# Alouette Project Water Use Plan

## Kokanee Age Structure Analysis

## Implementation Year 4

## Reference: ALUMON-6

**Alouette Lake WUP Monitor 6: Kokanee Population Analysis**

**Study Period: 2011 - 2012**

**Poisson Consulting**

**March 2013**

# ALOUETTE KOKANEE AGE STRUCTURE ANALYSIS

# (ALUMON#6)-2012

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Prepared for

Ministry of Environment and BC Hydro

Prepared by:

Redfish Consulting Ltd.
5244 Highway 3A
Nelson, British Columbia
V1L 6N6

and

Poisson Consulting Ltd.
4216 Shasheen Road
Nelson, British Columbia
V1L 6X1

**Cover Photo**: 'Photo of the Alouette Reservoir during the fall of 2012.' Photograph taken on the 9th of October 2012 by Greg Andrusak.

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# EXECUTIVE SUMMARY

The kokanee Age Structure Population Analysis (ALUMON #6) is in its fifth year of a multi-year study to address potential impacts of reservoir operations on the Alouette Lakes Reservoir (ALR) kokanee population. The focus of the study, undertaken as part of a larger monitoring protocol developed under the BC Hydro Alouette Reservoir Water Use Plan (WUP), is to address whether the current kokanee population is demonstrating recruitment limitation and whether any identified recruitment limitation is related to reservoir operations. This study addresses three important management questions: 1) is the existing kokanee population in the ALR 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?

Two approaches were utilized to address the key management questions within this study in 2012, including; 1) direct assessments of kokanee spawning distribution and abundance using daytime boat visual surveys and nighttime snorkel surveys based on recommendations from the previous year and 2) use of a model based approach to assess whether the kokanee population was recruitment limited and whether reservoir fluctuations during the spawning and incubation period affected subsequent fry and adult abundance. This model based approach utilized a size-at-age model of kokanee collected from gillnet data from 2000-2012 to determine if the population's size-at-age is stable or decreasing with optimized reservoir productivity. In addition, a kokanee stock-recruitment model was developed from hydroacoustic data collected from 2001-2012 to assess if reservoir fluctuations affected fry abundance and whether any decline in fry abundance persisted thus affecting the numbers of older age classes.

In the fall of 2012, surveys were conducted in order to determine spawner timing and abundance, and redd abundance and distribution in the Alouette Reservoir. Daytime visual counts along the shoreline by boat and nighttime snorkel surveys were the methods employed to assess near shore areas of the Alouette Reservoir. Neither the boat based surveys nor nighttime snorkel surveys conducted over the three day period in October 2012 observed the presence of spawning kokanee or redd construction in the near-shore areas of the reservoir. Maximum depth of observations by either method did not exceed 5 m.

Analysis of the size-at-age modeling indicates potential compensatory mechanisms regulating age 3+ kokanee. The kokanee population has undergone a substantial increase since 2000, while the average kokanee size from 2000 to 2004 has subsequently declined before stabilizing at the present level around which there are inter-annual fluctuations. However, the relation between abundance and size of kokanee in the reservoir is relatively weak and not significant ($p=0.221$, $R^2=0.14$) and this suggests that other factors related to reservoir productivity and/or food quality maybe influencing the compensatory mechanisms.

The stock recruitment analysis revealed that modeling the contribution of spawning stock to the age-0 population was a relevant predictor of the kokanee dynamics. The analysis indicated that density dependent factors likely regulate the population abundance of both age-0 and age-1 fish. Additional years of data will improve the support for model selection and the underlying mechanisms regulating the ALR kokanee population. The relative survival from age-0 to age-1 fish was estimated to be 29.7% in 2011, considerably higher than the mean survival of 20.2% from 2001-2011 (range=10.8-29.8%). The highest rate of relative survival of 29.8% was evident in the 2007, and may be coupled with low densities of age-0 fish. This record low age 0 abundance also coincided with a large out-migration (n=62,923) of juvenile kokanee from the reservoir during surface flow releases from the Alouette Dam, mostly assumed to be age-1 kokanee. Future assessment of large out-migrations of kokanee from the reservoir would be beneficial in understanding the underlying mechanisms regulating the ALR kokanee population while providing important data for BC Hydro as well as fisheries managers.

Based on assessment information and modeling results to date, it appears that reservoir operations may have a limited effect upon the kokanee population within the ALR. Importantly, it appears that there is an ability to address the key management questions in the Alouette WUP through the field assessment and the modeling of kokanee data collected on the reservoir.

