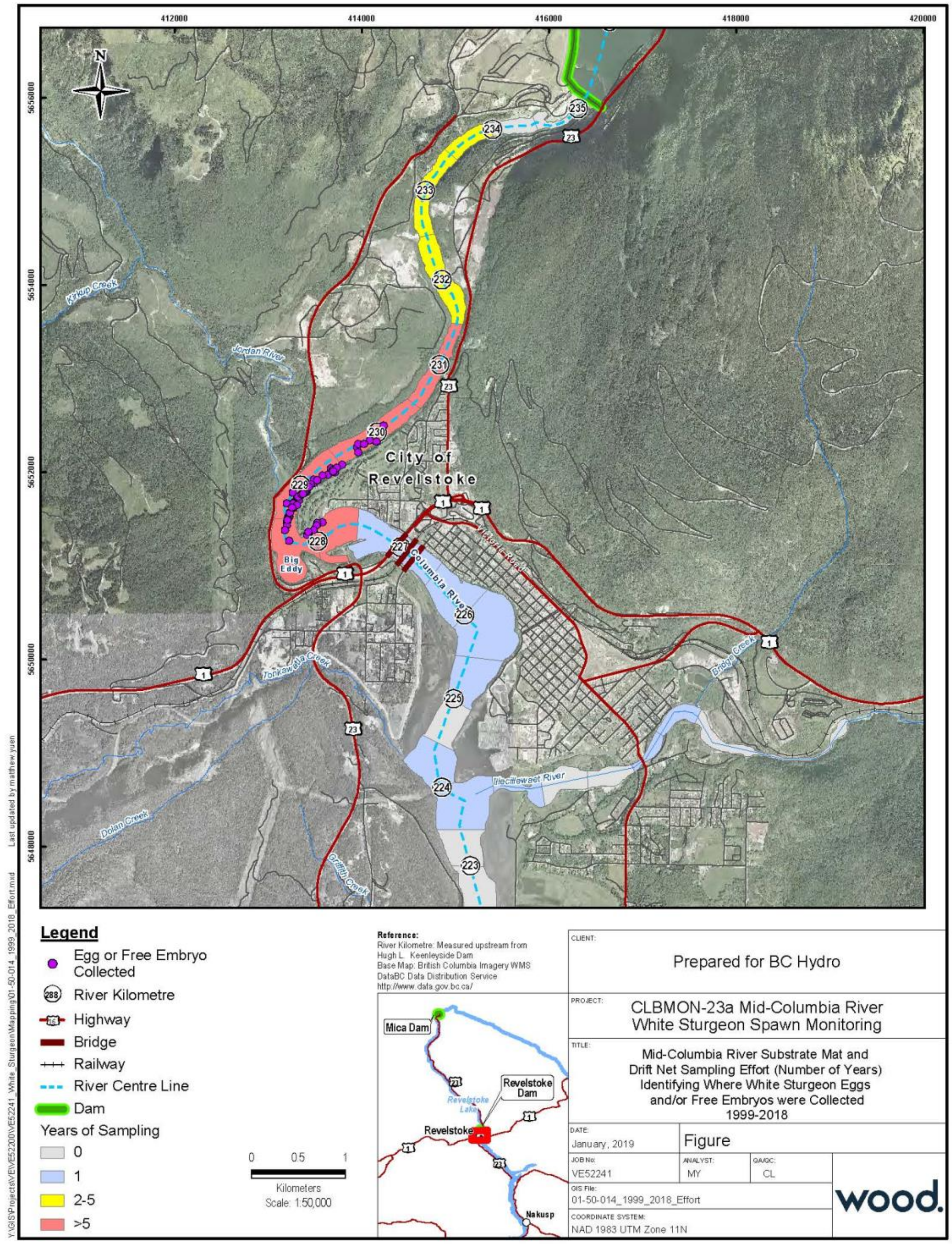

Figure 1: Mid-Columbia River substrate mat and drift net sampling effort (number of years) identifying where White Sturgeon eggs and free embryos were collected, 1999-2018. River kilometres refer to distance upstream from Hugh L. Keenleyside Dam.

Methods

Sampling was conducted annually between mid-July and early September during the documented White Sturgeon spawning period below REV. The collection of eggs and free embryos was faciliated by the deployment of egg mats and drift nets.

Between 20 and 22 egg mat stations were deployed within nearshore (both banks) and mid-channel habitats. Each egg mat (dimensions 0.77 m by 0.92 m) was comprised of a steel frame that enclosed latex covered animal hair filter material. The filter material was present on both sides of the frame, so when deployed, one side of the filter material was always sitting upward where drifting eggs and free embryos could lodge and attach. The egg mat system consisted of two 30 kg claw anchors attached to one another with an approximately 6 m galvanized steel chain and a float line which attached to the front anchor; a 10 m rope attached the rear anchor to the egg mat with a second float line (15 to 45 m) coming off the rear of the egg mat for retrieval. The lengths of rope used depended on depth and degree of flow fluctuations that were encountered.

Drift nets consist of a D-shaped metal frame (0.8 m wide by 0.6 m high) with an attached net (3.6 m long, 0.16 cm knotless mesh, 11.4 cm diameter collection bottle). Drift net sites were selected to cover the upper, middle and lower portion of the spawn monitoring area during each field survey. A minimum of six and maximum of 19 drift net sets were deployed weekly. Two 30 kg claw anchors were used for drift net sites. Anchors had approximately 6 m of galvanized steel chain between them. The first anchor had a float line attached and the second anchor had a section of chain then rope to attach the drift net. The bottom end of the drift net frame was clipped onto this chain/rope line. The drift net was weighted at the front corners (approximately 4.5 kg lead weight attached to each corner) to ensure it remained upright in the water in order to more effectively sample drifting debris/aquatic life.

Egg mats and drift nets were inspected for White Sturgeon eggs and larvae. Collected White Sturgeon were immediately staged on the boat upon capture. Standard egg staging procedures were used (e.g., Jay et al. 2016, Dettlaff et al. 1993, and Wang et al. 1985). Eggs staged in the field were placed in incubation trays that were anchored in the river in a location close to the point of capture. Incubation trays consisted of flat plastic trays with wells for approximately 100 individual eggs covered by a top plate. Eggs were then either incubated *in situ* until hatch or transferred to the Kootenay Trout Hatchery in Fort Steele, BC. If incubated *in situ*, eggs remained in incubation trays until hatch at which time all free embryos, including those collected in drift nets, were preserved in 90% ethanol to be used in future genetic analyses. If transferred to the Kootenay Trout Hatchery, eggs and/or free embryos were transferred to large ziploc bags half filled with fresh river water and half filled with air at the end of the weekly sample session. The ziploc bag was then packed securely in a cooler with ice packs and transferred to the Kootenay Trout Hatchery.

Egg stranding surveys were conducted opportunistically when White Sturgeon spawning event(s) were detected, depending on water levels. White Sturgeon eggs have been previously observed to dewater at a cobble/gravel bar across from the mouth of the Jordan River (~Km 228; Figure 1). Field crews inspected the dewatering area for eggs and free embryos and recorded area surveyed and any White Sturgeon eggs/free embryos detected.

Catch-per-unit effort (CPUE) was calculated for each egg mat and drift net (e.g., number of White Sturgeon eggs/hour of effort) for comparison between sampling locations and years. Egg and free embryo stages were used with mean water temperatures observed during sampling to estimate the number and timing of spawning events based on developed relationships (Parsley at al. 2011; Wang et al. 1985). The total number of eggs/free embryos, status (alive/dead/damaged), spawn timing and number of estimated spawning events were summarized. In the case of any free embryo stages falling between those noted by Wang et al. 1985, a range was calculated to cover the possible spawn timing.

Results & Discussion

Spawning Activity, Timing and Duration

White Sturgeon spawning was documented between 20 July and 28 August (1999-2018) and the number of spawning events has ranged from zero to six depending on year. Spawning has been observed in 12 of the 17 years spawn monitoring has been conducted. The highest number of spawning events was observed in 2018 (n=6), which had the highest number of eggs and free embryos collected (n=95 and 5, respectively) since 1999 (n=3 events, 82 eggs) (Wood In prep). There were no spawning events recorded in 2000, 2001, 2007, 2010 and 2015, whereas during other years between 1 and 3 spawning events was typical (Wood In prep).

Primary Incubation Areas

The primary White Sturgeon incubation area is located within a 2.2 km river section between Km 227.9 and 230.1, which encompasses the area adjacent to the Revelstoke golf course (Figure 1). All 393 eggs and 56 free embryos collected since 1999 have been captured in this area. White Sturgeon eggs have consistently been documented in this relatively small area despite past sampling at other potentially suitable areas between 1 km downstream of Revelstoke Dam (Km 234) and the Illecillewaet River (Km 223.5)

(Figure 1). The boundaries of this small spawning/ incubation area may shift slightly depending on flows and ALR elevation, but remains relatively similar between years.

Effective Methods for Monitoring

Based on the broadcast spawning of the species, the most effective method for monitoring White Sturgeon spawning in the mid-Columbia River is a combination of egg mats and drift nets. Egg mats sample continuously and can identify the duration of spawning with less intensive effort compared to drift nets. Drift nets are more efficient in collecting eggs and free embryos and they can be placed downstream of the known spawning site. In addition, they can identify the downstream dispersal of larvae, especially once spawning has been identified and time of hatch has been estimated. During the past 12 years of this program, an average of 126 egg mats have been deployed per spawning season for approximately 21,223 hours which resulted in an average catch-rate of 0.01 eggs/free embryos per hour. In contrast, an average of 40 drift nets have been deployed per spawning season for approximately 213 hours which resulted in an average catch-rate of 0.14 eggs/free embryos per hour. Although drift nets seem to have higher catch-rates, they do not fish continuously like egg mats and may miss downstream dispersal of free embryos after hatch occurs so it is important to consider how drift net sampling occurs once spawning is detected (Wood In prep).

Dewatering and Stranding Risk

The risk of egg dewatering and stranding is considered low at this time. Minimim flows implemented following the addition of a 5th turbine at REV in 2011 have increased the permanently wetted river bed area in the middle Columbia River and reduced the exposure of shallow gravel bars within the egg incubation area to the extent that egg and larval stranding is likely minimal (Dashti et al. 2016). Stranding surveys were conducted in 2009, 2011 and 2014, with stranded eggs located on an exposed gravel bar only observed in 2009 before minimum flows were implemented.

Protection and Enhancement of Spawning/Incubation

It is unknown at this time whether additional modifications to REV/ALR operations can be made to protect or enhance White Sturgeon incubation habitat. Flow modifications have already occurred with the addition of REV5. For example, a 142 m^3/s minimum flow requirement was initiated concurrent with REV5 coming online (December 2010). Preliminary information collected during this monitoring program before and after REV5 suggests that operational modifications have reduced White Sturgeon egg and larval stranding due to an increase in minimum flow. In addition, spawning has been recorded 7 of the 8 years following the addition of REV5. Additional studies conducted by BC Hydro have also noted variables such as velocity, depth and substrate in the study area are within the ranges observed in successfully recruiting White Sturgeon populations (e.g., Hildebrand et al. 2014).

Recommendations

Future monitoring should include additional egg stranding surveys for flows below the minimum and the collection of naturally spawned eggs for conservation aquaculture to improve juvenile survival in the mid-Columbia River.

Acknowledgements

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Additional information and reports are located at:
https://www.bchydro.com/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/columbia-sturgeon.html

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Terrestrial arthropod monitoring in Kinbasket Reservoir

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Background

The creation of Kinbasket Reservoir resulted in direct impacts to species, habitats, ecosystem function, biological processes, and several socioeconomic/cultural impacts. To balance environmental values, recreation, power generation, culture/heritage, navigation, and flood control, a multi-stakeholder consultative process was formed in 2007 which resulted in the Columbia River Water Use Plan (BC Hydro 2007). The consultative committee recognized the value of vegetation for aesthetics, dust control, protecting cultural heritage sites from erosion and human access, and enhancing productivity and wildlife habitat. In lieu of operational changes, a 10-year reservoir-wide planting and enhancement program (CLBWORKS-1) was initiated to maximize vegetation growth in the drawdown zone and to facilitate the development of long-term self-sustaining riparian vegetation.

Revegetation prescriptions 2008 – 2013

Several revegetation treatments were applied in Kinbasket Reservoir under CLBWORKS-1 between 2008 and 2013, amounting to ~75 ha treated (Keefer et al. 2007, 2008, 2010, 2011, Adama 2015). The main treatments were sedge plugs and black cottonwood live stakes. Despite widespread revegetation efforts, there was low survival of transplants (Figure 1). The revegetation effectiveness monitoring program (CLBMON-9) indicated that the revegetation program was unsuccessful and did not contribute to sustainable vegetation growth in the upper elevations of the reservoir drawdown zone (Hawkes et al. 2013). Coarse woody debris accumulation in the upper elevation band of some areas of the reservoir (Figure 2) was highlighted as a significant barrier to plant regeneration.

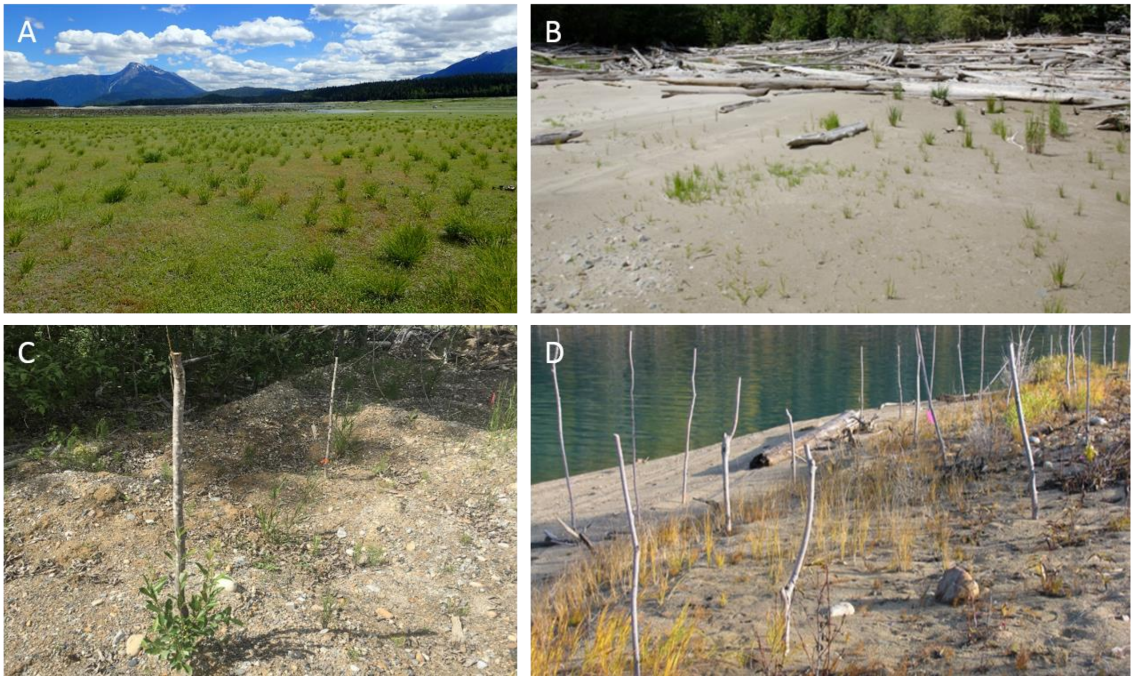

Figure1. Examples of revegetation transplants applied in Kinbasket Reservoir: A) successful sedge plug treatment at Km88 Big Bend (Bush Arm), B) failed sedge plug treatment at Windfall Creek, C) live cottonwood stakes planted at Bush Arm Causeway, and D) dead cottonwood stakes at Km79. Photo credits: Doug Adama, Flavia Papini, and Charlene Wood.

