Alouette Project Water Use Plan

Alouette Kokanee Age Structure Analysis

Implementation Year 6

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Study Period: 2013-2014

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ALOUETTE KOKANEE AGE STRUCTURE ANALYSIS (ALUMON#6)-2014

Prepared for:

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EXECUTIVE SUMMARY

The 2014 Kokanee Age Structure Population Analysis summarizes a multi-year investigation aimed at addressing whether reservoir operations impact Alouette Lake Reservoir (ALR) Kokanee population. This study is one component of the monitoring program developed under the BC Hydro Alouette Water Use Plan (WUP) aimed at determining whether the current Kokanee population is displaying recruitment limitation and whether any identified recruitment limitation is related to reservoir operations. Three questions to be addressed by this study include: 1) is the existing Kokanee population in the Alouette Lake Reservoir recruitment limited? 2) if there is evidence of a recruitment constraint to productivity, is it linked to reservoir operations? and 3) if found linked to reservoir operation, what is the nature of the relationship and can it guide development of alternative mitigative reservoir operations?

Lack of data on the Kokanee spawning population in Alouette Lake Reservoir required the use of gillnet and hydroacoustics data in development of models to assess whether the population is recruitment limited and whether reservoir fluctuations during the spawning and incubation period impact subsequent fry and adult abundance. This model-based approach utilized a size-at-age model of Kokanee collected from gillnet data from 2000-2014 to determine if the population's size-at-age is stable or decreasing with optimized reservoir productivity. Analysis of the size-at-age modeling indicates compensatory mechanisms potentially regulate age 3+ Kokanee. The average size of age 3+ Kokanee declined since 2000 before stabilizing in 2003; since then, Kokanee size for the time period of 2003-2014 fluctuated around an inter-annual mean of 267 mm.

Stock recruitment models were developed in a Bayesian framework for interpreting the effect of reservoir fluctuations on fry abundance. Analysis revealed that modeling the contribution of spawning stock (age 2+ and 3+) to the age-0 population, using a non-linear Beverton-Holt relationship, predicted the average carrying capacity of fry of 153,990 (95% CRI 128,720-181,150). This spawner-recruit model also predicted that current reservoir operations may potentially limit recruitment and the reproductive success of the ALR Kokanee population. In comparison, a second model analyzed age 0 (fry) and age 1+ (recruits) and the predicted outcome was a peak recruitment of 44,770 age 1+ Kokanee (95% CRI 34,950-58,260). The second model indicates that elevation changes (mean=5.4 m 2002-2014) during the Kokanee

spawning and rearing period does not limit recruitment of Kokanee at the age 1+ stage. Both models indicated that density dependent factors likely regulate the population abundance of both age-0 and age-1 fish. As with previous years, estimated age 0+ and age 1+ numbers are considered conservative since separation of older age classes from hydroacoustic data is inherently difficult due to size variability and may not be reliable.

Analysis of data suggests that the ALR Kokanee population is likely regulated by compensatory mechanisms. Size-at-age analysis suggests that hypothesis one ($H_0$1) under the first management question cannot be rejected since the data displays a size structure that has stabilized after initial increases under higher lake productivity. In addition, the Hierarchical Bayesian stock recruitment model results also failed to reject hypotheses two ($H_0$2) and three ($H_0$3) under management questions two and three. However, it is important to note the most recent modelling identified the possibility of a recruitment limitation to the ALR Kokanee population due to reservoir operations that was not previously observed. Potential for emigrations of juvenile Kokanee from reservoir operations, specifically through the spillway observed during an independent volitional migration success study may also impact the Kokanee population which could potentially persist through that cohort's life stage. There is the possibility of a compensatory benefit of increased growth and survival from the annual loss of juvenile Kokanee from the reservoir. However, it is acknowledged that there is considerable uncertainty in modeling the Kokanee data which can ultimately limit the ability to detect impacts from reservoir operations. Furthermore, spawning habitat availability in this reservoir also may be a limiting factor to Kokanee recruitment. Despite these limitations, the hydroacoustics data are the best available data for modeling purposes to gain informative insights into some of the mechanisms regulating the Kokanee population in the ALR.

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INTRODUCTION

Hydroelectric developments and reservoir formations are known to have profound effects upon the natural processes of lake limnology and the aquatic ecosystem those processes support (Moody et al., 2007; Utzig and Schmidt, 2011). In British Columbia, reservoirs have been investigated to understand if and by how much reservoir operations have the potential for adverse effects on fish distribution and abundance (Ashley et al., 1997; Ney, 1996; Stockner et al., 2005, 2000; Utzig and Schmidt, 2011). Ecological impacts can be seen from both footprint and operations related to the impoundment/inundation phase and with the water regulation phase. After impoundment, reservoirs commonly demonstrate an increase in productivity followed by a substantial decline in productivity, often coined “boom and bust” periods (Ney, 1996; Stockner et al., 2000). Reservoir operational impacts from water level fluctuations result in a loss of littoral area production and has been cited as factor in reducing reservoir productivity (Wetzel, 2001). Understanding the full footprint and operational impacts on fish populations can often be obscure and unclear; due to the large spatial and temporal aspects of these systems, they often require years of investigation to determine real effects.

The Kokanee Age Structure Population Analysis (ALUMON #6) is a multi-year study to address potential impacts of reservoir operations on the reservoirs’ Kokanee (*Oncorhynchus nerka*) population (BC Hydro, 2009). As part of the Alouette Water Use Plan (WUP), the study’s focus is to address whether the current Kokanee population is recruitment limited and if any identified recruitment limitation is related to BC Hydro operations. Alouette Lake Reservoir (ALR) has demonstrated an increase in productivity and fish abundance since the implementation of the nutrient restoration program in 1999 (Hebert et al., 2015), but there is a concern that reservoir operations may be limiting the Kokanee population from reaching full capacity.

Kokanee populations are often regulated by density dependent processes which display compensatory growth responses to variations in stock densities (Rieman and Myers, 1992). As well, the carrying capacity of the lacustrine environment which they inhabit is often regulated by "bottom up" processes associated with lake/reservoir productivity (Rieman and Myers, 1992). However, reservoir formation and operations can have adverse “footprint” and “operational” impacts upon fish populations over time (Matzinger et al., 2007; Moody et al., 2007; Stockner et al., 2005, 2000). Determining whether reservoir operations could limit recruitment of Alouette Kokanee through impacts to reproductive success under increased productivity are key management questions under the WUP.

Beginning in 2005, spring surface flow releases were initiated at Alouette Dam to evaluate the downstream migration success of marked Coho (*O. kisutch*), and then in 2006 marked steelhead (*O. mykiss*). In both years, coincidental *O. nerka* juveniles were found migrating downstream at the same time (LGL 2008). In 2007, the first Alouette Sockeye Salmon (*O. nerka*) returned to the Alouette Dam; since then, annual spring surface flow releases and sockeye trap-and-truck program have been undertaken. This migration of *O. nerka* confounds the ability to assess the operational impacts of the dam and reservoir operations on the Alouette Kokanee population. Furthermore, with the exception of McCusker et al. (2003), assessment of possible impacts of reservoir operations on the Kokanee population has been limited and has relied upon analysis of information from available hydroacoustic and gillnet data obtained in the reservoir (MFLNRO and MOE data on file; (Andrusak, 2014; Hebert et al. 2015). Limited additional information on the timing and distribution of spawners was obtained during surveys conducted in the fall of 2012 to assess the potential impact to reproductive success of Kokanee spawning within the drawdown zone of the reservoir (Andrusak and Irvine, 2013).

This report summarizes results up to and including 2014 data that is part of the larger monitoring protocol developed by the Alouette Water Use Plan Consultative Committee under the Alouette Water Use Plan (WUP). In this years' report, a hierarchical Bayesian analysis was conducted, utilizing a stock recruitment model and a size-at-age model, from hydroacoustic and gillnet survey data (1998-2014) collected from the reservoir to address management questions posed by the WUP, as described below.

Management Questions and Hypotheses

The management questions outlined in the WUP terms of reference were as follows:

1) Is the existing Kokanee population in Alouette Lake Reservoir recruitment limited?

2) If there is evidence of a recruitment constraint to productivity, can it be linked to reservoir operations, in particular the extent of reservoir fluctuations during the spawning and incubation period deemed to be mid-October to the end of February?

3) If found linked to reservoir operation, what is the nature of the relationship and can it guide the development of possible mitigative reservoir operations?

The key uncertainty identified is in the relationship between reservoir operations and recruitment potential of Kokanee in Alouette Lake Reservoir.

The hypotheses that flow from these management questions are:

$H_0$1: Once standing crop has stabilized with the annual addition of fertilizer, the size-at-age of the Kokanee population remains stable or decreases with time.

$H_0$2: Drops in fry abundance, relative to estimates in previous years and to that predicted by estimates of mature Kokanee, are uncorrelated with the extent of the reservoir fluctuations during the spawning and incubation period.

$H_0$3: Drops in fry abundance observed in one year do not persist through time to cause an impact on the abundance of mature Kokanee.

BACKGROUND

Alouette Reservoir is a comparatively small system with an average drawdown of nearly six meters. Fish surveys indicate Kokanee are the most abundant sport fish followed by Rainbow Trout (*Oncorhynchus mykiss*); non-game fish are seemingly far more abundant than sport fish, particularly Peamouth Chub (*Mylocheilus caurinus*), Northern Pike Minnow (*Ptychocheilus oregonensis*), Redside Shiner (*Richardsonius balteatus*) and various species of sucker (*Catostomus spp.*) (Hebert et al. 2015).

Alouette Reservoir has sustained substantial ecological impacts related to hydroelectric development, similar (though not in scale) to that observed throughout the Kootenay-Columbia Basins (Moody et al., 2007; Utzig and Schmidt, 2011). As part of the Stave Falls Disposition Order, the Alouette Reservoir Nutrient Restoration Project (RNRP) was initiated to address ecological impacts associated with the Alouette-Stave-Ruskin hydroelectric system (Harris et al., 2007, 2010). Whole reservoir nutrient additions have been conducted during the growing season since 2000, and under the Disposition Order, this work is expected to continue until 2068.