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# INTRODUCTION

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). The focus of the study, under the auspices of the BC Hydro Alouette Reservoir Water Use Plan (WUP), is to address whether the current kokanee population is demonstrating recruitment limitation and whether any identified recruitment limitation is related to operations-based limitations to reproductive success. The reservoir has demonstrated an increase in productivity and fish abundance since nutrient addition has commenced (Harris et al. 2007; Squires et al. 2009; Harris et al. 2010; Harris et al. 2011), but there is a concern that reservoir operations may be limiting the kokanee population from reaching full capacity. Smolt releases through intentional water withdrawals at the dam spillway and the planned re-introduction of anadromized kokanee/sockeye confound the ability to assess effects of hydro operations on the kokanee population.

Kokanee populations, similar to other nerkid populations, are often regulated by density dependent processes (Hyatt and Stockner 1985, Myers et al. 1997, Myers 2001). Moreover, 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). Nonetheless, it is well known that reservoir formation and operations have adverse "footprint" and "operational" effects upon fish populations (Ney 1996; Stockner et al. 2000; Stockner et al. 2005; Moody et al. 2007). Determining whether reservoir operations could potentially limit recruitment of Alouette kokanee through impacts to spawning and or incubation success under increased productivity are key management questions under the ALR WUP.

Previously, direct assessment of reservoir operations on spawning success was not possible due to limited information on kokanee spawning distribution and abundance. To address this shortcoming, surveys were conducted in 2012 to directly assess kokanee spawning distribution and abundance within the reservoir. Until 2012 assessment of possible impacts of reservoir operations on the kokanee population relied upon analysis of information from available hydroacoustic and gillnet data obtained in the reservoir (MFLNRO and MOE data on file; Andrusak and Irvine 2012). The 2012 study was undertaken in addition to the larger monitoring protocol developed by the Alouette Water Use Plan Consultative Committee under the Alouette Reservoir Water Use Plan (WUP). This report summarizes information from kokanee spawner surveys conducted in 2012 and results from analysis of hydroacoustic and gillnet data

(1998-2012) collected on the reservoir to begin to answer the three management questions posed by the ALR WUP.

## *Management Questions and Hypotheses*

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

1) Is the existing kokanee population in the 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)? and;

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.

# 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 1656 ha in area at full pool and has an average drawdown range of 5.7 m (2002-2011). 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 near low pool (Figure 3), based on licensed storage, providing 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 level drops below 116 m (BC Hydro, 1996). A spring surface release occurs from April 15$^{th}$ to June 14$^{th}$ to allow for the experimental release of kokanee smolts. The reservoir elevation is kept above 122.5 m from June 15$^{th}$ to Labour Day (Sept 5$^{th}$) for recreational purposes. The new water use plan allows for a short shoulder season where the reservoir elevation will be at 121.25 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.