Figure 2. Wood debris accumulation at the north end of Valemount Peatland (A) and Packsaddle Creek (B) in Canoe Reach, Kinbasket Reservoir in 2014. Photo credit: Charlene Wood.

Physical Works 2014 – 2018

In 2014, the approach to revegetating the drawdown zone shifted from planting sedges and live stakes to physical works trials to promote the natural establishment of vegetation. This work was performed under CLBWORKS-1 (Hawkes 2016; Hawkes

2017) and CLBWORKS-16 (Kinbasket Debris Inventory, Management Strategy and Removal). The physical works included the removal of wood debris from terrestrial portions of the drawdown zone (wood clearing), the removal of wood from existing wetlands in the drawdown zone (pond clearing), the use of wood debris to construct mounds, and the installation of log booms around cleared and treated areas to prevent further debris deposition.

Wildlife effectiveness monitoring 2008 – 2013

Wildlife effectiveness monitoring was conducted annually from 2008 to 2012 by CBA (CBA 2009, 2010, 2011; MacInnis et al. 2011, 2012), and by the Okanagan Nation Alliance and LGL Limited in 2013 under CLBMON-11A (Hawkes et al. 2014). Wildlife responses to revegetation were not detectable after 8 years of monitoring (CLBMON-11A). The wildlife monitoring program found a high degree of overlap in habitat use by wildlife taxa such as ungulates, small mammals, bats, and birds relative to treatment and control areas in the drawdown zone. The only consistent differences detected in wildlife use was between the reservoir drawdown zone and upland (non-reservoir) reference forests (Hawkes et al. 2014). The lack of difference in wildlife use of revegetation treatments was not surprising given the failure of revegetation treatments, small spatial scale of treatment areas, low replication of treatments, and choice of focal taxa.

Wildlife effectiveness monitoring 2014 – 2018

With an adaptive management approach, the goals of CLBMON-11A shifted in 2014 to focus on the efficacy of physical works trials in enhancing wildlife use of the drawdown zone in Kinbasket Reservoir. Our main study areas occurred in Valemount Peatland, Yellowjacket Creek, and Packsaddle Creek in Canoe Reach (near Valemount) and in Bush Arm near Donald, B.C. (Figure 3). Post-treatment monitoring of wood clearing was conducted from 2014 to 2018 (Wood et al. 2015, 2016, 2017, 2018, and 2019, draft). Focal taxa were streamlined to species of terrestrial arthropods and songbirds in efforts to increase our ability to detect changes in treated areas relative to untreated drawdown zone areas.

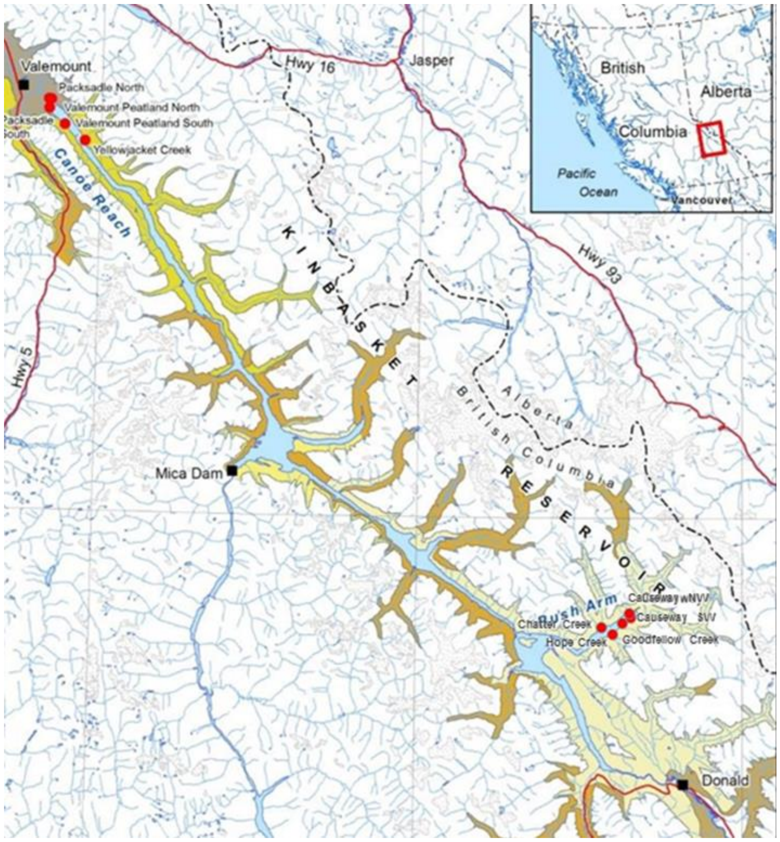

Figure 3. Location of Kinbasket Reservoir in eastern British Columbia (inset, top-right) and location of main study sites monitored of arthropod monitoring from 2014 to 2018 (red points).

Terrestrial arthropod monitoring

Effective monitoring programs rely on their ability to efficiently resolve responses in focal taxa. Terrestrial arthropods, including ground-dwelling spiders (Araneae) and ground beetles (Coleoptera: Carabidae), are effective focal taxa for habitat monitoring. These taxa are informative ecological indicators because they are easily sampled using pitfall traps (Figure 4) are the most abundance and diverse organisms of terrestrial habitats, occur in almost all terrestrial ecosystems, include both specialist and generalist species, can be studied across any gradient of habitat change, and respond to both fine-scale and landscape-scale environmental changes (Buddle and Shorthouse 2008; Marshall et al. 1994; Niemelä et al. 1993; Pinzon et al. 2013, 2016; Work et al. 2004). In addition, ground beetle species are effective bioindicators of short-term (< 5 years) environmental changes (Koivula 2011; Work et al. 2008). The highly species-specific nature of responses makes arthropods ideal ecological indicators (Langor and Spence 2006).

Figure 4. Ground-dwelling terrestrial arthropods are readily sampled by pitfall traps (A). Often spiders and beetles respond to fine-scale environmental conditions, such as increased vegetation structure or cover. For e.g., bare habitats (B) are dominated by ground-running spiders, such as Thin-legged wolf spiders (Lycosidae), while sites with low herbaceous and graminoid vegetation (C) offer habitat for web-builders such as funnel-web weavers (Agelenidae). Photo credit: Charlene Wood.

Responses to wood debris removal

Natural regeneration of vegetation

Following clearing of wood debris from the upper elevation bands of the drawdown zone of Kinbasket reservoir, natural vegetation establishment was documented in all plots. The cleared plots increased in the cover and growth of vegetation over time (Figure 5).

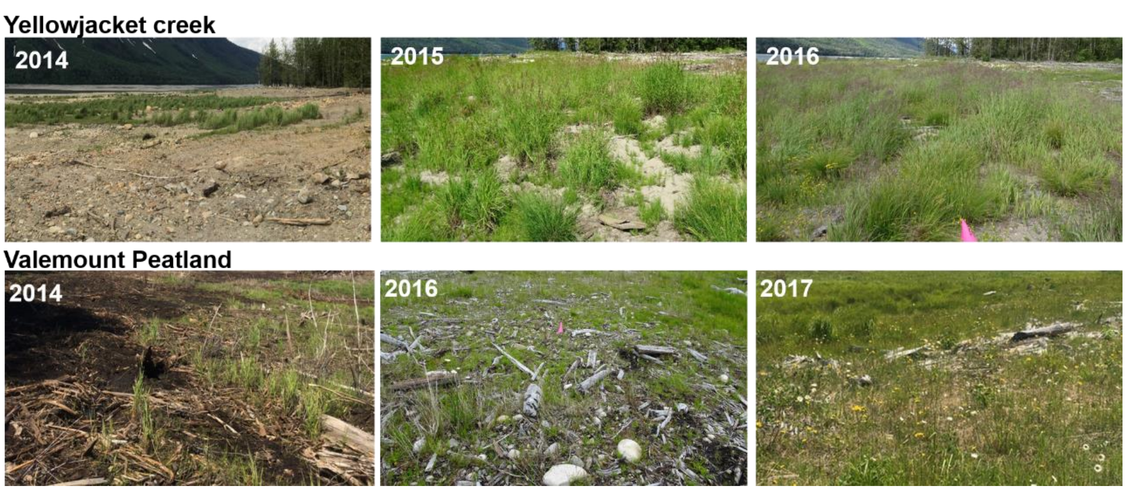

Figure 5. Vegetation establishment in treatment plots cleared of wood debris at Yellowjacket Creek (top) and Valemount Peatland (bottom) over time. Year of photo is given in white text. Photo credit: Charlene Wood.

Turnover of arthropod species

We collected a total of 302 species of beetles and spiders from pitfall trap samples, including 12795 individual spiders and 13088 individual ground beetles. In general, immediately after wood removal, treatment plots contained little vegetation and were dominated by open-habitat species, such as wolf spiders that do not require webs for prey-capture (e.g., *Pardosa moesta* and *Pardosa xerampelina*) and ground beetle species that prefer sandy substrates with low vegetation cover (e.g., *Bembidion obscurellum, B. planatum, Cicindela longilabris,* and *C. oregona*; Figure 6).

Figure 6. Characteristic ground beetle (Carabidae) species collected in treatment plots in the first year following wood debris removal. Left: *Cicindela longilabris* (Long-lipped Tiger Beetle). Right: *C. oregona* (Western Tiger Beetle). Photo credit: Charlene Wood.

Evidence of species turnover occurred within three to five years post-treatment. The initial bare-ground associated fauna became less prominent in trap captures, being replaced by other species associated with sparse and dense vegetation in open habitats (Figure 7). For example, *Pardosa moesta* which is most tolerant of completely open, extreme conditions, was most abundant in the first year after wood clearing but decreased in catch per trap per day in the following years. Coincident with vegetation establishment on treatment plots over time, other species such as *P. fuscula,* increased abundance caught per trap per day. Likewise, we observed an increase in the ground beetles *Pterostichus adstrictus* and *Platynus mannerheimii* in years since treatment (Figure 7) which are species associated in open and closed forests. This increase is coincident with a decrease in catch per trap per day of bare-ground associated species.

Initially after mechanical disturbance from wood removal, the catch of ground beetles was comprised of approximately 16% non-native ground beetle (Carabidae) species (Figure 7). This included six species: *Pterostichus melanarius, Agonum muelleri, Bembidion tetracolum, Amara familiaris, Amara apricaria,* and *Harpalus affinis*. However, the proportional catch of non-native species decreased over the study period, to approximately 5% non-native beetles five years post-treatment.

Spiders were also classified in several guilds based on their method of prey capture (Uetz et al. 1999). Spider guild composition changed over time since wood clearing. At Yellowjacket Creek, the "ground-runner" guild comprised the largest proportion of spider guild caught in the initial post-treatment samples. However, ground-runners became less prominent in years post-treatment, with increased proportional catch of wandering-sheet/tangle-weavers, sheet/funnel-weavers, and space-web builders. Increases in these guilds reflects the improved vegetation structure of these treatment areas relative to initial post-treatment conditions. However, in 2017, this site was disturbed by machinery used for the wood removal program (CLBWORKS-16) without prior notice. This resulted in a decrease in vegetation cover and ground disturbance. In 2017, we found the spider guild structure returned to a "ground-runner" dominant assemblage, which did not show recover in 2018, but is expected to recover if the area is left to regenerate naturally in the absence of disturbance.

At Valemount Peatland, where a shallow wetland and adjacent peatland was cleared of wood, the proportion of ground-runners remained similar over time. However, guild richness steadily increased (Figure 7) indicating a more heterogeneous/diverse functioning assemblage. By 2018, fishing spiders (*Dolomedes triton*) had colonized the site, which may be an early indication of improved wetland function.

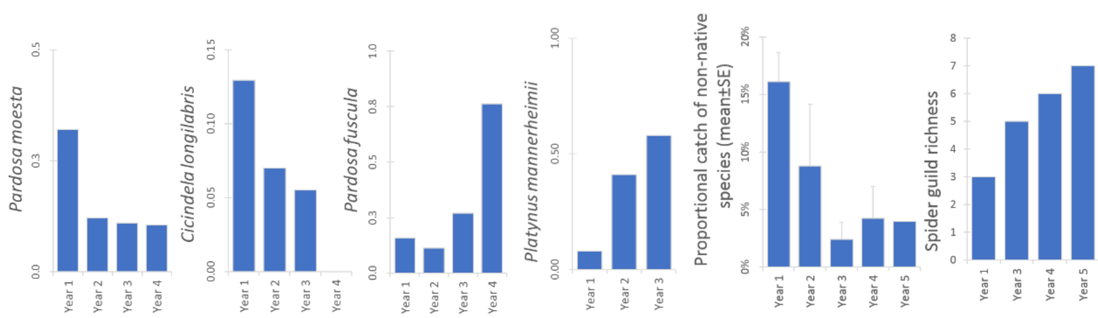

Figure 7. Bar plots supporting trends in species turnover for ground-dwelling spiders and beetles, including turnover of non-native species (all wood removal treatment data, combined) and changes in spider guild richness observed at Valemount Peatland.