In an overview, assessments of Alouette Reservoirs' fish populations indicate a substantial increase in abundance and overall biomass since the commencement of the nutrient restoration program. Annual nutrient inputs to the reservoir have resulted in a measurable response within the lower trophic levels of the reservoir (Hebert et al., 2015). Results suggest that food web interactions have mediated the transfer of nutrients to Kokanee, ultimately improving reservoir conditions for fish while providing increased benefits for the recreational fishery (Hebert et al., 2016).

Alouette Reservoir has also been the focus of a large number of studies as part of the WUP. Re-andromization of Kokanee into Sockeye salmon due to dam operations has received substantial attention by agencies and various stakeholders (Plate et al., 2014). As part of the WUP, spillway releases from the dam during the spring have been initiated since 2005 and were implemented to determine the volitional migration success of salmonids from the reservoir (Mathews et al., 2013; Mathews and Bocking, 2011). In addition, a trap-and-truck program to allow the passage of adult Sockeye that return to the Alouette dam into the reservoir has been ongoing since 2008. However, these ongoing releases of *O. nerka* from and into the reservoir complicate assessment of reservoir operations on the Kokanee population (i.e. separating Kokanee from juvenile sockeye would be difficult, very expensive and regardless, both are subject to the same influences of reservoir operations), thus this study will necessarily reference the nerkid population rather than simply Kokanee.

Generally speaking, reservoir operations tend to impact the lower reaches of spawning streams (access) especially for those fish species that spawn in the spring when reservoirs are usually low and refilling with spring runoff (i.e. redds are subjected to inundation that often results in lower egg-to-fry survival; Andrusak and Andrusak, 2013). Fall spawning fish such as Kokanee are faced with receding reservoir levels and this is particularly problematic for shore spawning Kokanee as documented on Okanagan Lake (Andrusak et al., 2005) and the West Arm of Kootenay Lake (Andrusak and Andrusak, 2013). Assessment of Alouette Lake Reservoir influences on Kokanee production has been severely limited due to the lack of information on Kokanee spawning and spawner metrics. No estimates of spawner numbers or their metrics such as length or fecundity have been reported. Limited observations of spawning in McCusker et al. (2003) who suggested shore spawning occurs at depths at least 5 m below average full pool. In addition, Plate and Bocking (2013) indicated that adult Sockeye were recorded spawning at depths between 20-40 m.

In addition no stream spawning has been recorded and a follow up snorkel survey of the shore line by Andrusak and Irvine (2013) showed no nerkid spawning observed at depths < 5 m. Deep water spawning must be the norm inferred from recent observations of tagged Sockeye located at depths of 20-40 m (Plate et al., 2014). Deep water (30-50 m) Kokanee spawning has also been confirmed in East Barriere Lake (Andrusak and Morris, 2005) while Morris and Caverly (2004) found Kokanee spawning at depths of 20-70 m in Anderson and Seton lakes believed to be attracted to thermal plumes that would have temperatures suitable for successful spawning.

STUDY AREA

Alouette Lake Reservoir

Alouette Lake Reservoir (ALR) was created with the construction of a low level dam at the south end of the lake from 1925 to 1928. The reservoir is 1,656 ha in area at full pool and has an average drawdown range of 5.4 m (2002-2014). ALR is located in the Coast Mountains at 49°17´N, 122°29´W, about 16 km northeast of Maple Ridge, in a steep-sided glacial trench (Figure 1; BC MOE on file). The reservoir is comprised of two basins separated by a narrow section approximately 9 km upstream from the dam. Alouette Reservoir elevations range between the normal maximum elevation of 125.51 m at full pool (Figure 2), above which water flows over the crest of the dam spillway, and the minimum elevation of 112.6 m at low pool (Figure 3), based on licensed storage; this range in elevation provides 147 x 10^6 m^3 of active storage volume (Table 1). The normal operating minimum is 116 m due to turbidity problems with the low level outlet flows when the reservoir drops below 116 m (BC Hydro, 1996). Since 2005, a spring surface release over the dam's spillway occurs annually from April 15 to June 14 to allow for the experimental release of out-migrant Kokanee as "smolts." The reservoir elevation is kept above 122.5 m from June 15 to Labour Day (first Monday in September) for recreational purposes. The 2009 WUP allows for a short shoulder season where the reservoir elevation is held at 121.25 m until September 15.

Table 1. Alouette Reservoir morphometric information. Source: Burrard Power Company (1923), BCF (1980), BC Hydro Survey and Photogrammetric Dept.

Metric	Original Lakes	Full Pool	Minimum Operating Level	Basin	
				North	South
Surface elevation (m)	113	125.51	112.6	123[a]	123[a]
Area (ha)	1,410	1,656	1,507	491	1,131
Total volume (m^3 x 10^6)		1,306	1,151		
Active volume (m^3 x 10^6)		147	0		
Length, max (km)			17[b]	6.7	10
Width, max (km)			1.6[b]	1.2	1.6
Width, mean (km)		0.95	0.87	0.73	1.13
Depth, max (m)		152	141	149	138
Depth, mean (m)		78.4	77.2		
Shoreline (km)			37.5[b]		

[a] average summer elevation
[b] from BCF map at reservoir elevation of approx. 117 m.

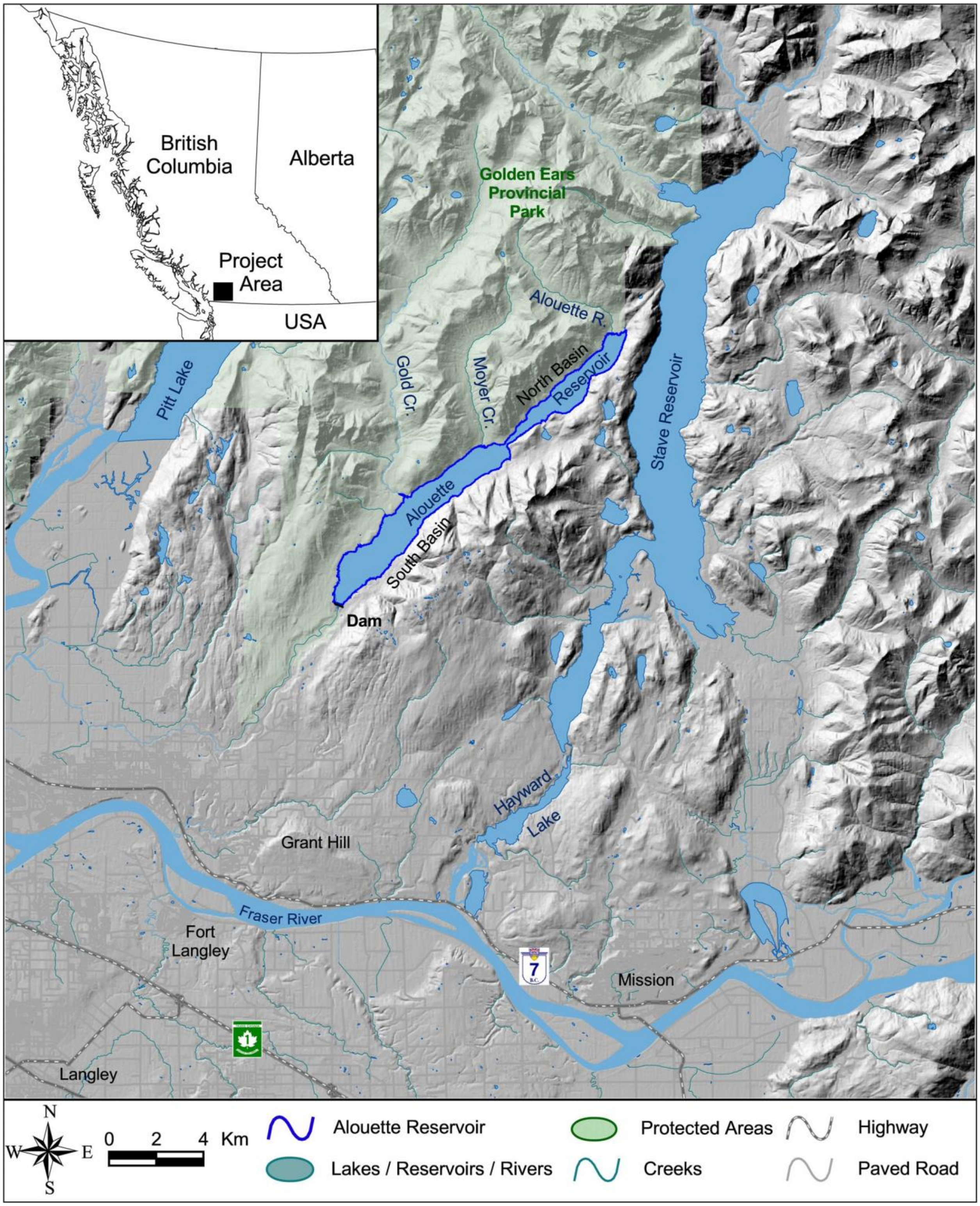

Figure 1. Location of Alouette Lake Reservoir.