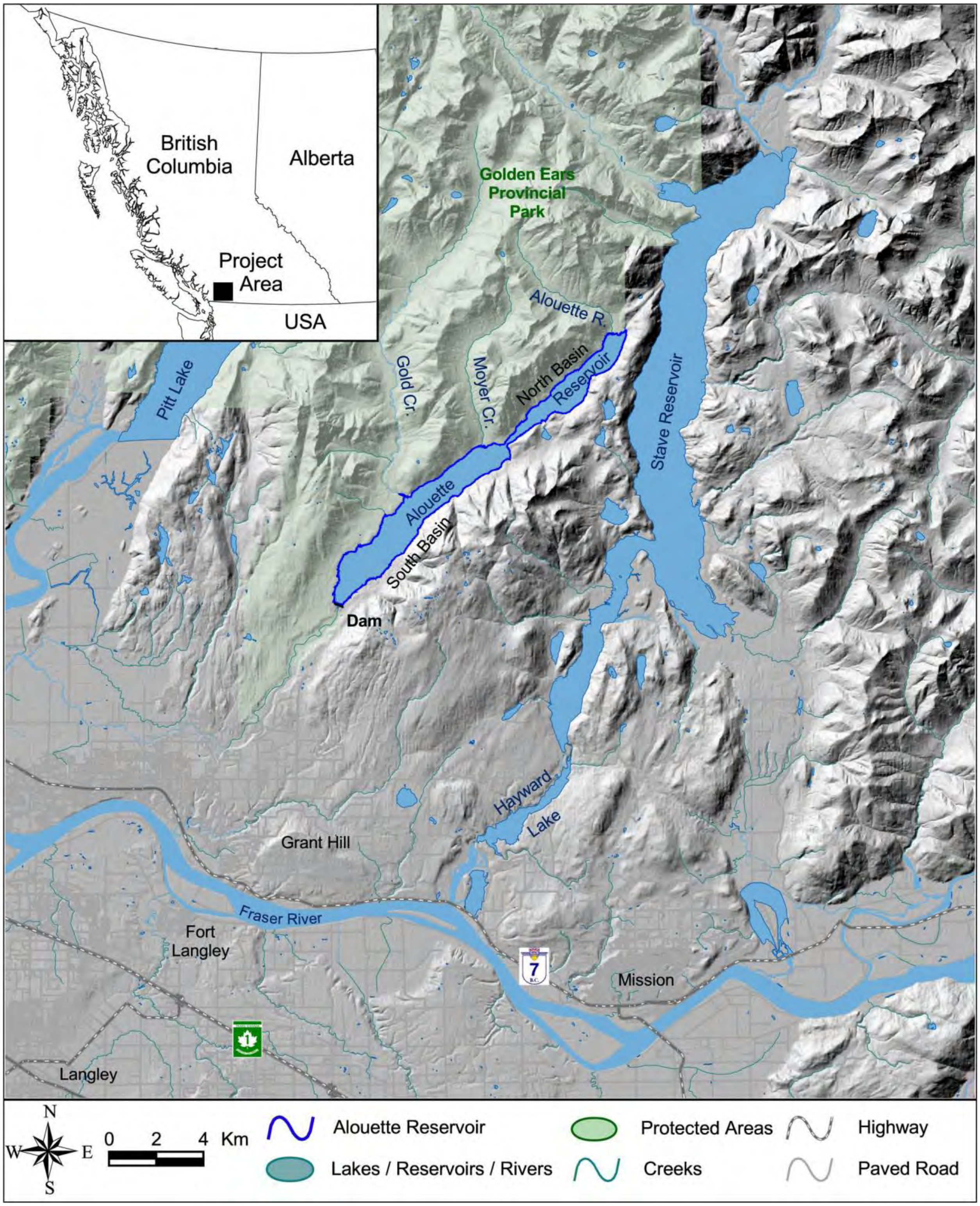


**Figure 1**. Location of Alouette Lake Reservoir.

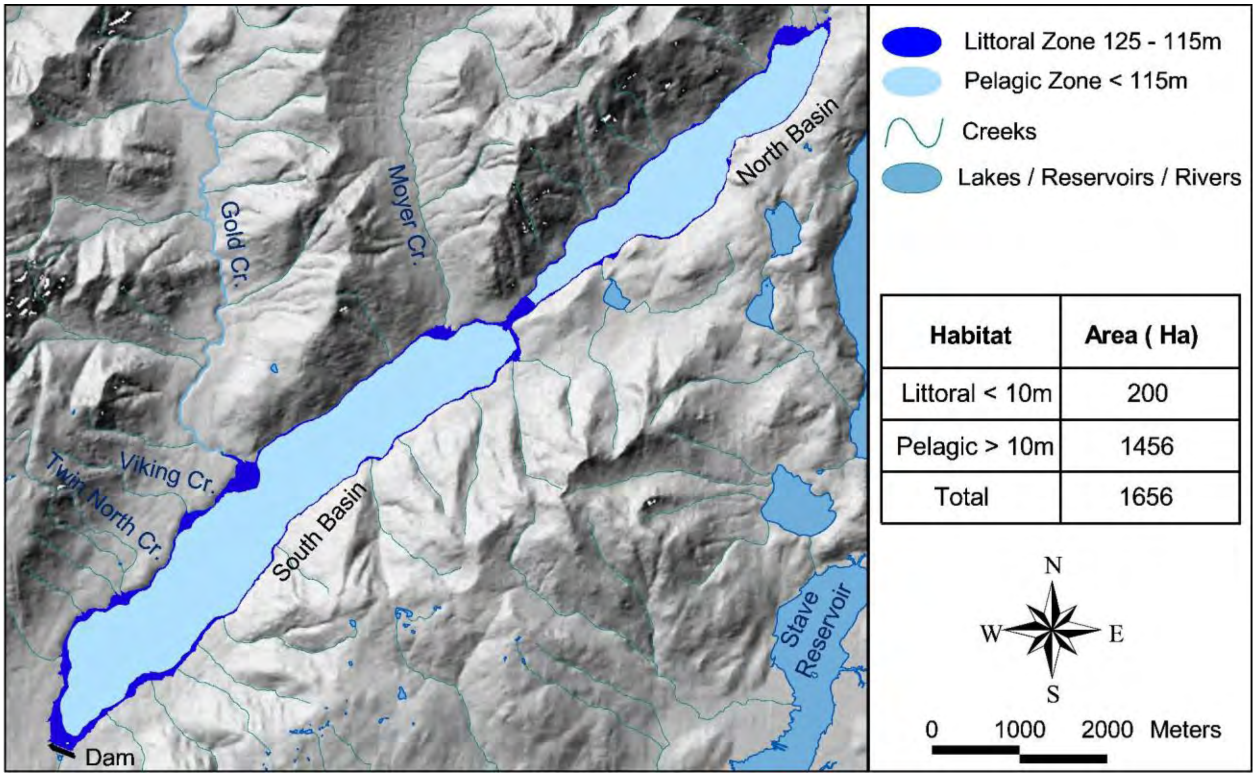


**Figure 2**. Maximum operating level (125 m) for Alouette Lakes Reservoir**.