Future opportunities

Our ability to assess the success of treatment areas in terms of restoration of the upper elevation bands of the drawdown zone was limited. Variable reservoir operation posed a challenge for long-term monitoring of Kinbasket reservoir. Over the course of the study, the reservoir maximum was lower than in pre-treatment years (2012-2013). Thus, to date, there has not been opportunity to truly test the effect of inundation on the experimental plots. Given the lack of inundation in the plots monitored over time, and the observed increase in vegetation in both treated and untreated areas of the drawdown zone, the measured responses in arthropods is likely reflective of recovery in the absence of inundation. Thus, there is a need for future monitoring to assess the efficacy of wood removal, mounds, log booms, and survival of vegetation after full-pool reservoir events.

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Diversion dams reduce thermal safety margin for amphibian larvae

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Introduction

The life history and physiology of riverine species is fundamentally shaped by natural flow and temperature regimes (Lytle & Poff 1997). During seasonal low flows, river diversion hydropower dams often remove a large portion (up to 90%) of natural streamflow, resulting in reaches with dramatically reduced discharge (Figure 1). Such conditions have the potential to create negative effects for stream biota by changing downstream thermal regimes and either exceeding species thermal performance optima (T_{opt}) or reducing thermal safety margin (TSM) between ambient environmental temperatures and physiological limits (Figure 2).

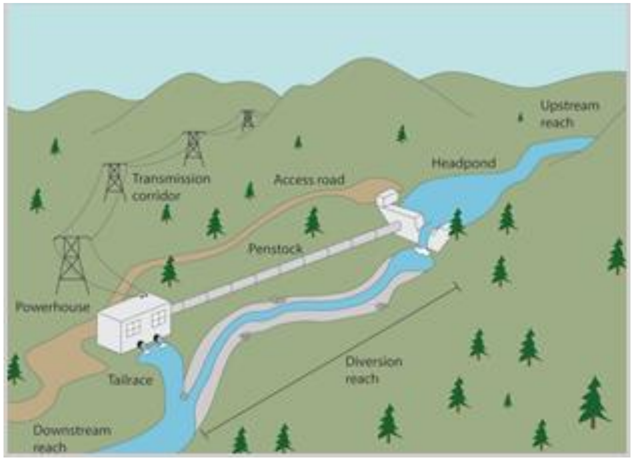
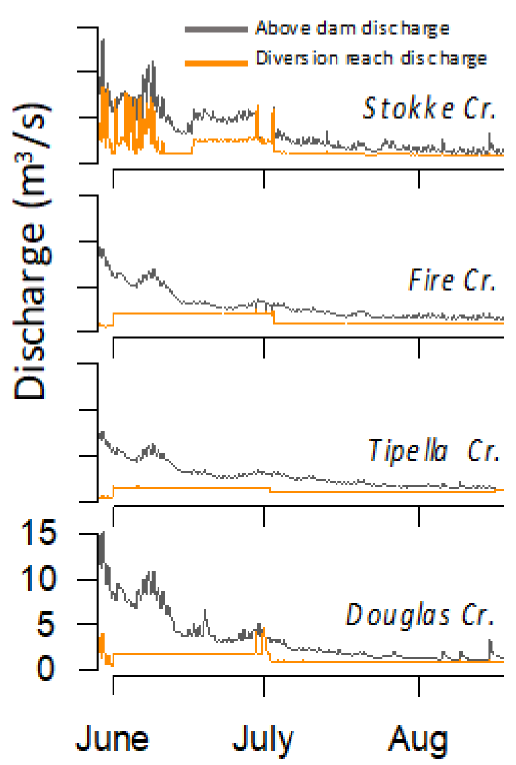


Figure1. River diversion hydro power diverts water to turbines at a lower elevation, which reduces discharge in large stream sections below dams (orange) compared to natural discharges above dames (grey).



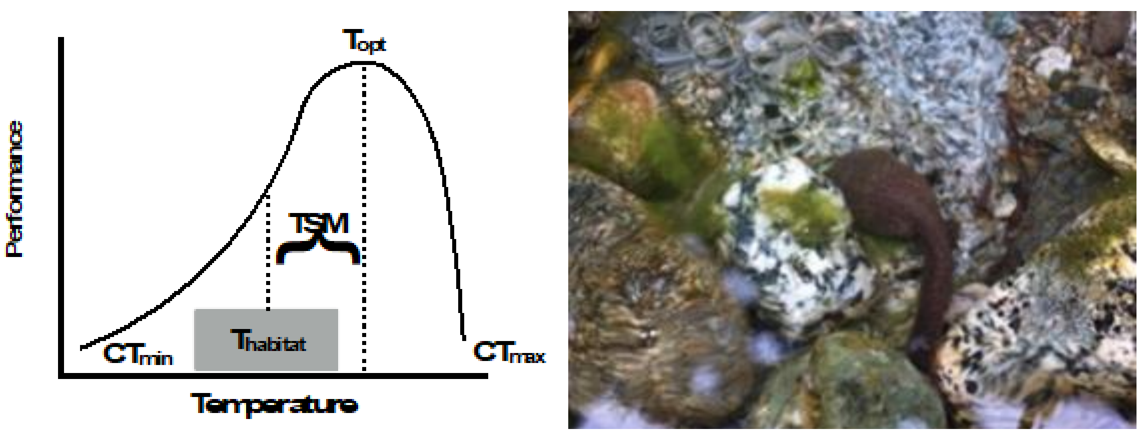


Figure 2. Ecotootherms living in temperatures beyond thermal optimum (T_{opt}) experience added metabolic costs which reduce survival and can cause populations to decline (Dunham & Overall 1994, Sinervo *et al.* 2010). Coastal tailed frog tadpoles live in cold mountain streams which are warming due to climate change and river diversion.

Methods

We quantified the magnitude of warming above and below four diversion dams in British Columbia, Canada, and predicted the impact of dam-induced warming for the thermal performance of Coastal tailed frog (*Ascaphus truei*) larvae. *A. truei* have high overlap with existing and future diversion dams in the region, are listed as a species of "special concern" and spend multiple years in high-gradient streams as larvae. Using laboratory-based thermal performance experiments at six temperatures, we estimated the thermal performance curves T_{opt}, and CT_{max} for three *A. truei* populations. We compared *A. truei* T_{opt} to summer water temperatures – sampled between June and September – measured above and below diversion dams.

Results

Streams warmed naturally at a rate of 0.2°C/km above dams, and warmed directly below dams by 0.2°C, and 0.1°C/km faster than above dams.

We estimated T_{opt} for *A. truei* larva was 19.7°C across all three populations. We found that daily mean water temperatures in the average diversion reach were 0.8°C warmer than natural expected temperature, and that summer temperatures never exceeded T_{opt} in either environment. However, TSM, measured as the difference between observed ambient mean maximum daily temperatures and T_{opt}, was reduced by 5%.

Conclusions

Diversion dams do not currently put A. truei larvae at risk of exceeding physiological thermal limits. However, water diversion-induced warming may be four times greater than climate-induced warming over the past 50 years (Isaak *et al.* 2016). Thus, warming due to water diversion is likely to compound the risk posed to *A. truei* from additional climate-induced warming in the next century.

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Kootenai River burbot, *Lota lota maculosa*, early life stage experimental releases identify recruitment bottlenecks

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Summary:
Burbot (*Lota lota maculosa*) were once abundant in the Kootenai/ay River Basin in Idaho and Montana, USA, and British Columbia, Canada, where they provided important cultural, recreational, and commercial fisheries throughout the basin. However, cumulative effects of habitat destruction and of Libby Dam hydro-power operations since 1972 lead to functional extirpation of the Burbot population by the 1990's. A multi-agency cooperative program lead by the Kootenai Tribe of Idaho (KTOI) and by the University of Idaho Aquaculture Research Institute UI-ARI) has resulted in successful hatchery production of burbot for population restoration. Early successes of the conservation aquaculture program have restored a functioning but still not self-sustaining hatchery-reared population in the river and lake, and have assisted with lab and field research to understand recruitment bottlenecks/failure.

From 2009-2018, the primary life stage at release to restore the population was a 4-month or 6-month post hatch juvenile, which has been a successful strategy. However, since 2015, additional releases of various life stages ranging from 7-d to 60-d old larvae at different times and places have shed light on temporal and spatial aspects of the altered ecosystem that are the likely causes of Kootenai Burbot recruitment failure. Monitoring and Evaluation sampling by Idaho Department of Fish and Game (IDFG), and BC Ministry (FLNRORD) have validated the survival of some of these early life releases. Ecosystem bio-monitoring by the collaborating agencies also monitors the abiotic and biotic conditions, including phytoplankton and zooplankton abundance from April-October. Thus, the multiple programs have collaborated in such a way that has identified proper habitat needs that support early life stages of burbot survival in the altered Kootenai River/Lake ecosystem. In general, this presentation will discuss how the altered hydrograph and thermograph affects general ecosystem function which in turn affects burbot physiology, ecology, and ultimately recruitment.

The Kootenai Tribe of Idaho completed a new conservation aquaculture facility during 2014. The first large-scale burbot rearing at the new facility occurred during 2015, and subsequent annual year classes have been released into Idaho and British Columbia. Much of the restoration strategy has focused on rearing 4-month to 6-month post-hatch

juveniles for release. Total juvenile releases have ranged from 40,000 (2017) – 260,000 (2015); and the juvenile life stage release strategy employed since 2009, with the assistance of UI-ARI from 2009-2014, has resulted in a functional adult spawning stock exceeding the conservation strategy goal of 17,500 sexually mature adults. The restored population consists almost entirely of burbot progeny from the Moyie Lake, BC, population (Donor Population).

In addition to the juvenile release strategy, the Lower Kootenai/y Burbot Working Group has taken advantage of surplus larval burbot that have resulted from better than predicted egg incubation/hatching success during some years. Also, beginning in 2017, the program has developed a second brood-stock spawning strategy that incorporates the now sexually mature hatchery-reared burbot captured from the Kootenai River in Idaho during winter hoop-net surveys. These adults volitionally spawn in-hatchery providing additional fertilized eggs for the recovery program. The two sources, wild-origin Moyie Lake Donor Population, and the hatchery-reared Kootenai River Population, provide a more reliable strategy to begin each year-class rearing-cycle with enough fertilized eggs to reliably meet annual juvenile release recommendations, and to release early life stages in an attempt to identify causation of persistent recruitment failure since 1970's.

Beginning in 2015, the burbot working group decided to strategically release early life stages of burbot across time and space in an attempt to understand the early life ecology of burbot in the altered Kootenai ecosystem. From 2011-2013, early life stages were also released out of necessity due to limited rearing space at UI-ARI. The working group suspected that some of these burbot may have survived given the increasing catch during winter hoop-net surveys, but could not verify. In the meantime, the working group lead by IDFG developed a highly reliable Parental-Based Tagging (PBT) genetic monitoring program. The premise of PBT is that if genetic samples are taken and analyzed for all broodstock, and the adult broodstock crosses are recorded, then the parents of any given group of burbot released would be known. Unique "family groups" are released into specific sites at specific times. Upon recapture of those progeny a genetic sample is collected, resulting in each individual being assigned back to their parents, or their respective "family group". Thus, the release site and release time for any survivor is identified with high confidence. Thereby, via PBT, unique release groups may be used as sentinels to evaluate survival in any given habitat at any given time. In subsequent years, if survivors of those habitats are recaptured and validated by PBT, one may correlate burbot survival with the environmental conditions present at the time of release, or the opposite, the lack of survival identifies the environmental conditions perpetuating recruitment failure. In the case discussed herein, both results have been validated, and have actually been equally important in the overall evaluation of Kootenai Burbot recruitment failure.

During 2016-2018, laboratory studies at the KTOI facility and UI-ARI have further validated that winter temperatures during February to mid-March of 2°C optimize egg survival. The rationale for egg incubation studies is to evaluate probability of egg survival during the variable winter scenarios created by Libby Dam operations in conjunction with recent climate variability. Post-Libby Dam winter river temperatures are warmer than pre-dam natural conditions. Surprisingly, preliminary results suggest that warmer temperatures do not inhibit adult spawning. However, they do confirm the suspicion that warmer than natural winters likely kill burbot eggs spawned in the main river, but tributary spawning may be successful given their colder temperatures. Thus, spawning success hinges on spawning locations selected by the restored population.

Also, beginning in April 2013, KTOI's biomonitoring program expanded their lower-trophic level sampling to include April and May because this time period is when burbot would be expected to hatch, and emerge to become pelagic, planktivorous larvae undergoing rapid development and frequent diet shifts to support that development. It has been well established that 6°C is lethal to younger burbot eggs; however, during late embryonic development, 6°C may trigger egg chorion disintegration leading to hatch typically during late March to mid-April. Burbot free-embryos / newly hatched larvae have very little yolk sac; thus, within 7-10 days post-hatch (dph), burbot develop their mouth and gut in preparation for first-feeding at average temperatures around 9°C. It is also well established that burbot are pelagic planktivores until 45-60 dph; however, the diet preference and selectivity from available prey is not well-known. In the hatchery, burbot are fed brackish Rotifers, smaller sized Artemia, and then larger sized Artemia with success. Therefore, at minimum in the wild, larval burbot require plankton rich habitats with warming temperatures increasing from 6 - 12°C during April - May.

Then in 2015, with the development and proper implementation of PBT, feeding-larvae releases in mid-May targeted the evaluation of whether later spring ecosystem conditions support advanced larval burbot survival. During mid-May 2015, 650,000 60-dph larvae were released, with about 325,000 released near Bonners Ferry, Idaho (rkm 245) and another 325,000 released at the international border near Porthill, Idaho (rkm 170). Subsequent recaptures during the 2017 and 2018 winter hoop-net surveys have confirmed survival from both release sites. However, no survival rate or percentage has been calculated due to necessity for more recaptures over time. But what can be extrapolated is the environmental conditions that supported that survival. Detailed environmental conditions were collected at the time of releases, and suggest that the warmer than average spring supported the proper metabolism and general physiology in combination with the ramping of primary and secondary ecosystem production (food) to support burbot life stage transition from a pelagic planktivore to a benthic generalist around 60-90 dph within the mainstem Kootenai River.