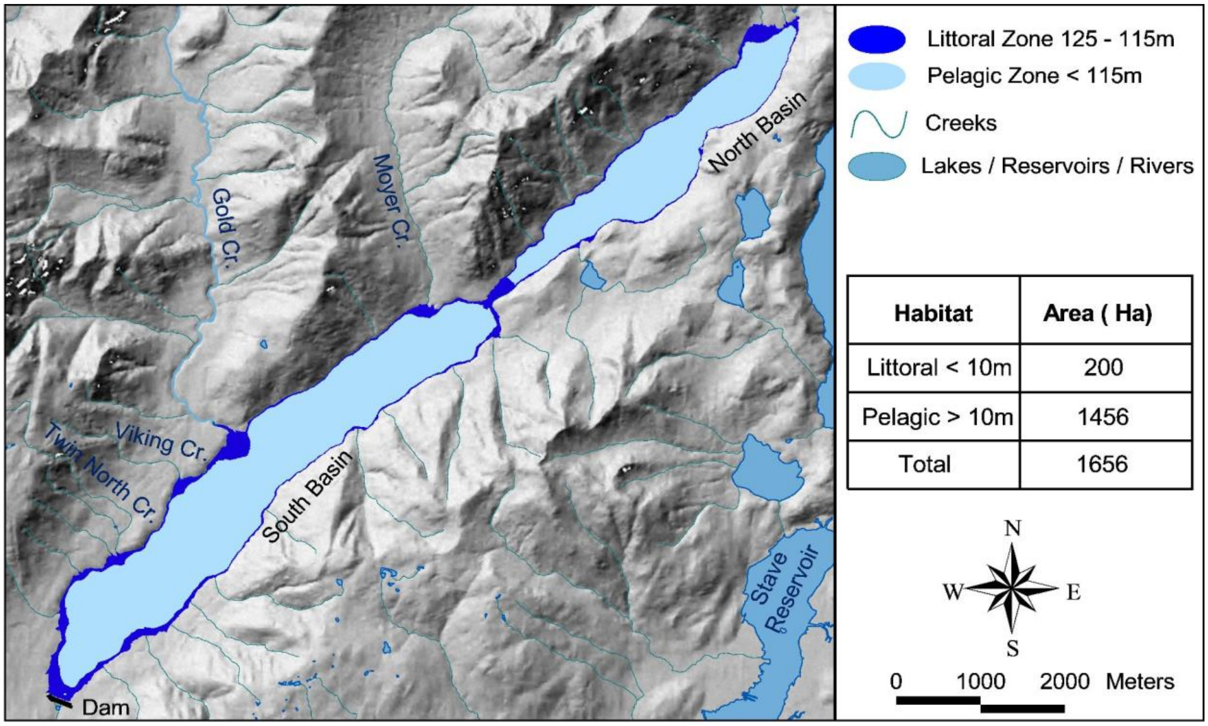

Figure 2. Maximum operating level (125 m) for Alouette Lakes Reservoir.

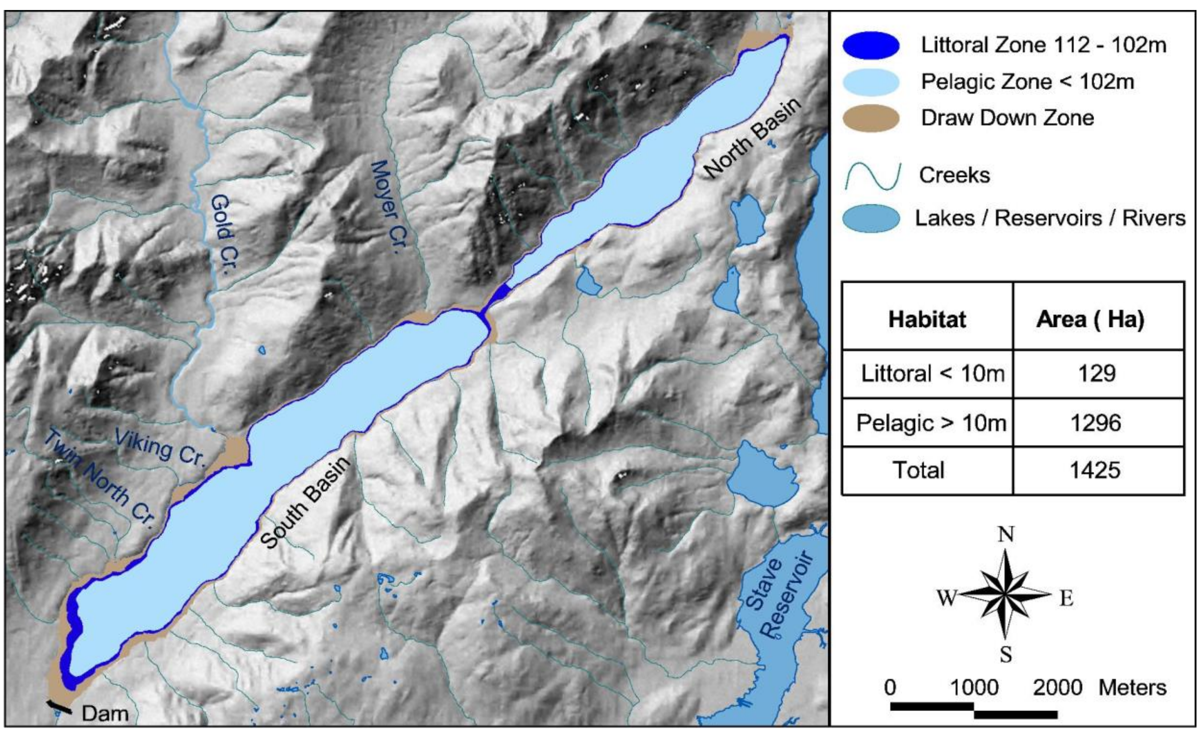

Figure 3. Minimum operating level (112 m) for Alouette Lakes Reservoir. Note drawdown zone and/or potential zone of impact for shore spawning Kokanee.

METHODS

Gillnet data

The primary data used for analysis was from gillnetting during 1998 to 2014. This data was obtained from various sample sites (Figure 4) and analyzed to assess the influence of various factors on Kokanee size-at-age. Near-shore gillnetting was completed from 1998 to 2009, as part of the reservoir nutrient restoration program (RNRP), to assess the response to nutrient additions (Hebert et al., 2015). In the fall of 2008 and 2009, gillnetting included pelagic netting and near-shore netting primarily to assess changes in methods. Pelagic netting (WUP) methods were designed to corroborate hydroacoustic data and address WUP management questions. Future sampling will include annual pelagic netting with near-shore netting every five years. The effect of netting methods was assessed to see if there is a difference between the two methods in their size selectivity (Andrusak and Irvine, 2013).

Captured Kokanee were aged using scale samples collected during 1998-2014. The actual data analysis excluded the 4+ and 5+ aged fish due to small sample sizes. Of the > 1,300 fish that have been aged using scales over the course of the study, 3 were classified as age 5+ fish and 94 as age 4+ fish. Kokanee older than 3+ only comprised 7.2% of the aged population. The sex of the fish was also modeled to account for any dimorphism due to gender. The analysis only utilized data from 3+ year old fish, considered the most common age at which sexual maturity is reached in this system and the age on which previous analyses have been completed (see Hebert et al., 2015).

Reservoir Productivity

In order to scale the size-at-age of Kokanee in relation to nutrient loading (and associated productivity) of the reservoir, a loading coefficient was modeled. The nutrient restoration program commenced in 1999, so data prior to 1999 were excluded. The nutrient data quantified the kilograms of agricultural grade liquid ammonium polyphosphate and urea-ammonium nitrate added to the system per year. In order to calculate the nutrient loading scalar, the ratio of added N:P was averaged over the last five years of the fertilization program in order to obtain an optimum ratio for the added fertilizers. This optimum N:P ratio was calculated as 7.45 for the years of 2008-2014 inclusive. Standing crop was considered to be stabilized by the year 2003. This value was then multiplied by the nutrient with the lower value in the ratio (P) in order to scale the two nutrients. The minimum scaled total N or total P was then selected for each year as a gross estimate of nutrient loading for inclusion in the model.

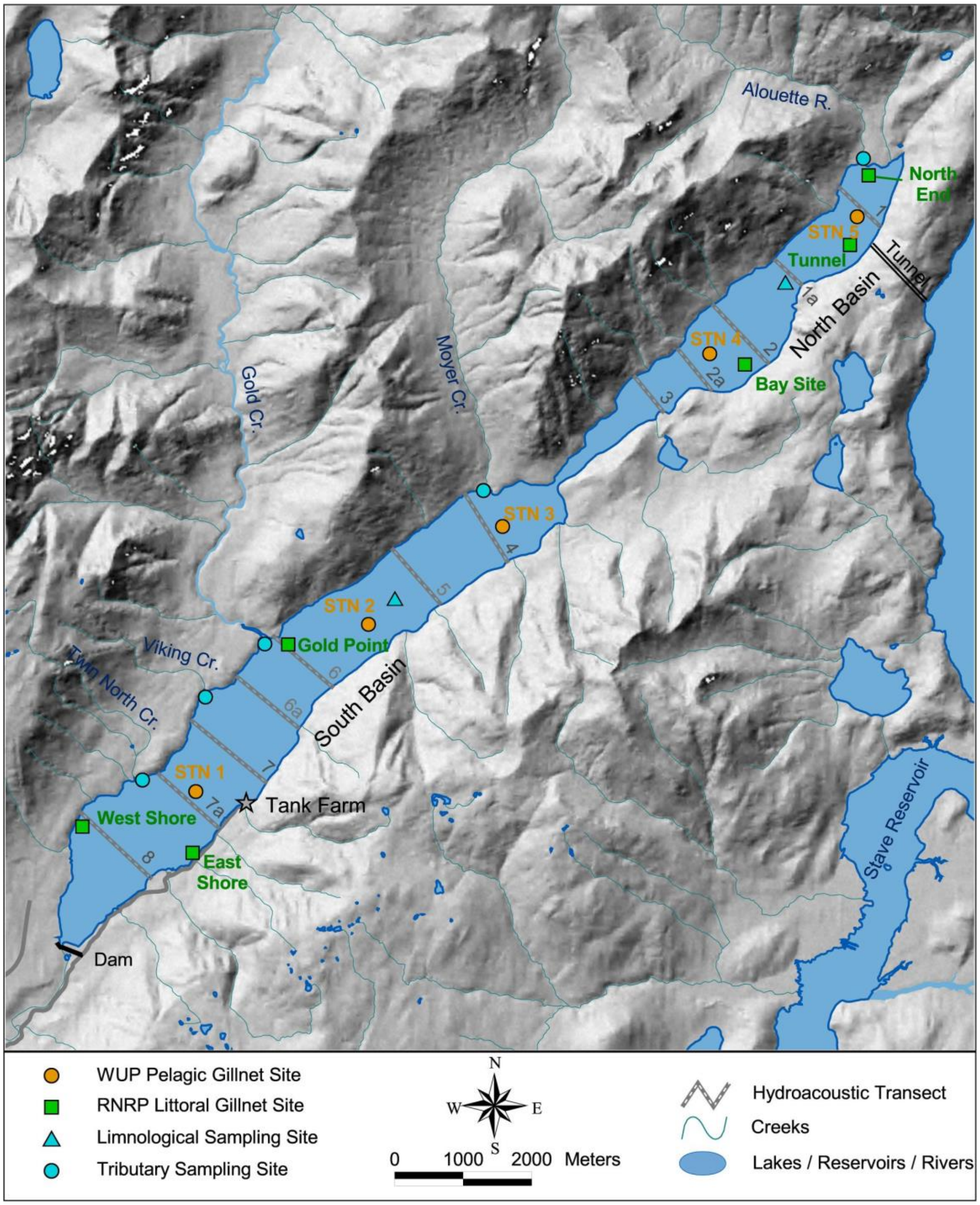

Figure 4. Locations for pelagic gillnetting (WUP; 2008-2014), littoral gillnetting (RNRP; 1998-2009), reservoir water sampling and tributary water sampling on the Alouette Lakes Reservoir