**

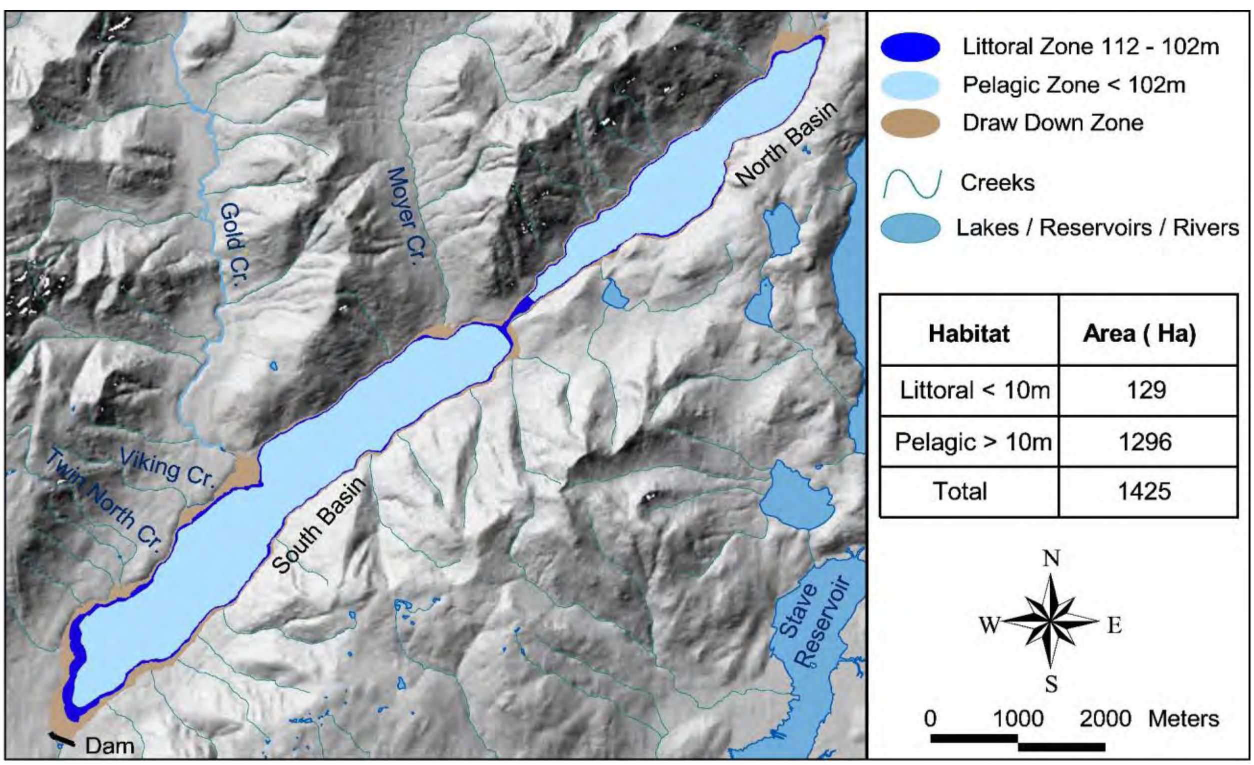


**Figure 3**. Minimum operating level (112 m) for Alouette Lakes Reservoir. Note drawdown zone and/or potential zone of impact for shore spawning kokanee.