The next early life stage release occurred during mid-April 2017. The rationale for this release was to further reduce the window of potential recruitment bottlenecks/failure. Given that some advanced feeding larvae survived a mid-May release during 2015, the burbot working group decided to release a large group (7,500,000) of pre-feeding, newly hatched larvae into the mainstem Kootenai River during mid-April, a time when temperatures are kept unnaturally colder than historical due to Koocanusa Reservoir thermal dynamics and the extensive diking eliminating off-channel habitats that may provide solar warming of shallow aquatic habitat. Biomonitoring data also exhibits these colder than historical April temperature subdue ecosystem productivity in the main river-channel. To date, no recaptures have been identified from this release; however, this is preliminary given it has only been two years post-release. Also, these younger larvae are the progeny of hatchery-reared adults from previous releases. During 2017, the second broodstock strategy using the now sexually-mature survivors from releases 2009-2015, was initiated and evaluated for feasibility. The result was better than expected, and the larvae were used for this 2017 early life evaluation.

Advancing on the main-river channel releases, the 2018 early life evaluations switched focus to off-channel habitats. Both pre-feeding (mid-April) and advanced feeding larvae (mid-May) were released at the same selected habitats, Nimz Project, a KTOI property with restored floodplain reconnection to the main river at rkm 221, and the side channel of Ferry Island at rkm 205. At the Nimz Project, approximately 750,000 pre-feeding larvae from unique family groups were released mid-April, and another 750,000 feeding larvae from unique family groups were released before river levels rose to reconnect and maintain reconnection from late-May to mid-June. It will be several years before determination as to whether burbot out-migrated during the reconnection and drawdown; however, KTOI staff confirmed that some pre-feeding and feeding larvae survived and thrived within the floodplain habitat. The recaptures did not out-migrate and remained after dis-connect from the flow reduction to summer flows. During August, KTOI staff recaptured 138 burbot. Length, weight, and a fin clip for PBT analysis were collected for each recapture. These data showed that some pre-feeding and feeding larvae survived post-release; and even more interesting, pre-feeding larvae survivors grew twice as large as the feeding larvae, and three times that of the year class remaining in the hatchery until August. These results suggest that off-channel habitats provide basic habitat requirements, and are likely considerably more suitable than the main-channel; and that the earlier the burbot are released in a habitat conducive to survival, a more rapid growth trajectory results and is maintained through life. This has also been corroborated from the recapture data from the above discussed 2015 early life releases. Environmental data was also collected at these habitats at multiple trophic levels for correlation of what conditions support burbot early life survival, and may be compared between the off-channel and main-channel. Further, 1,500,000 pre-feeding and 2,000,000 feeding larvae were released at the Ferry Island side channel. It will be several years before any survivors may be available to be recaptured in the winter hoop-net surveys, allowing for evaluation of these family groups' survivorship.

In conclusion, the development of a reliable Parental-Based Tagging program has provided a valuable tool to evaluate recruitment bottlenecks leading to persistent recruitment failure. The preliminary results from the multiple early life stage releases suggest that egg survival during February and March will be highly variable due to annual climate and Libby Dam operations variability. If the eggs do survive, the month of April is likely a leading cause of mortality and persistent recruitment failure due to the main-channel and tributary main-channels remaining too cold to support proper burbot metabolism and development while simultaneously subduing ecosystem productivity during the burbot time of first-feeding. Given the pelagic, planktivorous life strategy of burbot, habitats devoid of timely plankton blooms in synchrony with their hatch, and subsequent physiological development will maintain persistent mortality at a scale that perpetuates recruitment failure. The ecosystem scale causation of this dilemma is the altered dynamics caused by Libby Dam in conjunction with the widespread diking of almost all of the main channel and tributary channels disconnecting the floodplain and off-channel habitats. The altered temperature regimes leading to physiological issues and greatly reduced plankton densities in main-channels where burbot early life stages will likely reside are a major bottleneck. Given the results of the Nimz Project releases, the restoration of connections and functioning of transport processes to off-channel habitats is the most likely remedy to persistent burbot, and possibly other species, recruitment failure given limitations on Libby Dam operations and dike removals.

We would like to thank the Bonneville Power Administration for funding much of the work described herein. We greatly appreciate all of the work and dedication of our staff at KTOI, and all of the co-managing agencies' and entities' staff. Without the extensive collaboration of all of the agencies, and the programs within the agencies, we would not be able to conduct such a novel approach to ecosystem-wide issues. Finally, we would like to thank the Columbia Mountains Institute for creating the venue to disseminate this information in order to assist others facing similar situations, and hopefully help advance their efforts to reverse the overall trend of declining natural resources.

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Wildlife habitat and opportunities for restoration in the drawdown zones of hydroelectric reservoir

Presenter: **Virgil Hawkes**, LGL Ltd. Environmental Research Associates
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Abstract

The drawdown zone of a hydroelectric reservoir is a challenging environment for plants and animals, particularly when the annual change in reservoir elevation averages 25 m. Flooding and flow alteration resulting from reservoir creation and operations combine to create complex disturbances that can modify entire ecosystems. To assess and potentially mitigate for the varied effects of reservoir operations on wildlife and wildlife habitat occurring in the drawdown zone of Kinbasket Reservoir in southeastern, British Columbia, BC Hydro implemented several longer-term programs to study the occurrence and distribution of select species of wildlife using habitats in the drawdown zone. The objectives of the programs are to understand how reservoir operations affect wildlife and wildlife habitat and whether various mitigation measures can increase the cover and diversity of vegetation growing in the drawdown zone, resulting in improvements to wildlife habitat suitability. A summary of work conducted between 2007 and 2018 highlights some of the challenges associated with a program of this magnitude, particularly as they relate to the somewhat predictable, but varying effects of changing reservoir elevations. The results to date of the various revegetation prescriptions, physical works trials, and vegetation and wildlife effectiveness monitoring projects are summarized and a discussion of the data gaps and lessons learned is provided.

Introduction and Background

The drawdown zone of a hydroelectric reservoir is a challenging environment for plants and animals, particularly when the annual change in reservoir elevation can average as much as 25 m. (Figure 1). Flooding and flow alteration resulting from varied reservoir operations create complex disturbances that can modify entire ecosystems, with effects extending upstream and downstream of the dam. Currently, little is known about the influence of dam operations on the structural and functional components of the terrestrial and semi-terrestrial plant communities that establish on reservoir shorelines within the zone of water level fluctuation (i.e. the drawdown zone). In 2007, BC Hydro initiated a monitoring program (CLBMON-10) to assess the distribution and spatial extent of existing vegetation communities in the drawdown zone of Kinbasket Reservoir. The results of that study indicate that substantial portions of the drawdown zone are vegetated to some degree, with habitats higher in elevation associated with a higher cover of vegetation and increased species richness and diversity (Hawkes and Gibeau 2015).

Despite this, vast areas of the drawdown remain sparsely vegetated or completely devoid of vegetation. Several factors contribute to this lack of vegetation including the timing, duration, and frequency of inundation, substrate type, soil moisture and nutrient regimes, erosion and deposition of sediment associated with wave action and reservoir flows, and wood debris accumulation and scouring.

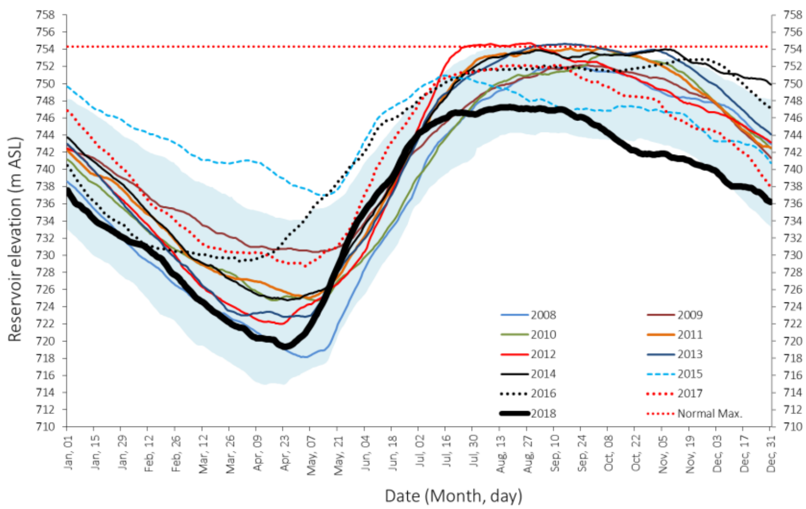

Figure 1. Kinbasket Reservoir elevations 2008 through 2018. The shaded region delineates the 10th and 90th percentile in reservoir elevation (1977 to 2018).

To mitigate for the varied effects of reservoir operations on vegetation establishment and development in the drawdown zone of Kinbasket Reservoir, BC Hydro implemented CLBWORKS-1, a 10-yr, reservoir-wide restoration program to enhance sustainable vegetation growth in the drawdown zone of Kinbasket Reservoir for ecological and social benefits (BC Hydro 2007). Between 2008 and 2011, a total of 69.15 ha in 19 treatment areas in the drawdown zone of Kinbasket Reservoir was planted by Keefer Ecological Services (Keefer et al. 2007, 2008, 2010, 2011). Eight different revegetation prescriptions were applied during this time, but plug seedling treatments, particularly those involving Kellogg's sedge (*Carex lenticularis*) alone or mixed with other species, dominated the planting regime (Hawkes et al. 2013). CLBMON-9, an effectiveness monitoring study of the revegetation efforts, occurred between 2008 and 2013 (Yazvenko 2008; Hawkes et al. 2013). The results of CLBMON-9 indicate that the revegetation program was associated with varying degrees of success and did not contribute to enhancing sustainable vegetation growth in the upper elevations of the reservoir.

More recent efforts to enhance the vegetation in the upper elevations of Kinbasket Reservoir appear to have achieved greater short-term success. For example, larger sedge plugs (i.e., larger than those used between 2008 and 2011) planted at an ecologically suitable site in Bush Arm in 2013 (Adama 2015) and a log boom installed around a wetland in the Valemount Peatland following the clearing of wood debris in 2014 have both contributed to either an increased cover of vegetation (sedge transplants) or the re-establishment of native vegetation in drawdown zone (wood removal and protection with a log boom).

In 2015, a physical works trial was initiated to test the efficacy of mound and windrow[1] creation to function both as a receptor site for revegetation (live stakes and sedge plugs) and to protect habitats cleared of wood debris, which should promote the natural re-establishment of vegetation in the drawdown zone. The physical works prescriptions implemented in Bush Arm of Kinbasket Reservoir during fall 2015 are discussed in Hawkes (2016). The physical works included the removal of wood debris, the use of wood debris to construct mounds, and the removal of wood from existing ponds in the drawdown zone (Figure 2). If successful, these physical works could function to increase vegetation cover and in turn help improve aesthetics, control dust, contribute to the protection of known cultural heritage sites from erosion and human access, enhance littoral productivity, and create wildlife habitat. The enhancements align with BC Hydro's Water Use Plan Consultative Committee's (WUP CC) support of a reservoir-wide planting and enhancement program in lieu of operational changes.

Figure 2. Before and after photos of pond clearing and cleanup at the Bush Arm Causeway north location. Note the positioning of a large sill log in the top right. The bottom panels are of the same pond, but from different perspectives to show the wood accumulation (bottom left) and cleaned pond (bottom right) with the retention of peat islands.

[1] A mound is defined as the systematic piling of wood debris and substrate into a tetrahedron-shaped pile. A wind row is similar to a mound, but is more linear in shape.

The areas treated in 2015 were evaluated in 2016 (spring, summer, and fall) for erosion, live stake survival, and sedge transplant survival following the winter. Live stakes planted in fall 2015 survived much better than those planted in the spring of 2016 (~ 93 per cent survival vs. 20 per cent). Overall, ~ 71 per cent of the live stakes planted were surviving up to one year following planting. All sedge transplants survived (i.e., 100 per cent survival achieved). Due to lower than expected reservoir elevations between November 2015 and October 2016, we were unable to assess the effects of reservoir inundation on the integrity of the mounds. This will have to wait until reservoir elevations exceed 753.5 m ASL. To protect wetland habitats and wood debris mounds at the Bush Causeway North site, a 312 m long log boom was installed in June 2016. The log boom should function to ensure wood debris doesn't deposit on the recently cleared wetlands and degrade the interiority of the mounds.

Performance measures generated following the implementation of the physical works in fall 2015 were assessed in 2016. Overall, the removal of wood debris from the drawdown zone and wetland habitat as a habitat enhancement technique appears to have great potential. Not only can the wood debris be used to construct mounds in the drawdown zone, thereby increasing topographic heterogeneity, but the removal of the wood from the drawdown zone promotes the natural establishment of vegetation. Revegetating of the mounds involved the use of live stakes as a means to expedite the revegetation process, but as with the areas cleared of wood debris, native vegetation also began to establish on the mound. This emphasizes the utility of wood removal and mound creation as a tool to increase the cover of vegetation in the drawdown zone of Kinbasket Reservoir. Despite these early signs of success, additional data are required before the widespread removal and mounding of wood is considered for Kinbasket Reservoir. The mounds and cleared areas need to be inundated by Kinbasket Reservoir so that the integrity of the mounds can be assessed following inundation and to determine if additional wood will deposit on those previously cleared sites.

Acknowledgements

Funding for this work was provided by BC Hydro.

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Deer Creek Drawdown Zone Fish Habitat Rehabilitation: A Pilot Project for Lower Arrow Lakes Tributary Kəkni (Kokanee) Access Improvements 2015 - 2018

Presenter: **Evan Smith**, Okanagan Nation Alliance, Castlegar, BC
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Presentation Summary

The Arrow Lakes Reservoir (ALR) was created as a result of the Columbia River Treaty (1964) and construction of Hugh Keenleyside Dam (1968). The reservoir is approximately 230 km long and has a footprint of 51,270 ha. The reservoir is home to both recreational and listed fish species including x^{w}mina? (Rainbow Trout), kəkni (Kokanee), c'm'tus (White Sturgeon), (aye che) Bull Trout, spəq^{w}lic (Burbot) and, prior to 1942 with the construction of Grand Coulee Dam, anadromous salmon. The ALR can fluctuate 20 m between high and low pool annually. The area within the reservoir between high and low pool is referred to as the drawdown zone (DDZ). At high pool, the ALR inundates 2,073 ha of low elevation river and stream habitats. At low pool many of the ALR tributaries braid in the DDZ resulting in low water depth and little cover and protection from predators. As such, migration through the DDZ during low pool can be difficult for fish at certain tributaries, particularly for kəkni, as the typically spawn when the reservoir is low (September - October).