Hydroacoustic data

Acoustic data are collected at 12 transect locations evenly spaced along the length of the north and south basins of Alouette Lake Reservoir (Figure 4). Only hydroacoustic data collected from 2001-2014 were used to estimate the limnetic abundance of Kokanee in the Alouette Lake Reservoir. The hydroacoustic data collected prior to 2001 were not used as they were not considered equivalent for this purpose due the differences in hydroacoustic equipment used (single beam vs. split beam) (Tyler Weir, MFLNRO Large Lakes Specialist, Victoria BC, pers. comm.).

Since 2001 the acoustic data were collected using a Simrad model EK60 120 KHz split beam system. The downward looking transducer was towed on a planer alongside the boat at a depth of 1 m, and data were collected continuously along survey lines at 2-5 pings$\cdot$s^{-1} while cruising at ~2 m$\cdot$s^{-1}. Navigation was by radar, GPS, and a 1:75,000 Canadian Hydrographics bathymetric chart. Echograms for each transect were analyzed from surface to 50 m depth in 10 equal depth layers with an exclusion zone of surface to 3 m in the shallowest layer. Fish densities in number$\cdot$ha^{-1} for each transect and depth strata were output in 1-decibel (dB) size groups and compiled on an Excel spreadsheet. Further detail of hydroacoustic survey methods can be found in Hebert et al. (2015).

The hydroacoustic data was interpreted and analyzed from transect information taken from 10-50 m 2001-2011 & 2013-2014 and 5-50 m in 2012 which comprise the majority of Kokanee (Hebert et al., 2016 in press). Assignment of target strength to age of Kokanee varied by year and age class of Kokanee (see section below). As well, to account for the proportion of Kokanee recruits in the limnetic area > 10 m, a scaling factor of 0.92 obtained from trawl sampling was used to multiply the number of fish in the decibel ranges used. As trawl sampling was not conducted each year, the average of 0.92 was applied to all years of acoustic data for the purpose of this analysis.

Management hypotheses 2 and 3 required assessing whether reservoir operations affect recruitment so the abundance data were modeled in relation to a measure of reservoir fluctuations. The reservoir operations were incorporated into the analysis by calculating the sum of all reservoir level declines over the spawning and incubation period for each year.

Increases in the reservoir level were not considered to be an issue since dewatering of redds and reduction of rearing habitat would not occur.

Limitations and Data Assumptions

All data for the modeling of recruitment and its relationship to reservoir productivity were provided by the Ministry of Environment (MOE) and the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO). Data included hydrologic and nutrient loading information, as well as fish biometrics, gillnet catches, and hydroacoustic estimates.

Recent refinement of the methods used to analyze the hydroacoustics data provided by MFLNRO staff has improved the ability to synthesize Kokanee population dynamics in ALR. Target strength (dB) ranges based on Kokanee size-at-age information from trawl and gillnet surveys have improved the ability to understand the Kokanee age structure in the reservoir. While improvements have been made, analyses of hydroacoustic and trawl data have inherent uncertainties complicated by a number of factors including: 1) temporal and spatial distribution of other species in the pelagic zone, 2) losses of a proportion of the population due to entrainment, 3) inability of hydroacoustics to separate older Kokanee age classes (e.g. 2+ vs. 3+, 4) limited trawling effectiveness due to small reservoir size to obtain accurate species composition estimates under low densities, and 5) lack of information on Kokanee spawning population distribution and abundance (Hebert et al., 2015).

In the absence of biological, distribution and abundance data for Kokanee spawners, several assumptions have been made for modeling. These include:

- Age at maturity as derived from the hydroacoustic data was defined as age 2+ (three summers of growth) and age 3+ fish (four summers of growth); age at maturity from the gillnet data was defined as age 3+ fish unless otherwise noted;
- Spawning habitat was not limiting;
- Hydroacoustic data were representative of the actual proportions of Kokanee by size class (age 0, age 1-3).
- Inherent limitations in the equipment/software and inadequate size separation between older age classes of Kokanee affect the ability to accurately estimate age structure for larger (1+, 2+ and 3+) Kokanee using hydroacoustic data alone. These shortcomings may

affect the reliability of the estimates, however given the lack of ancillary information this was considered the only viable alternative for addressing the management questions on ALR.

- Acoustic estimates from 2001-2008 assumed that 92% of all targets -61 to -48 dB range were Kokanee fry (0+), targets -47 to -40 dB range were Kokanee (1+) and targets -39 to -33 dB range were Kokanee (2+ and 3+); from 10-50 m depths;
- Acoustic estimates in 2009-2011 assumed that 92% of all targets -61 to -46 dB range were Kokanee fry (0+), targets -45 to -40 dB range were Kokanee (1+) and targets -39 to -33 dB range were Kokanee (2+ and 3+); from 10-50 m depths;
- Acoustic estimates in 2012 assumed that 92% of all targets -64 to -49 dB range were Kokanee fry (0+), targets -48 to -42 dB range were Kokanee (1+) and targets -41 to -33 dB range were Kokanee (2+ and 3+); from 5-50 m depths;
- Acoustic estimates in 2013 and 2014 assumed that 92% of all targets -61 to -47 dB range were Kokanee fry (0+), targets -46 to -40 dB range were Kokanee (1+) and targets --39 to -33 dB range were Kokanee (2+ and 3+); from 10-50 m depths;
- The 2012 hydroacoustic survey was conducted in July as opposed to in October in other years. The July 2012 thermocline was higher than observed during October surveys in previous years. Pelagic gillnetting verified that the Kokanee were concurrently higher in the water column as well, and confirmed that Kokanee were exclusively below 5 meters in 2012.
- Out-migrating Kokanee at the dam spillway are representative of age structure in the reservoir in early spring before young-of-the-year (YOY) fry emerge; and
- Acoustic estimates were derived from data collected >10 m (2001-2011 & 2013-2014) and >5 m (2012) because these data were considered good indicators of Kokanee abundance during this time period and were likely to be less confounded by species distribution overlap (see Hebert et al. 2016 *in press*).

Analysis

Hierarchical Bayesian models (HBM) were fitted to: a) the size-at-age data from gillnetting and b) the stock-recruitment data from the hydroacoustic data using R version 3.2.3 (R Core

Development Team, 2013) and JAGS 4.0.1 (Plummer, 2012) which interfaced with each other via the jaggernaut package (Thorley, 2014) (see Appendix 1). Additional information on hierarchical Bayesian modelling in the BUGS language is detailed in Kéry and Schaub (2011).

The models assumed vague (low information) prior distributions (Kéry and Schaub, 2011). The posterior distributions were estimated from a minimum of 10,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kéry and Schaub, 2011). Model convergence was confirmed by ensuring that Rhat was less than 1.1 for each of the parameters in the model (Kéry and Schaub, 2011). Model adequacy was confirmed by examination of residual plots.

The posterior distributions of the fixed parameters discussed in Kéry and Schaub (2011) are summarized below in terms of a point estimate (mean), lower and upper 95% credibility limits (2.5th and 97.5th percentiles), the standard deviation (SD), percent relative error (half the 95% credibility interval as a percent of the point estimate) and significance (Kéry and Schaub, 2011).

The model results are displayed graphically by plotting the relationships between particular variables and the response with 95% credible intervals with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values respectively while random variables are held constant at their typical values [expected values of the underlying hyper-distributions] (Kéry and Schaub, 2011). Where informative, the influence of particular variables is expressed in terms of the effect size (i.e., percent change in the response variable) with 95% credible intervals (Bradford et al., 2005). Plots were produced using the ggplot2 R package (Wickham, 2009).

Size-at-Age

The data used for size-at-age analysis were Kokanee Age-3 lengths obtained through gillnetting surveys from 2003-2014.

During the size-at-age survey data preparation:

- The productivity was calculated as the N:P ratio from 2008-2014 of 7.45 multiplied by the nutrient with the lower value in the ratio (P).
- Standing crop was considered to be stabilized in 2003.
- Fish that were netted in July were removed.

Table 2. The posterior distributions for the fixed parameters used in the size-at-age Bayesian model See Appendix 3 for full model details.