Deer Creek is a tributary to the Arrow Lakes Reservoir regulated by Hugh L. Keenleyside Dam on the Lower Columbia River in BC, Canada. Presently, Deer Creek is an important spawning stream for kəkni and provides habitat for xwmina?. When reservoir levels drop due dam operations, a significant portion of Deer Creek becomes exposed within the drawdown zone. This section is susceptible to braiding with little riparian and instream cover, which are important components for spawning Kokanee. Residents of Deer Park voiced their concern of insufficient water depth, and lack of cover resulting in predation of migrating Kokanee. Michael Zimmer (Okanagan Nation Alliance) conducted a spawning survey in 2013 at Deer Creek. The only Kokanee observed within the DDZ were holding under (or near) the few remnant root wads which remained in the creek. This observation, paired with Mr. Zimmer's observations of Tate Creek; where a larger number of root wads were present and appeared to reduce channel braiding through the DDZ by providing bank structure, provided the base inspiration for enhancement (improvement of current conditions) efforts on Deer Creek.

The proposal to enhance habitat and kokanee migration through the DDZ and into Deer Creek aligned with Arrow Lakes Reservoir Fish Priority number two in the Fish and Wildlife Compensation Program's (FWCP) Large Lakes Action Plan which includes increasing kəkni fishing opportunities in the Upper and Lower Arrow Lakes Reservoir by

improving access to spawning habitat. With the financial support of the FWCP, the Okanagan Nation Alliance (ONA) developed a two-phased pilot prescription to improve Kokanee access to Deer Creek.

Prior to fieldwork permission from relevant landowners was required. This included a License of Occupation from BC Hydro, permission from the Ministry of Transportation and Endorsement, and a Section 11 Permit (Change Approval; Water Sustainability Act 2016) from the Ministry of Forest Lands and Natural Resource Operations (currently Ministry of Forest Lands and Natural Resource Operations and Rural Development [MFLNRORD]).

The project was proposed in two phases: Phase I (2015) included the section of the DDZ originating at the high-water mark and ending approximately 100 m downstream, while Phase II (2017) was to continue from the end of Phase I works downstream another 100 m to an old bridge cribbing. The primary goal of the project was to add in-stream cover and increase water depth to define a single channel within the drawdown zone in order to improve kəkni migration. Structures consisting of large-woody debris anchored by large rock were used to define a bankfull channel and protect streambanks. Due to permit constraints which prohibited the use of cable in habitat structures (out of concern of public risk and exposure), woody debris were pinned with an abundance of large ballast rock. Several structures were created with the intent to improve holding/resting habitat within the low-flow wetted width. Most structures served both these purposes. Natural channel design principals were used in the design of fish habitat structures by utilizing upstream wetted and bankfull widths, sinuosity, parent creek-bed material, and channel slope as reference for the newly-defined, single stream channel. The new channel was designed to mimic a riffle-pool system in order to provide habitat associated with resident kəkni spawning and rearing requirements.

To monitor, pre- and post-enhancement maps were developed through a topographic survey to depict constructed habitat features. These maps show each structure's position within the drawdown zone and relative three-dimensional measurements. These maps, along with photo documentation, provide information regarding structure stability and function for both Phase I and II. The components of each structure and their order of placement within the stream were also documented for monitoring purposes. If a structure fails, we can reference this information to identify any potential limiting factors (wood volume by anchoring rock size). Kokanee counts from the MFLNRORD and observations of general use and migration success were monitored annually (to 2018) by volunteers from the Deer Creek Water Uses Group and opportunistically by the ONA. Since kəkni typically spawn in their fourth year, the impacts of this project may not be apparent until the year 2020 when kəkni hatched at Deer Creek in 2016 will return to spawn. Spawning survey data collected by the MFLNRORD from 1966 to 2016 will be used as a baseline to compare pre/post-treatment relative spawning success in Deer Creek. Data from future spawning surveys will be compared with this baseline data, while considering seasonal variability, to evaluate the project's success.

In total 19 structures were created within 180 m of DDZ. These structures included wood, root-wad and boulder anchored structures, root structures ballast by boulders, and boulder-lined banks. Boulders used to anchor large wood were an average diameter of 1.20 m b-axis. Three or four of these boulders were used on each wood component, and additional 40 – 60 cm size rock was used as fill. Minor excavation took place in front specific structures to increase the wetted width depth profile.

Preliminary post-construction observations have been positive: few components of the habitat structures have been lost to freshet and reservoir inundation, the single channel has remained stable and has become more defined over time due to habitat structures acting as a catalyst for sediment though reservoir deposition, and kəkni have been observed preferring cover habitat in the treated section vs untreated areas of the DDZ. Kəkni spawning among structures within the DDZ has been documented, indicating the structures have aided in gravel deposition and supporting cover.

The core purpose of this study was to test a treatment which could potentially enhance ALR tributaries capacity to provide kəkni spawning habitat through increased migration success. The ONA is attempting to replicate this preliminary success through a similar project at Eagle Creek (Edgewood, BC); an ALR tributary which is far more dynamic than Deer Creek, in an effort to identify the versatility of this treatment to other ALR tributaries. This pilot study is still relatively young and additional replication, evaluation, and monitoring is required to determine the effectiveness of this treatment.

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Understanding the ecology of recovery in reservoirs across southern British Columbia

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Presentation Summary
Hydropower generation sometimes results in large annual fluctuations in reservoir water levels, which constrains the establishment and growth of vegetation within the reservoir drawdown zones. By understanding the ecology of vegetation recovery in reservoirs across BC, we can improve the revegetation of the sometimes-vast and barren drawdown zones within these managed ecosystems.

Conditions for vegetation in the reservoirs can be challenging. Typically, reservoirs fill to capacity during the spring as the snow melts, inundating vegetation within the reservoir. Plants growing within this inundation zone must grow quickly, then survive flooded conditions until the fall when water levels begin to drop. Due to the long inundation period, soils in the reservoirs may become anoxic (have low oxygen levels). Waves can erode the soils and vegetation, disturb germinating seeds, or reduce nutrient availability. Floating woody debris can also abrade or smother vegetation as the water draws down. Finally, as water levels are drawn down, plants are left exposed, sometimes for long periods and must endure drought-like conditions.

Figure 1-1 Typical drawdown zone with steep slopes and coarse substrates.

Another challenge to vegetation establishment is the steep slopes and course soil textures in drawdown zones (Figure 1-1). Slopes can be unstable, causing low germination rates, and have limited soil moisture retention because the course textures are rapidly draining. Overall, these factors limit plant growth and survival during low water.

Ecology is greatly influenced by local climate and elevation. BC's large reservoirs are in a variety of biogeoclimatic units (i.e. regional climate units that are deduced from vegetation, soils, and topography, applied to geographic areas that have relatively uniform climate). The Kinbasket Reservoir spans 195 km running northwest to southeast and covers three different Biogeoclimatic zones along its shorelines (Figure 1-2). As well, extreme weather conditions due to climate change also influence the timing and duration of inundation periods, water temperature, from the surrounding landscape, all of which affect reservoir ecology.

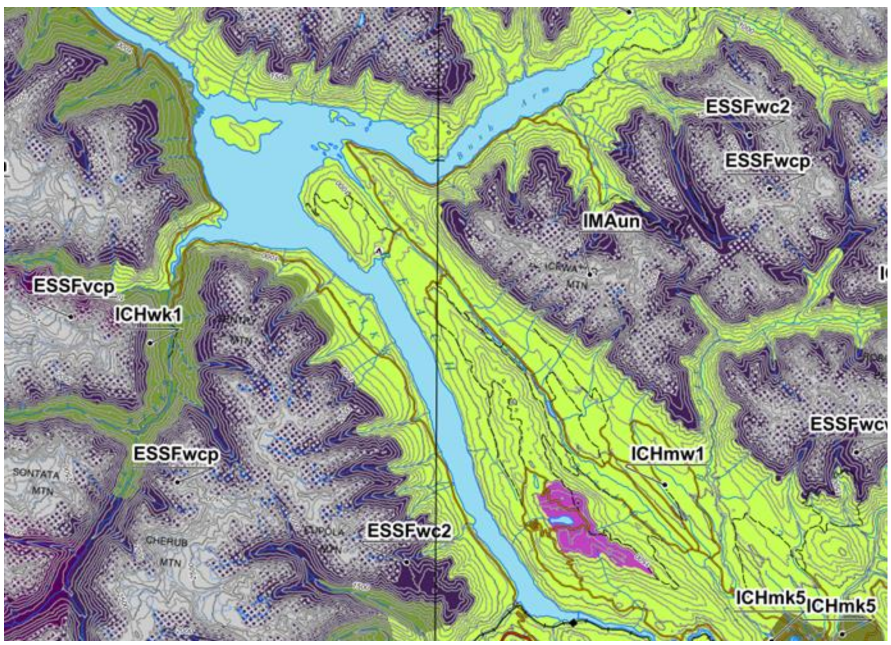

Figure 1-2 Biogeoclimatic subzone variants around the Kinbasket Reservoir

Another aspect to the ecology of recovery is reservoir management and operations (Figure 1-3). Water level management and operations must shift to adapt to the implications of climate change. Because of climate change, water inputs into these systems is changing. Higher temperatures in the summer and winter cause increased drought in the summer and precipitation falling as rain during the winter. Increased winter rainfall increases water levels over the winter months to higher than are typical. Earlier snowmelt causes an increase in water levels in early spring as vegetation is initiating growth. The necessary changes in operations to respond to these issues could affect ecosystem recovery by shortening the growing season, increasing drought and other stresses. In general, weedy species are more tolerant of stressful conditions and are more likely to become established than the more desirable native species (i.e. sedges) which may limit the diversity of species to create a resilient ecosystem.

Our growing understanding of reservoir ecology, which relates to vegetation species establishment and climate, is being used to improve the success of reservoir revegetation programs. Through trial and experience, we are learning how to revegtate targeted areas. Options for ecologic recovery are better understood by looking at all novel ecosystems established under similar conditions (elevation, slope, aspect and soil substrate) within different reservoirs across BC.

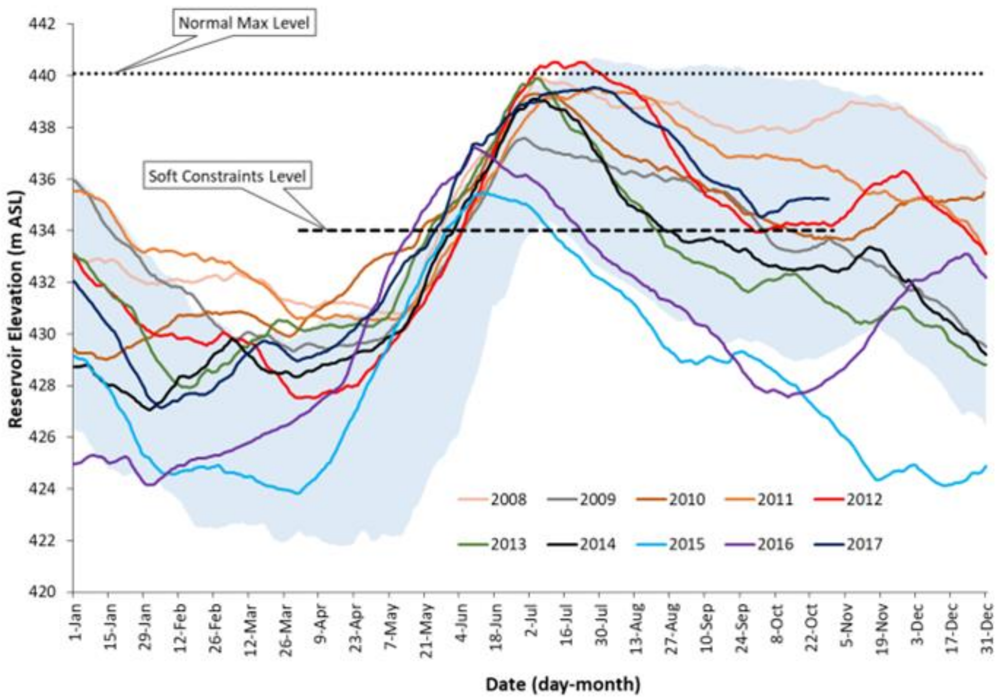

Figure 1-3 Daily water levels in Arrow Lakes Reservoir shown by year for 2008-2017

Figure 1-3 Credit: Miller, M.T., P. Gibeau, and V.C. Hawkes. 2018. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Final Report – 2017. LGL Report EA3545C.

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Regreening a semi-barren reservoir drawdown zone: intractable challenge or achievable dream?

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Abstract (Miller et al. 2018)
The Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis (CLBMON-12) is a Water Licence Requirement project initiated in 2008 to assess the effectiveness of revegetation treatments applied to the reservoir drawdown zone between 2009 and 2011 under the CLBWORKS-2 program.
The primary objectives of this study were: (i) to assess the short-term effectiveness of the revegetation program at expanding the quality (as measured by diversity, distribution and vigour) and quantity (as measured by cover, abundance and biomass) of vegetation in the drawdown zone within the 434 to 440 m ASL elevation band; and (ii) to assess whether revegetation establishment is facilitated by the implementation of the Water Use Plan operating regime (2007-2017), including soft constraints.[2]

Prior to 2017, data collection entailed resampling vegetation composition and cover within previously established and monitored long-term plots stratified by region, elevation band, and treatment type (Miller *et al*. 2016). For 2017, we expanded the scope of sampling to include an array of CLBWORKS-2 treatment areas (mapped polygons) not previously covered under the CLBMON-12 monitoring scheme. At each new

[2] Soft Constraints are operational targets developed by the Columbia Water Use Planning Consultative Committee (WUP CC) for the benefit of various interests (vegetation, wildlife, fish, culture and heritage, recreation, erosion, and power generation). Each target identifies the ideal/preferred reservoir operations (water level over the year) for a specific interest. While the reservoir was not operated to target specific soft constraints, the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2017, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 47% of the time.

polygon, as well as at polygons already containing permanent plots, we established from one to seven (depending on polygon size and habitat heterogeneity) new "survivorship" plots. The plots were situated semi-randomly within representative revegetation areas. At each survivorship plot, we recorded the numbers of surviving individuals associated with each CLBWORKS-2 revegetation treatment. These totals were subsequently used to generate survival rate estimates for specific species, sites, and planting methods (e.g., seedlings versus live stakes) based on the reported initial planting densities provided by the CLBWORKS-2 annual reports and associated databases

Our overall conclusions are consistent with those reached following previous study years (Enns and Overholt 2013, Miller *et al.* 2016): revegetation efforts to date have achieved mixed success. A portion of the stock (primarily Kellogg's sedge, Columbia sedge, and black cottonwood) planted between 2009 and 2011 has survived and taken root and, in limited areas, is growing vigorously. An estimated 76 per cent of treated polygons, representing about 82 ha of drawdown zone habitat, support at least some surviving transplants. The plantings in these areas may now be providing some ancillary ecological services such as increased erosion control, browse for waterfowl, and perching habitat for birds. For about one quarter of the treated areas (approximately 26 ha), survival of plantings has been minimal to non-existent.

Multivariate analyses identified site, vegetation community type (VCT), and rooting zone soil texture as potentially important predictors of transplant establishment success and long-term survivorship. Elevation within the drawdown zone (which may be regarded as a proxy for operating conditions since low elevations are inundated earlier, for longer periods, and to greater depth than high elevations) was a less informative predictor of revegetation performance.

In several areas, survival of plantings has been minimal or has failed. Failures can probably be ascribed to a combination of environmental factors including prolonged inundation, infertile or unstable substrates, wave action and erosion/deposition, soil moisture deficits, ATV traffic and other forms of human disturbance, and herbivory. In areas where revegetated plants have taken hold, a lack of new recruits indicates that ecological filters preventing natural succession have not been adequately addressed and suggests that revegetated populations may not be self-sustaining over the long term. These areas may require additional physical works (i.e., site alterations such as tilling, diking, windrows, mounding) or repeat planting entries to maintain the presence of vegetation over time.

At the community level, treatments have resulted in some local increases in species cover and richness, both via infill planting of graminoids (primarily sedges) and shrubs (primarily black cottonwood) in previously vegetated habitats, and through the introduction of these taxa into otherwise unvegetated microsites. Surviving sedge plugs (primarily those of Kellogg's sedge and Columbia sedge) have contributed sporadically to the ground cover at various locations, while in areas such as 12 Mile (Revelstoke Reach) and Lower Inonoaklin (Arrow Lakes), planted cottonwood stakes have successfully taken root and now form small leafy stands several metres in height. Soil textures on favourable microsites ranged from loamy to sandy to fragmental, and were usually well-drained.

Despite a statistically significant increase in shrub cover between treated and untreated sites for certain habitat types such as PA (redtop upland), the overall contributions from revegetation have not led to statistically significant changes in terms of species composition, richness, or diversity. This could be because not enough time has elapsed since treatments were applied for successional effects to manifest themselves (particularly in the case of developing cottonwood stands). Nevertheless, it is becoming evident that for many barren regions of the drawdown zone, additional physical modifications aimed at ameliorating site conditions will likely have to be applied in concert with repeated planting interventions if lasting community changes are to be achieved.

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Enns, K., and J. Overholt. 2013. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis: 2013 Draft Report. Unpublished report by Delphinium Holdings Inc. for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 65 pages.

Miller, M.T., P. Gibeau, and V.C. Hawkes. 2016. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Annual Report – 2015. LGL Report EA3545. Unpublished report by Okanagan Nation Alliance, Westbank, BC, and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Castlegar, BC. 55 pp + Appendices.

Acknowledgements: This was a BC Hydro-funded and managed project. ONA (Okanagan Nation Alliance) was the primary contractor on the project from 2014 to 2018. Delphinium Holdings Inc contributed to the original study design and led the initial research from 2008 to 2013.

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Reservoir Regulation and Vegetation in the Draw-down and Delta Zones of the Duncan Lake Reservoir, British Columbia

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What happened?

The Duncan River provides the northern inflow into Kootenay Lake and was dammed in 1967 with the Duncan Dam, the first dam that followed the Columbia River Treaty between Canada and the United States. This earth-fill dam is 40 m tall and imposes an annual 30 m (100 ft) rise and fall in the level of the upstream reservoir (Figure 1). The dam is operated to trap inflow and fill the reservoir each spring and thus attenuate the peak in order to reduce flooding downstream along the Columbia River. The reservoir is full through much of the summer, and then drawn down through the winter season, to enable hydroelectricity generation when power demands are highest. There is no hydroelectric facility at the Duncan Dam but the released water flows through seventeen hydroelectric dams downstream along the Kootenay and Columbia Rivers.

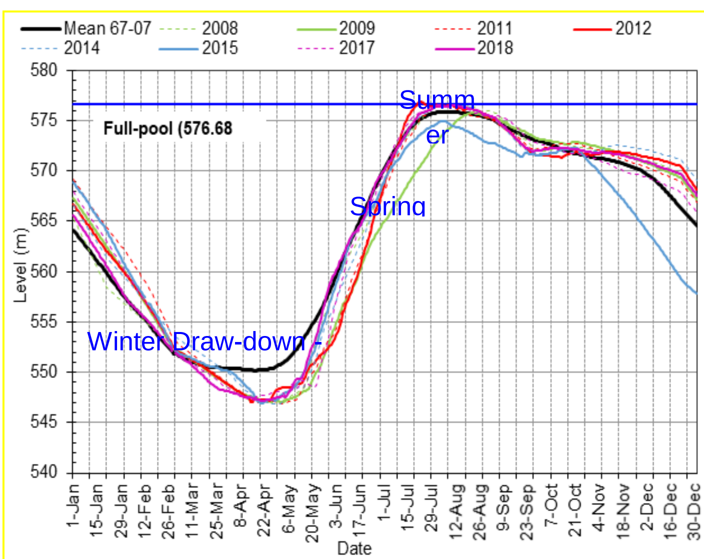

Figure 1. Annual patterns in the level of the Duncan Reservoir, with the average for the post-dam interval up to 2007, and then yearly patterns after the implementation of the new regime, Alt S73. There has been ~30 m annual fluctuation with draw-down through the winter and refilling into the summer (modified from Polzin and Rood, 2019).

What's new?

Following the Duncan Dam Project Water Use Plan (WUP), a new operational regime, Alternative S73 (Alt S73), commenced in 2008. This was intended to benefit riparian woodlands and fish along the lower Duncan River, downstream from the dam. This also resulted in changes in the patterns of reservoir draw-down and fill, which was predicted to decrease the suitability for vegetation around the reservoir. However, the actual changes in the annual patterns of reservoir drain and fill were relatively slightly changed over the decade following Alt S73 (Figure 1).

What we did.

To explore the consequences of the new, Alt S73 reservoir regime, we analyzed aerial photographs and undertook field studies in 2009, 2012, 2015 and 2018 to assess surface conditions and vegetation. We inventoried vegetation within the upper 10 m draw-down zone at 12 sites at alluvial fans from creek outflows, which would provide more favorable locations for riparian vegetation. Supporting the prediction, we found a decrease in vegetation; some areas that were sparsely vegetated in 2009 were relatively barren by 2018 (Polzin and Rood, 2019).

Species richness, the number of plant species, was highest near the full-pool shoreline and this band included shrubs and trees, including black cottonwoods (*Populus trichocarpa*). Within the draw-down zones that were inundated annually, the primitive plant, common horsetail (*Equisetum arvense*) was the most abundant species. The vegetation patterns at three year intervals are reported, and a final report coordinates the ten-year findings (Polzin et al., 2010; Polzin and Rood, 2013, 2016, 2019). These provide effective hydrogeomorphic models for vegetation cover (abundance) and richness (diversity), which consider the site locations, elevations and associated exposure durations, substrate texture and surface slope. Thus, vegetation in the reservoir draw down zones was sparse and followed somewhat predictable patterns based on the physical environment.

What was lost?

The Duncan River is within the Purcell Trench and along much of its length, steep rocky mountain slopes drop directly into the relatively narrow, 1.5 to 2 km wide river valley. Prior to damming, the valley included the 25 km long Duncan Lake, and extensive wetlands and riparian zones in the Duncan River valley downstream and especially upstream of that natural lake (Figure 2). Following damming, upstream flooding elevated the natural lake surface, and created the 45 km long Duncan Lake Reservoir ('Duncan Reservoir'). This inundated zones with the river and its biodiverse riparian floodplain, ecologically rich areas with inflows from the tributary creeks, and extensive wetland complexes with braided stream channels, shallow ponds and rich and diverse riparian woodlands. This loss of wetlands with the Duncan Reservoir was proportionally much more extensive than for the other regional reservoirs (Utzig and Schmidt, 2011).

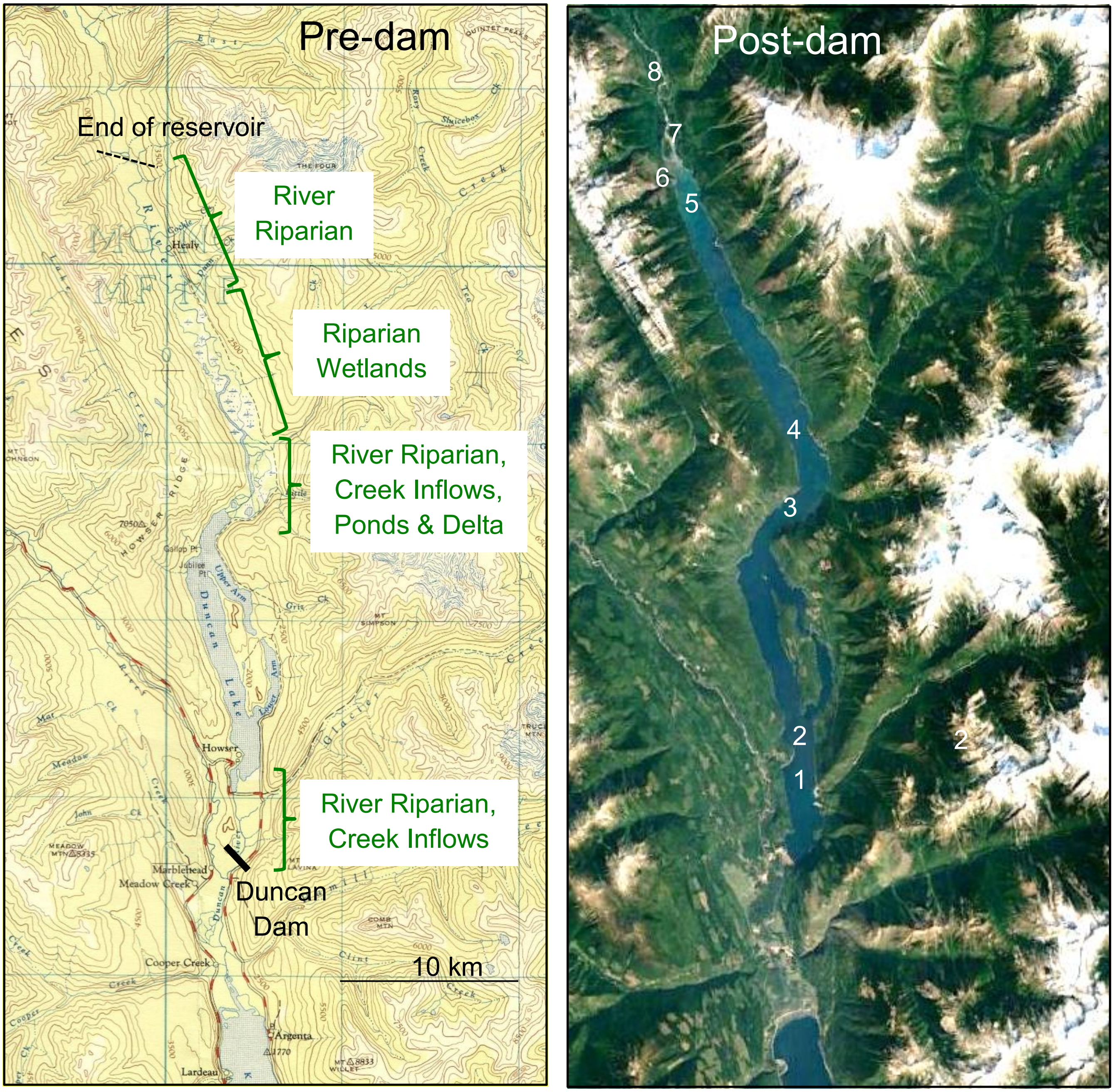

Figure 2. (left) Pre-dam conditions along the Duncan River valley displayed in the 1959 Canadian Surveys and Mapping Branch topographic map from 1953 air photos (82K Lardeau, 1:250,000, 500 ft contours) versus the filled Duncan Reservoir (Google Earth, Landsat composite, 2016), with numbers for photograph locations that follow.

What are the current conditions along the Duncan Reservoir?

Through the summer interval of July and August, when recreation use is highest, the Duncan Reservoir is near full pool, with the water approaching the ring of coniferous woodland persists around the reservoir from the pre-dam interval. The reservoir is drawn down through the autumn and especially the winter season to the lowest levels in early May and these are displayed in the ground level photos that follow, with numbering as in Figure 2.

Figure 4. Photographs of the Duncan Reservoir at full draw down (May 7, 2019). (1) The alluvial fan at Glacier Creek, with an extensive area this is only slightly below the full pool elevation. (2) Sloping bank and boat launch near the town of Howser. (3) A steep slope drops directly into the former Duncan Lake and the draw down zone provides a near-vertical bedrock band. (4) Perhaps the greatest ecological loss was the wetland zone upstream of the prior lake. Here, Howser Creek inflows from the left and will join the Duncan River along the right bank. The wetland zone was quite flat along the transverse (valley wall to valley wall) and longitudinal (along river corridor) axes, and surface sediments were finer, with fewer large trees (stumps following clearing).

Figure 5. More photographs of the Duncan Reservoir, extending upstream (northward, 5 & 6 May 2019). (5) The elevation of the reservoir bottom progressively increases to the upstream end and consequently the depth and interval of inundation decline. Associated with this, vegetation increase as with this fairly complete ground cover of grass. (6) Puddingbowl Creek (study Site 13, aerial view) provides the most upstream inflow and its alluvial fan supports abundant shrugs and trees. Extending into the inundated zone, horsetail (*Equisetum arvense*) was prolific. (7) The most abundant woody vegetation was situated at the upstream end of the reservoir with the inflow delta from the upper Duncan River (aerial view with the reservoir near full pool, July 2018). This delta zone included braided distributaries from the river, which created a mosaic of wetland and riparian patches with abundant cottonwoods, willows (*Salix* species) and alder (*Alnus incana*) and could be deserving of conservation such as through ecological reserve designation. (8) Upstream from the delta, the upper Duncan River is free-flowing and relatively pristine (July, 2018).

Could vegetation be enhanced around the Duncan Reservoir?