Variable/Parameter	Description
bLength	Intercept for log(eLength)
bLengthDayte	Effect of Dayte on log(eLength)
bLengthLocationYear[i, j]	Effect of i^{th} Location in j^{th} Year on log(eLength)
bLengthProductivity	Effect of Productivity on log(eLength)
bLengthYear[i]	Effect of i^{th} Year on log(eLength)
Dayte[i]	Day of the year of capture of i^{th} fish
eLength[i]	Predicted length of i^{th} fish
Length[i]	Measured length of i^{th} fish
Location[i]	Location of capture of i^{th} fish
Productivity[i]	Productivity in year of capture of i^{th} fish
sLength	Standard deviation of residual variation in log(eLength)
sLengthLocationYear	Standard deviation of effect of i^{th} Location in j^{th} Year on log(eLength)
sLengthYear	Standard deviation of effect of i^{th} Year on log(eLength)
Year[i]	Year of capture of i^{th} fish

Stock-Recruitment

Stock recruitment (SR) analysis has a particular data requirement of accurate and precise measures of the reproductive productivity of the mature population. While the best measure of this is the number of eggs spawned, alternative measures of spawning stock that are commonly used include average fecundity by age and proportion of each age class in a population; multiplying the number of mature females by the average fecundity or total biomass of mature individuals; or an index of abundance of mature fish (Walters and Martell, 2004). Stock recruitment also requires an estimate of recruitment defined by the life stage at which the fish first become vulnerable to fishing gear, or an estimate of the population still alive any set time after the egg stage (Walters and Martell, 2004). All of these measures introduce uncertainty into the analysis before even beginning to assess recruitment (Walters and Martell, 2004).

To assess whether declines in fry abundance persist through time and cause an impact on the abundance of mature Kokanee a stock-recruitment model was also developed where age-0 fish were the stock and age-1 fish were considered the recruits. This analysis provided an estimation of the carrying capacity of age-1 fish.

The spawner to fry and fry to age-1 data were analyzed using a Bayesian Beverton-Holt stock-recruitment model. A better understanding of the Beverton-Holt stock-recruitment model can be found in Myers (2001). A further understanding of the Beverton-Holt stock-recruitment model with a Bayesian inference is detailed in Michielsens and McAllister (2004).

The posterior distributions for the fixed parameters used in the stock-recruitment model are detailed in Table 3. Full model details are provided in Appendix 1. Key assumptions of the stock-recruitment model include:

1) Fry numbers were multiplied by 0.92 to correct for non-Kokanee detections;
2) Recruitment varies with stock as described by a Beverton-Holt curve;
3) Recruitment varies with the sum of all reservoir elevation declines from Oct 15 to Feb 28;
4) The residual variation in recruitment is log-normally distributed.

Table 3. The posterior distributions for the fixed parameters used in the Bayesian stock-recruitment model spawners to fry. See Appendix 3 for full model details.

Variable/Parameter	Description
bElevationalDrop	Effect of ElevationalDrop on log(eRecruits)
ElevationalDrop[i]	Mean daily drop in reservoir elevation in i^{th} spawn year
eRecruits[i]	Expected number of recruits in i^{th} spawn year
K	Carrying capacity of the environment
R0	Proliferation rate per generation
Recruits[i]	Observed number of recruits in i^{th} spawn year
sRecruits	Standard deviation of residual variation in log(eRecruits)
Stock[i]	Observed number of spawners in i^{th} spawn year

Table 4. The posterior distributions for the fixed parameters used in the Bayesian stock-recruitment model fry to age 1. See Appendix 3 for full model details.

Variable/Parameter	Description
bElevationalDrop	Effect of ElevationalDrop on log(eRecruits)
ElevationalDrop[i]	Mean daily drop in reservoir elevation in i^{th} spawn year
eRecruits[i]	Expected number of recruits in i^{th} spawn year
K	Carrying capacity of the environment
R0	Proliferation rate per generation
Recruits[i]	Observed number of recruits in i^{th} spawn year
sRecruits	Standard deviation of residual variation in log(eRecruits)
Stock[i]	Observed number of spawners in i^{th} spawn year

RESULTS

Reservoir Elevation 2014

The 2014 average reservoir elevation was 122.6 m (GSC), almost identical to the long term mean of 121.7 m since 1984 (Figure 5). Average reservoir drawdown was 4.4 m in 2014, slightly lower than 5.03 m drawdown in 2013 (Appendix 2). The reservoir was at an average elevation of 122.5 m (GSC) during the months of nutrient restoration usually late April-September (MOE data on file). Following this period and similar to previous years (Hebert et al., 2015), reservoir elevation declined precipitously as a result of operations. Significantly, the decline in reservoir elevation during the fall coincides with the spawning and incubation period of mid-October to the end of February for shoal spawning Kokanee in the reservoir as detailed in Figure 6 (BC Hydro 2009).

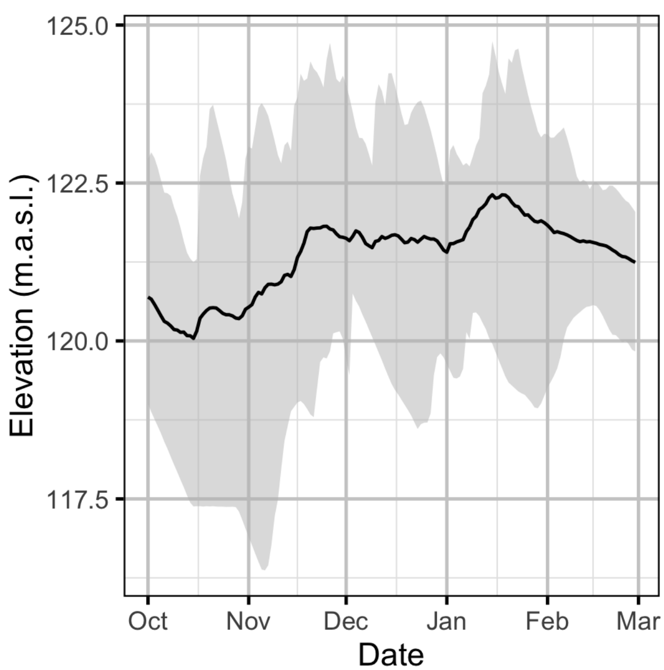

Figure 5. Alouette Reservoir mean, minimum and maximum daily elevations by date for spawn years 2002-2014. The minimum and maximum daily elevation are plotted with the grey band, the mean daily elevation for all years is plotted with the solid black line. (m.a.s.l=meters above sea level).

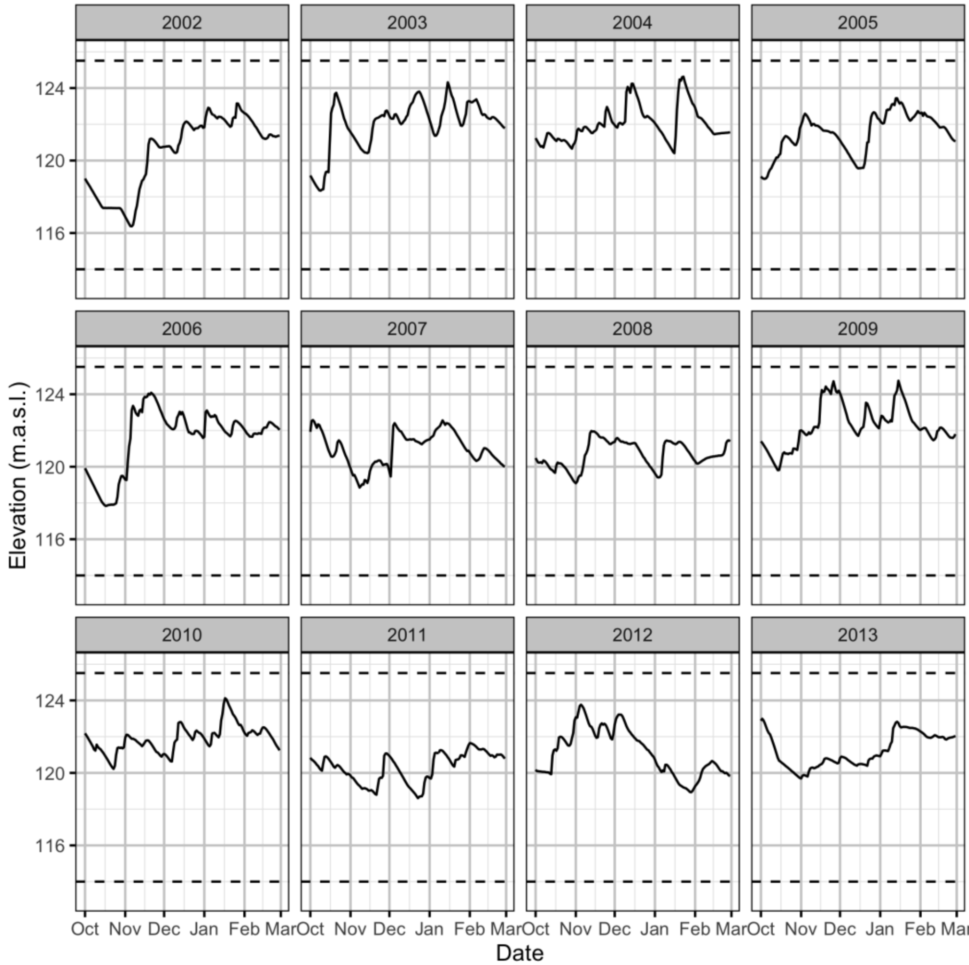

Figure 6. Alouette reservoir elevation in meters by month during the spawning and incubation season (October 15- February 28) for Kokanee from 2002-2014. Note-data is displayed by spawning year. Upper and lower dashed lines represent maximum and minimum allowable reservoir operations. (m.a.s.l=meters above sea level).

Size-at-Age

Size-at-age data from ALR gillnet captured Kokanee (age-3+) was analyzed using data from 2003-2014 and is displayed in Figure 7. As previously mentioned, the analysis of size-at-age data started in 2003 when the standing crop of Kokanee was considered to be stabilized following initial years of nutrient addition. Observed size data suggests a relatively stable pattern has developed since 2003 (Figure 7). However, size data in 2014 deviated substantially from the average and this deviation is suspected to be related to limited nutrient inputs in 2014 (Shannon Harris pers. comm.).