Yes, but there would be costs and trade-offs. And due to irreversible influences such as introductions of non-native plant species, even with the removal of the Duncan Dam, the reservoir zones would not fully return to the natural complex of riparian woodlands and wetlands that existed prior to the clearing and flooding in the 1960s. More favorably, relatively slight changes in the reservoir level patterns might benefit some vegetation and particularly perennial woody shrubs and trees such as cottonwoods and willows (*Salix* species), which are especially important for wildlife habitat, and benefit the broader riparian and aquatic ecosystems.

The prior challenge for vegetation has been that the post-dam regime provided conditions with the reservoir being: (1) too high, (2) for too long, and (3) too often. The inundation creates anoxic root conditions that are lethal for most terrestrial plants. Even for willows and other plants with aerenchyma that enable root oxygenation, inundated shoots are unable to survive. Hydrophytes are better able to survive inundation but they are highly susceptible to drought. The annual reservoir pattern imposes inundation and then complete drying, a combination of stresses that excludes all perennial plant species from the lower draw down zones.

Some perennial plants survive near the full pool elevation around Duncan Reservoir and these zones experience shorter intervals of shallower inundation. This band of woody vegetation should be promoted and expanded downwards if the reservoir: (1) was not filled to full pool, (2) experienced shorter intervals near full pool, and/or (3) had occasional, rather than annual filling to full pool. Some combination of these changes would reduce the magnitude, duration and frequency of inundation, and provide more favorable conditions for vegetation.

The most promising locations would continue to be on the alluvial fans from inflowing creeks, such as in Figure 4, photo 1; and towards the upstream end of the reservoir as in Figure 5, photos 5, 6 and 7. These locations provide more gradual slopes that would expand the exposed surfaces, and are at relatively higher elevations with reduced inundation depth and duration. Additionally, the inflowing creeks or river provide alternative alluvial groundwater sources when the reservoir is deeply drawn down.

The deliberate regulation of water stage has been successfully implemented to restore river riparian vegetation along a number of dammed rivers in western North America and the ecophysiological foundation is well established (Cooper et al., 1999; Dixon, 2003; Rood et al., 2005; Polzin and Rood, 2006; Shafroth et al., 2017). It would be expected that the same principles and parameters would apply to reservoir zones but experiments or restoration applications have been uncommon and this application would be more novel and less certain.

The prospect of changing reservoir regulation for environmental and social benefit, including vegetation enhancement, has also been proposed for Arrow Lakes Reservoir (Thompson et al., 2016). That system might have a higher priority than the Duncan Reservoir, due to the increased human use and adjacent towns, along with differences in the valley topography. If implemented, lessons from the Arrow Lakes Reservoir changes would benefit planning for environmental management of the Duncan Lake Reservoir.

Acknowledgements

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Bottom-up and Top-down: Compound Influences of River Regulation and Beavers on Riparian Cottonwoods along the Duncan River, British Columbia

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Abstract

The Duncan Dam near the north end of Kootenay Lake was the first of four Columbia River Treaty dams. For the past two decades, we have been investigating the environmental impacts from this dam, and particularly influences from instream flow regulation on riparian processes and vegetation. For this study component, we investigated interactions between river regulation, riparian black cottonwoods (*Populus trichocarpa*) and beavers (*Castor canadensis*), with a paired comparison between the regulated lower Duncan River and its free-flowing tributary, the Lardeau River. Cottonwood saplings occurred more broadly along Lardeau River transects (63% vs. 38%) and with increased density. Along both rivers, beavers preferred cottonwood saplings over other shrubs and cutting was more intense along the regulated Duncan River (36% vs. 7% of stems cut). Beaver cutting also occurred in wider bands along the Duncan (25 m vs. 11 m from river), and there was evidence for increased cutting of a less-favored alternate, alder (*Alnus incana*), while willows (*Salix* spp.) were substantially cut along both rivers. River regulation has apparently reduced cottonwood recruitment along the Duncan River and probably increased beaver accessibility to cottonwood saplings since higher river levels in late summer and autumn would promote inland access. These ecosystem alterations may create an imbalance between bottom-up cottonwood recruitment versus top-down mortality. We represent the ecological interactions with a schematic model that incorporates river flow regime, bank forms and alluvial sediment patterns, and other riparian vegetation as key factors influencing riparian cottonwoods and beavers.

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Collateral Benefits: Common Instream Flow Needs for Fish and Forests along the Kootenai River, USA

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Abstract

The transboundary Kootenay River originates in the Rocky Mountains of British Columbia and is joined by numerous tributaries as it flows into Montana and Idaho, and then back to BC before providing the 2nd largest tributary of the Columbia River. Following the international Columbia River Treaty, the Libby Dam was constructed in Montana in 1975 and creates the 140 km long Koocanusa Reservoir across the international border. This large reservoir has attenuated flood flows and traps sands and other sediments, leading to coarsening of the channel and banks downstream. Impoundment was followed by expansion of riparian woodlands dominated by black cottonwoods (*Populus trichocarpa*) into the previously barren zones but following this initial pulse, cottonwood colonization became limited due to the moderated flow and floodplain dynamics.

Due to draining and diking of the extensive wetlands upstream from Kootenay Lake and the river damming and flow regulation, the Kootenai River (US spelling) white sturgeon (*Acipenser transmontanus*) population declined and was listed under the American Endangered Species Act in 1994. Listing prompted recovery measures that included changes in Libby Dam operations in the late 1990s, with higher spring flows in high water years, intended to promote white sturgeon spawning. After 2006, flow normalization was more complete, including substantial peak flows and gradual post-peak recession. While the flow changes have not yet increased natural reproduction of the ancient and long-lived fish, these did increase seedling colonization of black cottonwoods and the streamside sandbar willow (*Salix exigua*). Additionally, in the channelized meander reach through the prior wetland zone, bands of prairie cottonwoods (*P. deltoides*) have established and their reproduction has benefited from the normalized flow regime. This promising case study demonstrates the common reliance of fish and

forests on characteristics of the natural flow regime. Consequently, the restoration of more normalized river flow patterns should provide broad ecological benefits along regulated rivers.

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Developing a Method of Enumeration and Measurement of Gerrard Rainbow Trout with Drones

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Abstract
Rainbow Trout are an important sport and food fish in the Columbia and Kootenay rivers, and their abundance is significantly influenced by hydroelectric activity in the region. Management of these salmonids in regulated rivers is facilitated by accurate estimates of egg deposition. Although spawner counts are conducted by observers on many systems, accurate estimates of spawner size, which is strongly correlated with fecundity, are more difficult to obtain. Increasingly, unmanned aerial vehicles (UAVs), more commonly known as drones, are being used in industry and research as a cost-effective alternative for collecting aerial imagery and other data. The goal of this project is to develop a method for enumeration and measurement of Rainbow Trout spawners at Gerrard, BC using UAVs. In May 2019, a field team will assemble, and work collaboratively to collect aerial imagery and video of the entire spawning area. A method of analyzing the data will then be developed. In short, once many individual photos are georeferenced and stitched together, and the optical distortion of the water is calibrated for, it should be possible to calculate the length and width of each fish. The further goal is to extend the use of this monitoring technique to other species and systems.

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Kootenay Bullfrog Management – Update, Lessons Learned, Looking Forward

Presenter: Khaylish Fraser, Aquatic Invasive Species Program Coordinator, Central Kootenay Invasive Species Society, Nelson, BC

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Abstract

The American bullfrog (*Lithobates catesbeianus*) is listed as one of the 100 Worst Alien Invasive Species internationally due to its adaptable, prolific, competitively exclusive, and predatory nature. It was historically exported from its native eastern North American habitat, to supply international markets for frog meat, for use as a biocontrol agent, and for use in the pet industry. Unfortunately, bullfrogs acclimatize readily to habitats ranging from temperate to tropical and can now be found as an invasive species in western North America, Hawaii, South America, Asia, Caribbean Islands, and Europe. Bullfrogs are notoriously aggressive, voracious, opportunistic, ambush predators. These attributes, coupled with rapid population growth rates (up to 20,000 eggs per female bullfrog annually) and broad temperature tolerances (preferring 15-32 degrees Celsius) has expedited their spread northward into British Columbia.

American bullfrogs were first detected in the Central Kootenay region in 2015; the leading edge of incursion was alarmingly close to the three sole populations of northern leopard frogs (*Lithobates pipiens*, Rocky Mountain population; SARA Schedule 1 Endangered) in B.C. Bullfrogs can exert predatory pressure, compete for resources, and impose disease risk on northern leopard frogs. The prevention of bullfrog range expansion has been identified as a high priority for northern leopard frog recovery. Bullfrog early detection efforts include the use of song meters, environmental DNA analyses, nocturnal eye shine, call playback, and education-outreach. Targeted rapid response methods include utilizing an electro-frogger, fyke nets, and rifles to eliminate bullfrogs.

In response to the threat of the American bullfrog, the American Bullfrog Action Team (ABAT) was created in 2015 to ensure a collaborative and strategic approach to monitoring and management. The ABAT is formed of eight organizations, including non-profits, Canadian and US government departments and First Nations. The ABAT's goal is to reduce the threats posed by incursion of American bullfrog through a targeted surveillance and eradication program. As a member of the ABAT, the Central Kootenay Invasive Species Society conducts monitoring and control of the American bullfrog in the Central Kootenay region.

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Potential Measures to Return Ecosystem Function to the Upper Columbia Basin

Presenter: **Dr. Martin Carver**, Peng/PGeo, PAg, Upper Columbia Basin Environmental Collaborative, Nelson, BC
Email: aqua@netidea.com

Abstract
The Upper Columbia Basin Environmental Collaborative (UCBEC) is a partnership of a cross-section of environmental voices from the Upper Columbia Basin, representing provincial, regional and local environmental organizations. Founded in late 2016 to provide a unified environmental voice for consideration by all parties engaged in the renegotiation of the Columbia River Treaty (CRT), UCBEC identifies scientifically-based perspectives and describes technically-robust proposals to support full incorporation of ecosystem function (EF) within a renegotiated CRT. UCBEC seeks ecosystem restoration, creation and enhancement in relation to all affected Canadian reservoirs and major river reaches and recognizes the need to balance restoration and enhancement efforts to achieve greatest net ecological benefit.

UCBEC's primary focus is to improve the function of Canadian ecosystems impacted by dams and reservoirs in the Columbia Basin, including those in the terrestrial, aquatic and riparian/wetland realms. Salmon reintroduction is a potential component of improved ecosystem function. However, successful spawning of salmon in the upper Columbia Basin is, in part, dependent on other habitat improvements. Although emphasis is on Canadian reservoirs and river reaches, ecosystem restoration in the US is also necessary to ensure maximum ecosystem function is maintained and improved throughout the entire Basin.

The poster is a combined information and engagement opportunity for conference participants. The poster will present examples of reach- and reservoir-specific measures that promote EF, while inviting participants to comment on those measures or suggest additional ones.

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Sharing local government and Basin resident views about Columbia River system management

Presenters: **Columbia River Treaty Local Governments Committee**
Linda Worley, Chair
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Cindy Pearce, Executive Director
Email: cindypearce@telus.net

Columbia Basin residents are passionate about Columbia River ecosystems. They are concerned about the footprint and ongoing impacts from hydroelectric operations across the Basin and they support changes in operations to improve ecosystem conditions and other issues. The Columbia River Treaty Local Governments Committee believes understanding and considering the views of local residents and governments is essential to deciding on improved management of this regulated river system. Since 2011 the Committee has sought citizen input and expert advice to understand the concerns and the wishes of Basin local governments and residents. The Committee continues to communicate these views to the BC and federal governments for inclusion in the current negotiations to improve the Columbia River Treaty. The Committee has secured advice from experts in water system management and commissioned studies of the role of local governments and non-government organizations in the negotiation of international water management treaties. These studies inform the Committee's approaches to ensuring the views of local residents are included in the ongoing negotiations and management of the system.

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The effects of flood discharge on benthic invertebrate communities and the quality of water and sediment in Lower Vernon Creek, located downstream of the Kalamalka Lake reservoir

Presenter: **Trina Koch**, R.P.Bio. Senior Biologist, Western Water Associates Ltd.
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Abstract
The City of Vernon retained Western Water Associates Ltd. (WWAL) to complete a three-year baseline monitoring study of Lower Vernon Creek and BX Creek where they flow through city boundaries. This area includes the entire length of Lower Vernon Creek which flows out of the Kalamalka Lake reservoir and through the south end of downtown Vernon before entering the Okanagan Lake Reservoir (approximately 30 km). The project included collecting routine measurements and samples at four creek sites and two stormwater outfall sites along Lower Vernon Creek. At each site monthly field water quality was measured and seasonal water and sediment samples were collected for laboratory analysis of bacteria, metals, hydrocarbons, nutrients and chlorophyll-α. Benthic invertebrate samples were collected from the four creek sites each September. In 2017, a 1:200 flood event occurred which resulted in the discharge of reservoir flood waters into Lower Vernon Creek during the months of May and June.

We will compare Lower Vernon Creek's water, sediment and benthic results from 2016 and 2018 to those from 2017. Flooding along Lower Vernon Creek did not occur in 2016 or 2018; creek discharge conditions in the freshet of 2016 were below normal and in 2018, the Province kept Kalamalka Lake lower than normal in the anticipation of high freshet flows. Results show that 2017 flooding significantly impacted the overall health of Lower Vernon Creek. The extreme 2017 flooding exacerbated the normal freshet impacts with a significant increase in hydrocarbons, dissolved iron, nickel and lead concentrations in creek sediments and water. Some creeks sites also peaked in nitrate and bacterial concentrations. Sediments became elevated in PAH's HEPH's and lead concetrations. In addition, to measurable laboratory water and soil quality parameters, flooding significantly affected the creek health in other ways including increases in bank erosion, debris jams and sediment deposition. The overall benthic invertebrate community in Lower Vernon Creek in 2017 included a statistically significant increase in tolerant taxa compared to 2016 and 2018 communities. Managing reservoir flooding in controlled creek systems is critical to the health of such water bodies.

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Hydro and Whitewater – seeking a balance between river regulation and conservation in Québec

Presenter: **Yann Troutet**, Selkirk College, Castlegar, BC
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Abstract
As a hydrological feature, whitewater has important ecological functions. Its social functions, however, are often neglected in the decision-making that underpins the management of fluvial systems. This interactive web-mapping project presents the history and state of hydroelectric development in Québec, highlighting the loss of whitewater features as an unavoidable yet overlooked consequence of hydroelectric development. As the province contemplates the construction of several new large hydro complexes, this web map shows that there are now only a few remaining large free-flowing whitewater rivers in the province, most of which are located in a region called Minganie. Of these, the Romaine River, is currently being dammed.