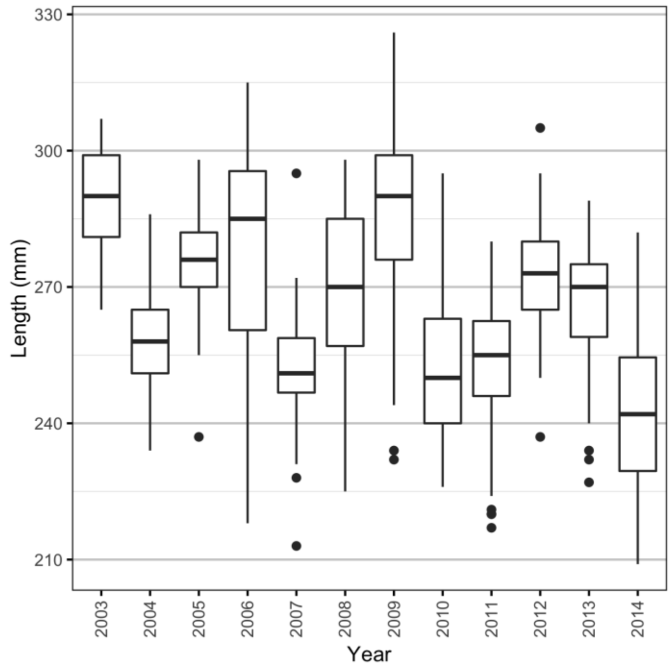

Figure 7. Observed length of Age-3 Kokanee captured with gillnets on Alouette Lake Reservoir from 2003-2014 when the standing crop of Kokanee was considered to be stabilized.

Size-at-age model results suggest predicted size has declined since 2003 (Figure 8). Size has declined from the mean of 278 mm in 2003 to below the average of 267 mm for the time period (2003-2014) to 252 mm in 2014 (Table 5).

Table 5. Predicted length of Age-3 Kokanee (with 95% CRIs) from 2003-2014.

Year	Estimate	Lower 95% CRI	Upper 95% CRI	SD	Error
2003	278.13	267.58	289.04	5.56	4
2004	261.33	243.64	281.88	9.49	7
2005	270.40	251.19	293.43	10.2	8
2006	267.66	256.57	277.62	5.47	4
2007	248.70	241.18	256.33	3.9	3
2008	267.36	259.81	275.66	4.08	3
2009	293.07	286.24	299.74	3.47	2
2010	272.67	262.97	283.09	5.19	4
2011	254.63	244.44	264.57	5.17	4
2012	269.01	259.60	278.64	4.85	4
2013	264.97	255.91	274.23	4.41	3
2014	252.69	241.93	264.44	5.67	4

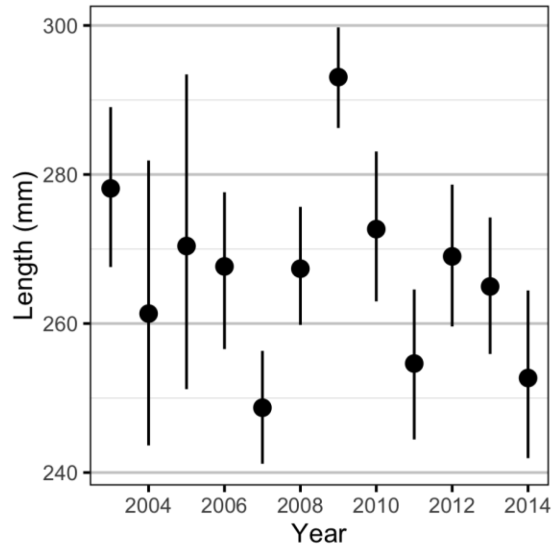

Figure 8. Predicted length of Age-3 Kokanee (with 95% CRIs) from 2003-2014 when the standing crop of Kokanee was considered to be stabilized.

ALR productivity used in the analysis was calculated as the N:P ratio from 2008-2014 of 7.45 multiplied by the nutrient with the lower value in the ratio (P) displayed in Figure 9. Model results indicate that the productivity (N:P ratio) was not a significant predictor of Kokanee length, but does indicate a slight positive trend in length as productivity increases (Figure 10; Appendix 3). However, it should be noted that the model did not account for variation in fish density over time which is known to affect Kokanee size (Rieman and Myers 1992).

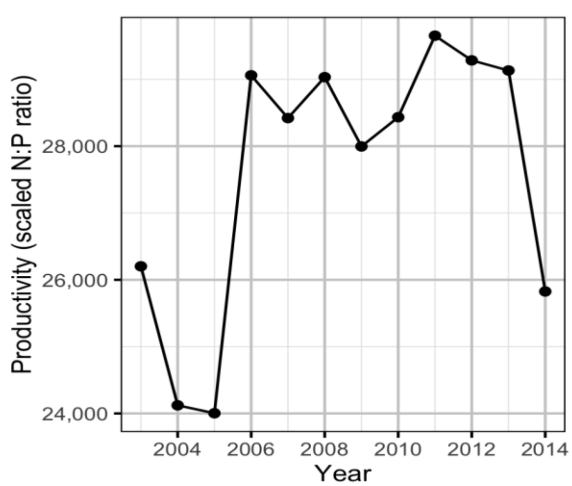

Figure 9. Calculated productivity in Alouette Reservoir from 2003-2014 when the standing crop of Kokanee was considered to be stabilized.

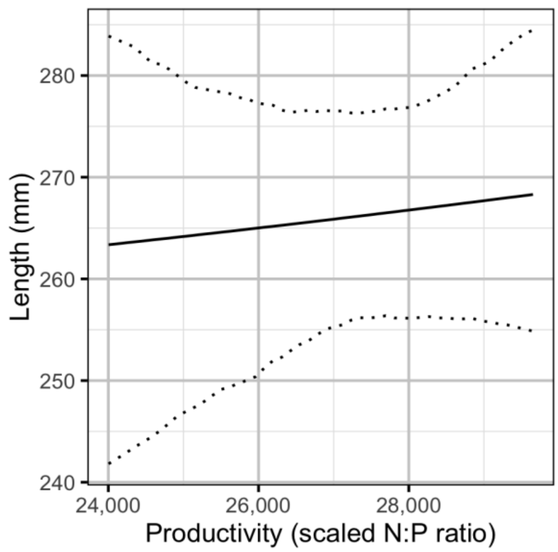

Figure 10. Relationship between productivity (scaled N:P ratio, see methods for detail) and length of age-3+ Kokanee captured in gillnets from 2000-2014 in ALR. Dotted lines indicate 95% credibility intervals.

Kokanee abundance by age class determined from hydroacoustic data (2002-2014) demonstrates variable trends over time (Figure 11). Kokanee fry abundance appears to have increased until 2010, Kokanee age 1s display three peaks and two valleys whereas the age 2s and 3s Kokanee appear to have increased up to 2012 before declining for the last three years (Figure 11). Most notably all Kokanee age classes indicate a substantial decline in 2014 likely associated with limited nutrient inputs as a result of distribution and delivery problems (Shannon Harris pers. comm.).

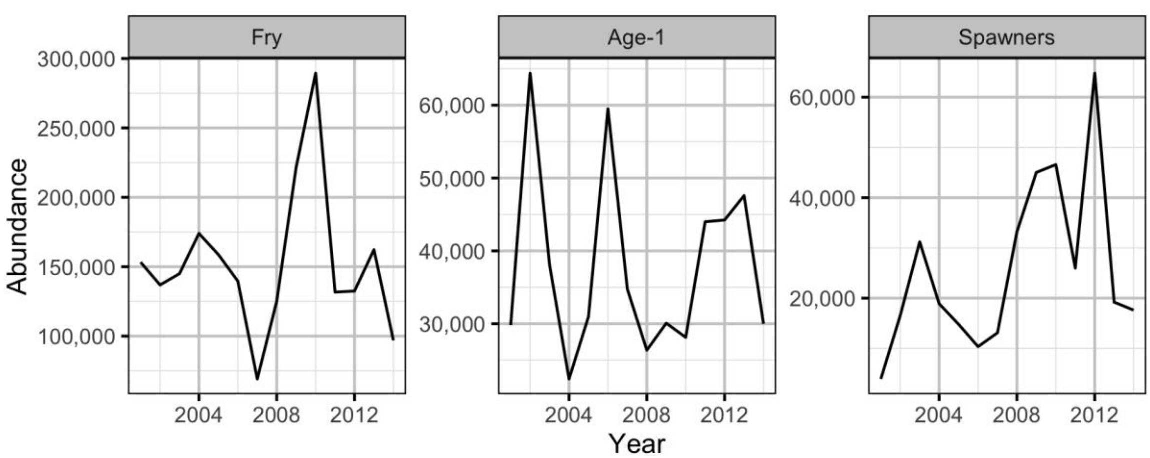

Figure 11. Abundance of fry, age 1 and age 3 (spawners) old Kokanee from 2002-2014 as assessed from hydroacoustic data. Note 2001 data from split beam not included.

Stock Recruitment

Two models were used to determine the stock-recruitment relationship for ALR Kokanee. Results from the first stock recruitment model used to assess the spawner recruitment relationship from combined age-2+ and age-3+ fish (spawners) to age-0+ fish (recruits) for Kokanee, predicted an average carrying capacity of fry of 153,990 (95% CRI 128,720-181,150) in ALR (Table 6; Figure 12). This model assumes a density dependent response where the relationship between the spawners and the recruits is non-linear and reaches an asymptotic level in which recruitment does not increase with further increases in spawners.

Table 6. Estimated carrying capacity of age-0 and age-1 Kokanee in Alouette Lake Reservoir based on a Beverton-Holt stock recruitment model.

Age Class	Estimate	Lower 95% CRI	Upper 95% CRI	SD	Error
age 0	153,990	128,720	181,150	13,600	17
age 1	44,770	34,950	58,260	6,050	26

In relation to reservoir operations, the spawner-recruit model also predicted that daily reservoir elevation changes (October 15-February 28) could potentially limit recruitment and the reproductive success of the ALR Kokanee population (Figure 13). However it is important to note the relationship was not considered significant and demonstrated substantial uncertainty (Figure 13; Appendix 3).