The web map introduces a method that was devised by Association Eaux-Vives Minganie to inform the Joint Review Panel on the Romaine River Complex. Relying on detailed whitewater river maps used by recreational paddlers, a "Whitewater Index" can be calculated for any given river. Based on this index and derived statistics, the largest and longest known whitewater rivers in Québec were analysed. Two rivers stood out with exceptional results: the Romaine River and one of its lesser known neighbours, the Magpie River. Considering the above results, the Federal-Provincial Joint Review Panel, voiced opinions supporting river conservation projects in Minganie. Association Eaux-Vives Minganie then partnered with the Canadian Parks and Wilderness Society and Université du Québec à Chicoutimi to run similar comparisons between the Magpie River and four world-renowned rafting expedition destinations.

According to the results, the Magpie River proves to be a world-class whitewater destination.

The *Story Map* retraces the efforts of the provincial Environment Ministry, the Regional Conference of Elected Officials and the Ekuanitshit Innu Band Council in support of the permanent protection of *Mutehekau Shipu*, the Magpie River. It also recounts the journalistic work that revealed how Québec's *Ministère des ressources naturelles* (which oversees Hydro-Québec) opposes the idea because of the river's hydroelectric potential.

The Story Map can be viewed at:
https://selkirk.maps.arcgis.com/apps/Cascade/index.html?appid=f281ccbb86e845d5bc1c10ec07c0b4b3

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Compensating for the Nutrient Impacts of Impoundment in Kootenay Lake and Arrow Lakes Reservoir

Presenter: **Kristen Peck**, BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Nelson, BC
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Abstract
Dams change nutrient inputs by inundating littoral zones, fluctuating water levels, changing the natural seasonal timing of high and low flows, and trapping or diverting nutrients. These changes impact the amount of nutrients available for productivity in pelagic food webs. We have been adding nutrients in the form of agricultural-grade fertilizer directly into Kootenay Lake since 1992 and into Arrow Lakes Reservoir since 1999 to help compensate for the nutrient impacts of upstream dams and reservoir creation by downstream dams. Along with adding nutrients, we have closely monitored responses at several levels of the pelagic food web. Between the kokanee collapse in Kootenay Lake and several years of impactful flows in Arrow, measuring the success of these programs is complex. We will present results and emerging challenges from the last several years of the nutrient restoration programs as well as some future questions to explore.

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Small streams, big decisions: Hydrometric monitoring of small tributaries by the North Kootenay Lake Water Monitoring Project

Presenter: **Samuel Lyster**, PEng, North Kootenay Lake Water Monitoring Project, Nelson, BC
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Co-Author: D.r Martin Carver Peng/PGeo, PAg, North Kootenay Lake Water Monitoring Project, Nelson, BC
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Abstract

Small stream systems can have a disproportionate influence on weighty decisions such as those required in reservoir operations integral to large regulated systems like the Kootenay and Columbia Rivers. For example: i) reservoir operational rules may need to take into account reservoir connectivity with small fish-bearing tributaries, ii) reservoir levels for recreational purposes are influenced by shoreline developments which, in turn, are influenced by debris-flow hazards of small steep creeks, and iii) road access to dams often involves culverted crossings of seemingly benign small streams that can experience debris floods leading to road failure and blocked access to dams. However, despite these important hydrological and geohazard effects of small streams, they are not well understood due to a shortage of hydrometric data in comparison with that of their larger counterparts.

The network of regional hydrometric monitoring stations managed by government agencies has declined since the 1950s. This decline has yielded a network that underrepresents watersheds with drainage areas below ~100 km2. The North Kootenay Lake Water Monitoring Project (NKLWMP) manages and operates seven hydrometric stations in watersheds ranging from 2 km2 to 64 km2, as well as three climate stations and two snow courses. Data collected by the project complement the existing network by filling important gaps at watershed scales not captured within the regional network. NKLWMP data have direct applications in regulated stream systems by providing biologists, foresters, agrologists, geoscientists, engineers, other environmental scientists and resource decision makers with a clearer picture of how these small systems behave. An increased understanding of the function of these systems enables more effective decisions in reservoir operations, environmental flow-determinations, infrastructure design, water allocation, land-use planning, forest management, and in other applications.

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Restoration of 40-Mile Creek

Chad Townsend (in abstentia)**,** Town of Banff, AB
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Abstract
The Town of Banff and its contractors, in a carefully planned project, drained the reservoir and carefully removed a portion of the 40 Mile Creek Dam to restore connectivity in an important trout bearing watercourse. This proposed presentation would describe a challenging but successful partial dam removal project, screen a short summary video(s) that raised awareness on the project to an important audience, and briefly describe follow-up research on the restored river connectivity for an endangered trout species.

The 40 Mile Creek reservoir supplied the town of Banff with drinking water and firefighting capacity for about 80 years. The second, larger dam was a significant local engineering feat when built in 1946. While the reservoir ceased to be used as a water source in the mid-1980s when wells were drilled, the dam remained in place disrupting connectivity, continuing to amass sediment, and presenting a liability in various ways.

Removal was a project that both the Town of Banff and Parks Canada had wanted to complete for years, but the cost of demolishing the dam while it was still full of water, and the implications of releasing sediment into the stream, had always been a deterrent. The high water event in June 2013 both pushed the dam to its limits, and provided an opportunity to progress the project. During the flood, Town staff were able to drain the dam to remove pressure, and remove a significant portion of the sediment. The flood also washed out the access road, exposing the associated pipes in the riverbed.

With the reservoir drained, there was another spring freshet window of opportunity to demolish a portion of the dam, release sediment, and remove those exposed pipes. Using relief funding from the provincial government, and after thorough environmental assessment (EA), a temporary access route was recreated for heavy equipment and the dam was opened by the Town’s contractors in the spring of 2014. The presenter was both involved with the EA, and on site each day of the work in a project documentation and environmental monitoring capacity. A remote camera was put in place that took a quality image of the reservoir hourly over the entire project.

The presenter was then fortunate to have the opportunity to act as a video producer. At the invitation of the Banff Mountain Film Festival, the Town’s photo and video footage

was assembled into a compelling short film that premiered with Patagonia's feature-length documentary DamNation:
https://www.youtube.com/watch?v=5rtbTKUWsFI

40-Mile Creek has been restored to a more natural state and now allows for greater aquatic habitat connectivity. To test that success, subsequent research has involved Parks Canada and Carlton University. Recent techniques have involved placing miniature radio telemetry tags on endangered bull trout and using receivers stationed at the former dam to record upstream and downstream bull trout movement. As a partial dam removal, the channel created for aquatic connectivity is constrained and assessing its effectiveness is important.

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Summary of conference evaluations

There were ~105 people at the forum, and 33 evaluation forms were returned.
Not all forms had a response for each question.

1. How well did the conference meet your expectations?

a. Exceeded **- 5**
b. Fully met **- 21**
c. Met most **- 8**
d. Met only a few **- 0**
e. Did not meet any **- 0**

2. Please suggest two or three key things that you learned at this event that will have an impact on your work. Are there things that you will be doing differently in the future?

- Run-of-river related coho fry & ramping; tailed frog & ramping
- Stats talk on Day 2
- Riparian/wetland impacts
- Quite a few folks are thinking similarly about the future attempts at restoration/preservation. Great that key relationships are being strengthened or rebuilt.
- I was pleased to see how we are mitigating the impacts of regulated rivers.
- The existence of the groups bringing up ecosystem function @ CRT talks was good to know about.
- Factors related to didymo mat formation
- Bottlenecks to burbot recruitment
- Different factors limiting sturgeon recruitment in different areas
- No eDNA evidence of pick upstream of Keenleyside Dam
- Fire retardants have high phosphorous content
- There was a huge reduction in carbon sequestered in this region due to dams
- Flow impact on ecosystems
- Challenges faced by native species
- Being extra diligent in conservation efforts at generation facilities
- Offsite wildlife compensation programs
- Current & future habitat restoration efforts in drawdown zones
- Enjoyed and learned from Joe's statistical talk – really simple explanation – might look at significance differently now!
- Enjoyed hearing about the arthropod study at Kinbasket
- Learned there is a lot of great research being done

- Alternative statistical methods and pattern modeling
- Revegetation complications and resolutions
- Glacier mass balance influence on water availability & chemistry
- New stat approaches & water chemistry approaches will improve my analytical approaches
- What data to request of dam operators
- Presentations by Alan Thompson & Eva Schindler were very informative for covering terrestrial impacts & highlighting that Kinbasket is a unique system in terms of forest/wetland productivity pre dam construction
- Tailed frog info was great! Didn't know they spent 4 years as tadpoles or that they could live 15-20 years…wow!
- Emphasis on adaptive management, changing a treatment to see what effect that might have
- Wetland work being done
- Productivity in riverine habitats
- What the relationship is between flow and elevation
- Use of arthropoda as indicator wildlife species within reservoir drawdown zones
- Implementation of coarse woody debris into the ground as shelter for kokanee
- Restoration techniques along reservoirs
- Importance of site selection and understanding flow levels
- Importance of water temperature on larval stages of different species & how global warming can affect these species
- Complexity of reservoir operations; goals and objectives of different projects and altered flows to meet these may have adverse effects on other projects
- Great overview of a broad range of topics. My work is fish-focused, so learning about other related processes in the Columbia basin (ie, wildlife, vegetation) will help inform my work.
- The ability/suggestions for revegetating the drawdown zones of reservoirs (and mitigating other impacts)
- The efforts in place to foster burbot recruitment
- Culturally informed ecosystem-based management
- Flow discussions vs. stable elevation of reservoirs
- Great discussion with an attendee on dipper predation of tadpoles
- Interesting talk on stats and using priors (all of the probability distribution, away p-values). Would like to try to use priors/baysien modelling in the future.
- Started to think further about the changes that are needed in each of our reservoirs & reaches
- The magnitude of projects related to compensation to mitigate dam impacts not only by FWCP but by many other organizations
- Who is doing what research & projects – good networking

- Trying more to share info, collaborate with others & use info from past researchers
- Climate related impacts
- Promoting data sharing
- Reminder to keep ecosystem function in mind at all times
- Emphasis on effect size & uncertainty (from Joe's talk)
- Good to see collaboration among people

3. Was there anything you hoped to learn that you did not?

a. No – **7**

b. Yes

- A bit more on determining minimum environmental flows
- Why no discussion on Water Use Plan for Kootenay Lake?
- I would like to see more movement towards addressing the root cause of many of the impacts of maintaining a constant reservoir elevations
- It would have been helpful to have upper level BC Hydro and Columbia Power Corp staff talk about future paradigm in basin; What's after WLR/WUP?
- I would have liked to see a presentation on Site C impacts, since it seems very ironic that people here are talking about ways of recovering some ecological function, at the very time our province is destroying a very diverse & beautiful valley – the last unimpounded reach of the Peace River in BC.
- Mine/petrol remediation efforts
- More presentations from decision makers and how they use or incorporate ecological advice into agreements/land management decisions
- It would be interesting to learn from the operations/regulators what flexibility is available to change reservoir operations at the benefit of taxa/ecosystem function
- I found information pertaining to BC Hydro operations or information pertaining to the CRT is not completely accurately represented.
- Would liked to have learned details and research into re-introduction of Columbia River salmon
- More whole ecosystem approaches to compensation/restoration rather than case-studies
- Would have liked to see more about interactions between reservoirs & between US and Canada
- Definitely would have liked more related to the Columbia River Treaty
- More about wetlands
- More terrestrial presentations

4. **If we run a sequel to this event, what topics would you like to see included?**

- Status updates of major endeavours such as salmon reintroduction
- Feasibility of Columbia River salmon
- Associated workshop or field trip
- Hearing about any research that quantifies the effects of reservoirs on climate
- Studies on new techniques used by dams to mitigate ecosystem impacts
- More info on floating islands as habitat in reservoirs
- Presentation on the Data Hub and Water Monitoring collaboration
- Hydro operations overview of constraints on flow regimes
- Results of created wetland habitats in reservoirs
- Wetlands, more riparian info
- Stream habitat restoration
- More wildlife restoration/compensation projects
- Climate change models to local area; what are we looking at in the future & how will we adjust our programs?
- More content on affected watersheds other than the Columbia
- Incorporate cultural topics (ie, TEK and historical losses within the Basin)
- Incorporating global warming scenarios into regulation/management around reservoirs
- Update on CRT negotiations and how these projects have fed into them
- Additional presentations on promoting recruitment of species (aquatic, riparian, terrestrial, wetland)
- More pelagic lake discussions
- Values discussion, ie, trade-offs of recreational angling/First Nation harvest vs. riparian/littoral restoration
- Small hydro section
- Status of efforts for protecting and restoring old growth forests at low elevations
- Wetland restoration and enhancement
- Birds and a wider range of wildlife impacts (e.g. beaver? Ungulates? Etc.)
- Meet more often/have this event more often; interested in RRIII

5. **Do you have any other comments about the event?**
- It's such a great occasion to hear about other research and to network
- Excellent list of presentation topics, presenters, and very well run
- Seamless. The posters could have been put further apart on the wall to make it easier to see the poster; tended to be too crowded when only one or two people were there.
- Great job and thanks to organizers/volunteers. Ideally 1 screen/projector next time, but difficult for venue.

- I learned a lot! It was helpful to me to hear about specific topics/components that are part of Columbia Basin ecosystems. And I felt all the presentations, while on specific issues, helped create a big picture understanding all the efforts & challenges in the Basin.
- Very well organized. Organizers do a very good job providing nutrition breaks with healthy choices. The poster session combined with wine/cheese networking worked really well. Great if more frequent!!! Ie, Regulated Rivers III in two years?
- Everything was great. Encourage discussion more through more question time.
- Interesting presentations; however, there seemed to be some with the same/similar topics (overlap).
- Have a subject matter expert speak about BC Hydro operations to set the stage for subsequent speakers. For example, introductory slides on BC Hydro operations, as it pertains to the Columbia and its associated agreements.
- Great event, many interesting presentations. Maybe extra time for presentations in the future.
- Please consider broadening the event to be a transboundary scope so that ecologists on both sides of the international basin could exchange perspectives/information.
- I was surprised at how you managed to get all of those presentations into the agenda without loss of meaningful content.
- Super informative & interesting! Learned a lot!

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