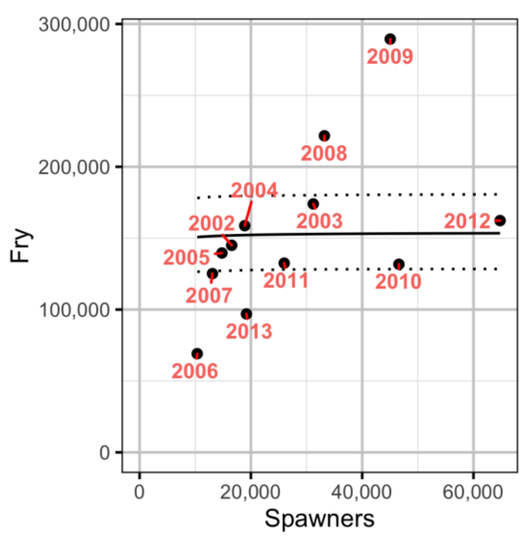

Figure 12. Predicted stock-recruitment relationship by spawn year (with 95% CRIs). Points are labeled with the year in which sampling of spawners occurred.

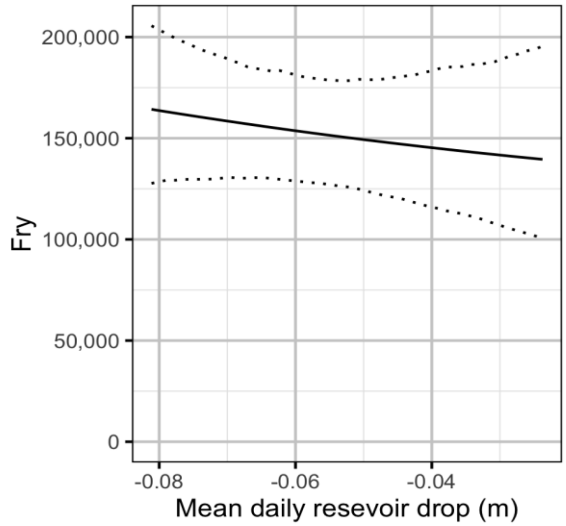

Figure 13. Predicted influence of reservoir fluctuations on spawners to fry recruitment (with 95% CRIs).

The second stock recruitment model, used to assess the spawner recruitment relationship from age-0+ (fry) to age-1+ fish (recruits) for Kokanee, predicts an average age-1+ carrying capacity of 44,770 (95% CRI 34,950-58,260) in ALR (Table 6; Figure 14). Once again this model indicates a density dependent response where the relationship between age-0 and age-1+ is non-linear and reaches an asymptotic level in which age 1+ recruitment does not increase with further increases in age-0+ fry.

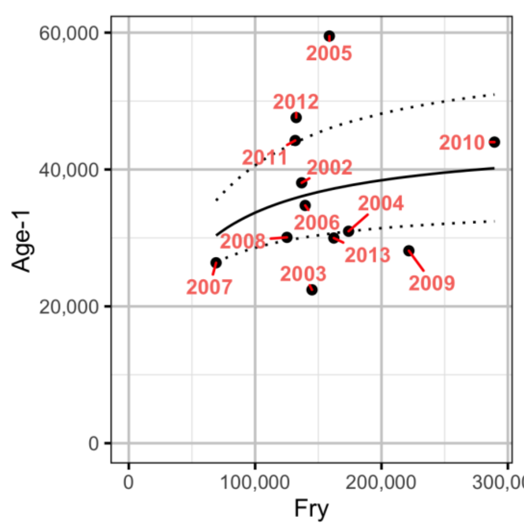

Figure 14. Predicted stock-recruitment relationship by fry year (with 95% CRIs). The year label is for the year in which the age-0 fish were enumerated and the age-1 fish are from the subsequent year.

In contrast to the first stock recruitment model (previous section), daily reservoir elevation changes (October 15-February 28) do not appear to limit recruitment of the ALR Kokanee population from fry to age 1 (Figure 15). However, similar to the first model, there was substantial uncertainty in the model estimates. It should also be noted that the stock recruitment model did not account for nerkid out-migrations from the reservoir through water withdrawals at the dam spillway or losses via entrainment through the tunnel.

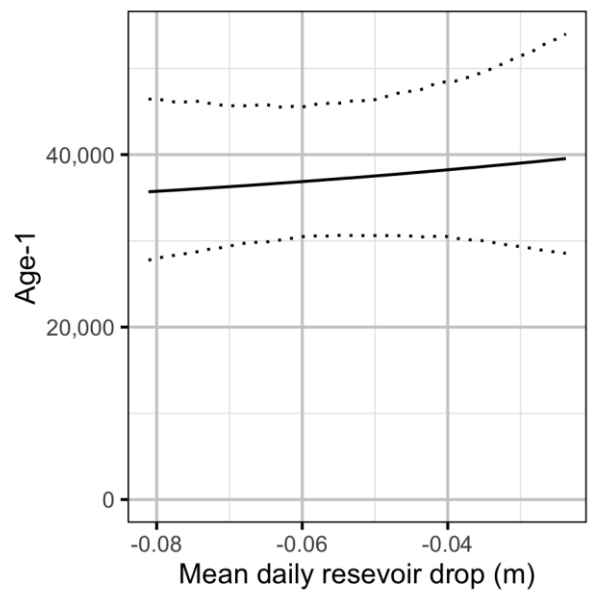

Figure 15. Predicted influence of reservoir fluctuations on fry to age-1 recruitment (with 95% CRIs) in Alouette Lakes Reservoir from stock recruitment model.

DISCUSSION

Observations by McCusker et al. (2003) suggest that reservoir operations during the Kokanee spawning and egg incubation window may impact the Kokanee population in ALR, similar to that observed on the West Arm of Kootenay Lake (Andrusak and Andrusak, 2013, 2014). In order to mitigate the effects of drawdown on the West Arm Kokanee population, drawdown on the West Arm of Kootenay Lake was recommended to occur before the spawning period so that when spawning occurs when the lake level is lower than the normal winter operating level (Andrusak and Andrusak, 2014, 2013); i.e. spawning occurs at the low lake level rather to ensure redds are not stranded when drawdown occurs. However subsequent studies by Plate et al. (2003) suggest that ALR Kokanee may primarily spawn at depths of 20-40 m. Similar observations of Kokanee spawning at depths beyond the areas of reservoir drawdown zone have been documented on Seton Lake Reservoir and Anderson Lake (Morris and Caverly 2004).

The ALUMON#6 WUP study has relied solely on gillnet and hydroacoustic data to assess the influence of reservoir operations on the Kokanee population primarily because of the scarcity of data on the distribution and abundance of the spawning population. Consequently, an indirect method has been used involving fitting size-at-age data to an age model using gillnet data to determine if the population’s size-at-age is increasing, stable or decreasing with optimized reservoir productivity. In addition, a Kokanee stock-recruitment model was developed from the hydroacoustic data to assess if reservoir fluctuations affected fry abundance and whether any decline in fry abundance persisted thus affecting the abundance of older age classes. Invariably, these analyses are fraught with numerous assumptions based on the available but limited data thus there is substantial uncertainty in the derived model results.

Similar to previous years, size-at-age modeling confirmed the immediate size increased following the commencement of the nutrient addition program in 1999. In recent years following nutrient addition in the ALR, the size-at-age information indicates a relatively stable pattern of size exists for Kokanee with average spawner size ~267 mm since 2003. The initial larger size of Kokanee from 2000-2002 corresponded to when Kokanee abundance was considerably lower than the present day estimates (Hebert et al. 2015). The present day (2014) Kokanee mean size of 252 mm is smaller, which may be a result of limited nutrient inputs associated with distribution and delivery problems in 2014. Size-at-age analysis suggests that hypothesis one ($H_0 1$) under the first ALUMON management question cannot be rejected since the data displays a size structure that has stabilized after initial increases under higher lake productivity.

Unlike previous years reporting (Andrusak and Irvine, 2013), the current stock recruitment models were developed in a Bayesian framework for interpreting the effect of reservoir fluctuations on fry abundance. The Bayesian inference can be more flexible and interpretable for management purposes and is often better at representing the uncertainty (Punt and Punt, 1997; Michielsens and McAllister, 2004). This spawner-recruit (SR) model of spawning stock to age-0 predicted that reservoir drawdown could potentially limit recruitment and the reproductive success of the ALR Kokanee population. However it is important to note the relationship was not considered significant and demonstrated substantial uncertainty. In contrast to the first stock recruitment model, the fry to age 1 SR model indicates that daily elevation changes during the Kokanee spawning and rearing period does not limit recruitment of Kokanee from age-0 to the age-1+ stage. Both models indicated that density dependent factors likely regulate the abundance of age-0 and age-1 fish. In summary, the Hierarchical Bayesian stock recruitment model results failed to reject hypotheses two ($H_0$2) and three ($H_0$3) under management question number 2 and 3.

The stock recruit analysis suggests the possibility that reservoir operations may be impacting Kokanee fry production. Nonetheless, it is acknowledged that there is substantial uncertainty associated with the results and further refinement of the model and analyses is recommended. For example, the model did not assess variables that account for time dependence or lags often associated with density dependent growth responses; these are commonly observed in many nerkid populations (Myers et al., 1997; Rieman and Myers, 1992). Finally, competition and growth between and within cohorts may be important factors in regulating the size-at-age of Kokanee within ALR (Myers 2001; Myers et al. 1997), similar to that observed on Quesnel Lake (Dolighan et al. 2012).

Spillway releases from the dam during the spring have also occurred since 2005 and were implemented to determine the volitional migration success of juvenile salmonids from the reservoir (Mathews et al., 2013). It is suspected that spillway releases may impact the Kokanee population due to the apparent high proportion of age-1+ fish that emigrate. An average of ~16,000 juvenile *O. nerka* per year have emigrated from ALR since 2005 (Plate et al., 2014), not a small number if the MFLNRO in-reservoir estimates on file are accurate. However, as previously discussed, there is the possibility of a compensatory benefit of increased growth and survival from the annual loss of juvenile Kokanee from the reservoir. These potential benefits may provide regulatory agencies (MOE and DFO) with the ability to meet objectives for the restoration of ALR and the Alouette River Sockeye Re-Anadromization Project (Plate et al., 2014).

Analysis of data suggests that the ALR Kokanee population is likely regulated by compensatory mechanisms, similar to other Kokanee populations (Bassett et al., 2016; Hebert et al., 2015). Nonetheless, model results did identify the possibility of a recruitment limitation to the ALR Kokanee population due to reservoir operations, previously identified in Andrusak (2014). The latter null hypotheses ($H_0 2$ and $H_0 3$) are somewhat problematic due to the nature of such dichotomous tests, similar to that detailed in Bradford et al. (2005). Confounding the effect of reservoir operations, emigrations of Kokanee through the spillway during migration success studies may also affect the *in situ* Kokanee population estimate, and such effects would likely persist throughout that cohort's life stage. Combined with the considerable uncertainty in modeling of the Kokanee data, the ability to detect impacts from reservoir operations is limited. As well, spawning habitat cannot be ruled out as a limiting factor to Kokanee recruitment within ALR. Overall, although it is preferred to have better data on the spawning population, acquiring that data would be outside the scope of the WUP and despite the limitations of the data used, this information is deemed adequate for modeling purposes and has led to informative insight into some of the potential mechanisms regulating the ALR Kokanee population.

Conclusions

Utilizing information (1998-2014) on the reservoir, the Alouette WUP attempts to address key management questions and hypotheses, including:

1) Is the existing Kokanee population in Alouette Lake Reservoir recruitment limited?

   Size-at-age analysis suggests that hypothesis one (H01) under the first management question cannot be rejected since the data displays a size structure that has stabilized after initial increases under higher lake productivity.

2) If there is evidence of a recruitment constraint to productivity, can it be linked to reservoir operations, in particular the extent of reservoir fluctuations during the spawning and incubation period deemed to be mid-October to the end of February?

   The stock recruitment model results failed to reject hypotheses two (H02) under management question two. The spawner-recruit (SR) model predicted that reservoir drawdown could potentially limit recruitment and the reproductive success of the ALR Kokanee population.

3) If found linked to reservoir operation, what is the nature of the relationship and can it guide the development of possible mitigative reservoir operations?

The stock recruitment model results failed to reject hypotheses three (H03) under management questions three. In relation to reservoir operations, the spawner-recruit model predicted that daily reservoir elevation changes (October 15-February 28) could potentially limit recruitment and the reproductive success of the ALR Kokanee population. However, the relationship was not considered significant and demonstrated substantial uncertainty.

RECOMMENDATIONS

While the management questions for this study have been addressed, uncertainties with the model results still exist. If during the future Water use plan Order review (WUPOR) these uncertainties require further review or it is determined that the refinement of the model is necessary, we recommend the following:

- Fisheries work should be directed at obtaining Kokanee spawning timing window, distribution, this work will be addressed through the ARSRP multi-year plan funded through the FWCP.
- While all available data was included in the modeling exercise, the data only represented three generations of Kokanee. It is recommended that new data be incorporated in the hierarchical Bayesian framework to reduce uncertainties.
- To improve model outcomes, Kokanee density information could be incorporated to model variability in size-at-age.
- Incorporating the losses of biomass from Alouette Reservoir would reduce the models uncertainty. However, given that this data was not available at the time of model development it was determined that incorporating partial losses would not increase clarity. In Alouette Reservoir fish biomass is exported from the reservoir from: 1) entrainment through the tunnel to Stave Reservoir; 2) through export over the spillway; and 3) through the fishery. Using BC Hydro's Fish Entrainment Strategy screening methodology (BC Hydro 2006), a qualitative screening exercise reported that entrainment from Alouette Reservoir to Stave Reservoir was likely low (Squires 2009). However this screening exercise was not available for review at the time of model development. It is recommended that this report be reviewed prior to removing from further consideration in the model. For export over the spillway, data is available for smolt outmigration during the WLR project from the WLR managed rotary screw trap however data is not available during other controlled spills that in all likelihood export fish from the reservoir. Finally, biomass removed from the reservoir from the fishery cannot be accounted for as the annual monitoring program does not include a creel survey.

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Appendix 1 Model Code

Size-At-Age - Model

```
model{
  bLength ~ dnorm(5, 5^-2)

  bLengthDayte ~ dnorm(0, 5^-2)

  bLengthProductivity ~ dnorm(0, 5^-2)

  sLengthYear ~ dunif(0, 5)
  for (i in 1:nYear) {
      bLengthYear[i] ~ dnorm(0, sLengthYear^-2)
  }

  sLengthLocationYear ~ dunif(0, 5)
  for (i in 1:nLocation) {
    for(j in 1:nYear) {
      bLengthLocationYear[i, j] ~ dnorm(0, sLengthLocationYear^-2)
    }
  }

  sLength ~ dunif(0, 5)

  for(i in 1:length(Length)){
    log(eLength[i]) <- bLength
                     + bLengthDayte * Dayte[i]
                     + bLengthProductivity * Productivity[i]
                     + bLengthYear[Year[i]]
                     + bLengthLocationYear[Location[i], Year[i]]

    Length[i] ~ dlnorm(log(eLength[i]), sLength^-2)
  }
}
```

Stock-Recruitment – Spawner to fry

```
model {
  K ~ dnorm(10^3, (10^3 /2)^-2) T(1, )
  R0 ~  dnorm(10^5, (10^5)^-2) T(10^4, 10^7)

  bElevationalDrop ~ dnorm(0, 5^-2)

  sRecruits ~ dunif(0, 5)

  for(i in 1:length(Stock)){
    log(eRecruits[i]) <- log(K * Stock[i] / (1 + Stock[i] * (K - 1) / R0))
                       + bElevationalDrop * ElevationalDrop[i]

    Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
  }
}
```

Stock-Recruitment – Fry to age 1

```
model {
  K ~ dnorm(2, 1^-2) T(1, )
  R0 ~  dnorm(10^4, (10^3)^-2) T(0, )

  bElevationalDrop ~ dnorm(0, 5^-2)

  sRecruits ~ dunif(0, 5)

  for(i in 1:length(Stock)){
    log(eRecruits[i]) <- log(K * Stock[i] / (1 + Stock[i] * (K - 1) / R0))
                       + bElevationalDrop * ElevationalDrop[i]

    Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
```

Appendix 2 Alouette Lake Reservoir Elevation 1984-2014

Year	Maximum Elevation (m)	Minimum. Elevation (m)	Reservoir Draw (m)	Mean Elevation (m)	SD
1984	124.99	117.73	7.26	122.04	1.85
1985	124.71	116.57	8.15	121.66	2.38
1986	125.68	118.03	7.65	122.68	1.51
1987	124.57	115.84	8.73	121.34	2.14
1988	124.85	118.39	6.46	121.73	1.84
1989	124.37	118.28	6.09	122.26	1.25
1990	124.74	116.04	8.7	120.25	2.2
1991	124.24	116.1	8.14	119.95	2.19
1992	122.77	116	6.77	118.9	1.98
1993	124.89	116.18	8.72	120.1	2.69
1994	125.27	117.07	8.2	121.88	2.09
1995	126.14	119.21	6.93	122.96	1.3
1996	124.64	120.7	3.94	122.13	0.62
1997	125.08	120.11	4.97	122.5	1.08
1998	124.03	117.24	6.79	121.81	1.51
1999	124.45	119.5	4.95	122.4	1.09
2000	124.43	118.92	5.51	121.27	1.46
2001	123.95	117.62	6.33	121.33	1.6
2002	124.39	116.37	8.02	121.76	1.95
2003	124.3	118.34	5.96	122.13	1.06
2004	124.32	120.22	4.1	122.16	0.89
2005	124.63	118.84	5.79	121.78	1.11
2006	124.08	117.84	6.25	121.54	1.27
2007	125.29	118.85	6.44	122.4	1.19
2008	124.27	119.09	5.18	121.96	1.4
2009	124.72	119.41	5.31	122.27	1.18
2010	124.74	120.22	4.52	122.3	0.8
2011	124.12	118.61	5.51	121.92	1.43
2012	124.09	119.69	4.4	122.21	1.09
2013	123.96	118.94	5.03	121.82	1.38
2014	124.38	119.97	4.41	122.60	0.81

Appendix 3 Parameter Estimates

Parameter Estimates-Size-At-Age

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bLength	5.5853800	5.5461800	5.622780	0.0184600	1	0.0010
bLengthDayte	-0.0027770	-0.0036510	-0.001861	0.0004620	32	0.0010
bLengthProductivity	0.0000034	-0.0000154	0.000023	0.0000096	570	0.7066
sLength	0.0530720	0.0500760	0.056145	0.0015270	6	0.0010
sLengthLocationYear	0.0194600	0.0102700	0.029700	0.0049600	50	0.0010
sLengthYear	0.0573900	0.0337000	0.101740	0.0168000	59	0.0010

Convergence	Iterations
1.01	50000

Parameter Estimates-Stock-Recruitment (Spawners To Fry)

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bElevationalDrop	-2.9600	-10.9100	5.4800e+00	4.150e+00	280	0.4492
K	1009.0000	154.0000	1.9330e+03	4.740e+02	88	0.0010
R0	141580.0000	118630.0000	1.6048e+05	1.099e+04	15	0.0010
sRecruits	0.3914	0.2566	6.5410e-01	1.007e-01	51	0.0010

Convergence	Iterations
1.09	1e+05

Parameter Estimates Stock-Recruitment (Fry To Age-1)

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bElevationalDrop	1.7200	-5.3100	8.7000	3.62e+00	410	0.6188
K	1.3235	1.2009	1.4893	7.25e-02	11	0.0010
R0	10127.0000	8135.0000	12060.0000	1.01e+03	19	0.0010
sRecruits	0.3097	0.2018	0.4934	7.55e-02	47	0.0010

Convergence	Iterations
1.01	10000