# METHODS

## Spawner Surveys

In the fall of 2012, surveys were conducted in order to determine spawner timing and abundance, and redd abundance and distribution in the Alouette Reservoir. Daytime visual counts along the shoreline by boat and nighttime snorkel surveys were the methods employed to assess near shore areas of the Alouette Reservoir, similar to that on the West Arm of Kootenay Lake (Andrusak and Andrusak 2011; Irvine et al. 2012).

Near shore assessments included observations < 3 m in depth during the day, sometimes exceeding this depth depending on light intensity and or surface water conditions (i.e. wave action). Boat surveys paralleled the shoreline at 800-1,200 rpm along the 3-4 m depth contour, similar to that on Okanagan Lake outlined in Andrusak et al. (2003). The numbers of spawners inshore of this point were estimated visually by experienced staff. The boat surveys were conducted to account for the large spatial area that spawners could potentially occupy and increase the probability of observing them in the littoral areas. Daytime boat surveys also allowed crews to reference the shoreline and index sites for potential nighttime surveys. Daytime surveys were geo-referenced using GPS track logs and snorkel index sites were referenced by UTM's.

Snorkel surveys were conducted to account for the nocturnal behaviour observed during spawning for some kokanee populations (McLean and Webster 2004; Andrusak et al. 2007). These surveys provided the opportunity to document if spawning fish and/or redds were distributed beyond the observable depths (> 3 m) of the boat based surveys. Nighttime snorkel survey sites were selected and referenced using UTM's recorded during daytime boat surveys and commenced 0.5 h after dusk. In many cases, snorkel index sites were sub-sampled lengths of near shore areas identified to be potentially used by spawning kokanee and based on historic survey site information by McCusker et al. (2003). The swimmers swam parallel to the shoreline using a four member crew covering equidistant lanes, following natural depth contours lines between 0 and 5 m of the reservoir shoreline (Appendix 1). The distance between transects was dependent on visibility and each of the four member crew swam their respective transects at the same time. All spawning and/or redd observations were recorded in waterproof books during the surveys and geo-referenced using track logs (time) from a waterproof GPS (Appendix 1).

## *Data*

All data for the modeling of recruitment and its relationship to reservoir productivity were provided by the Ministry of Environment and the Ministry of Forests, Lands and Natural Resource Operations. Data included hydrologic and nutrient loading information as well as fish biometric data, gillnetting data, daily reservoir elevation data and hydroacoustic data. Site locations for gillnetting and hydroacoustics surveys are detailed in Figure 4. The assumptions, limitations and structure of each type of data used are described in more detail below. Data were plotted and assessed during the analytic process to provide quality assurance and control.

### *Limitations and Data Assumptions*

Recent refinement of the method used to analyze the hydroacoustics data provided by MFLNRO staff has improved the ability to synthesize kokanee population dynamics on ALR. Target strength (dB) ranges based on kokanee size-at-age information from trawl surveys have increased the ability to understand the kokanee age structure in the reservoir. However, analyses still present substantial uncertainty and are confounded 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 ability of trawling to obtain accurate compositional estimates by species under low densities and the ability to get accurate compositional estimates by species; and 5) lack of information on kokanee spawning population distribution and abundance (Sebastian et al. 2009; Harris et al. 2011). Refinement of the proportion of kokanee below 10 m depth from trawl information is needed to further reduce the uncertainty in the abundance estimates used in the stock recruitment relationship and is recommended for future reporting and analysis. As well, obtaining better estimates of kokanee abundance throughout the entire water column would substantially reduce uncertainty in underlying stock mechanisms.

In the absence of spawner biological, distribution and abundance data, several assumptions have been made. 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 is not considered to be limiting;

- Gillnet data are representative of the actual proportions of age 1-3 fish but does not account for the selectivity of gillnets and the bias associated with sampling using this method ;
- 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 challenges may affect the reliability of the estimates, however given the lack of ancillary information this was considered the only viable alternative in addressing the management questions on ALR.
- Acoustic estimates from 2001-2008 assumed that 75% 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 75% of all targets -64 to -49 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 75% of all targets -61 to -46 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;
- 2012 hydroacoustic surveys were conducted in July compared to other years when survey was conducted in October. The July 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 exclusively kokanee were present 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 deeper than 10 m (2001-2011) 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 Harris et al. 2011).

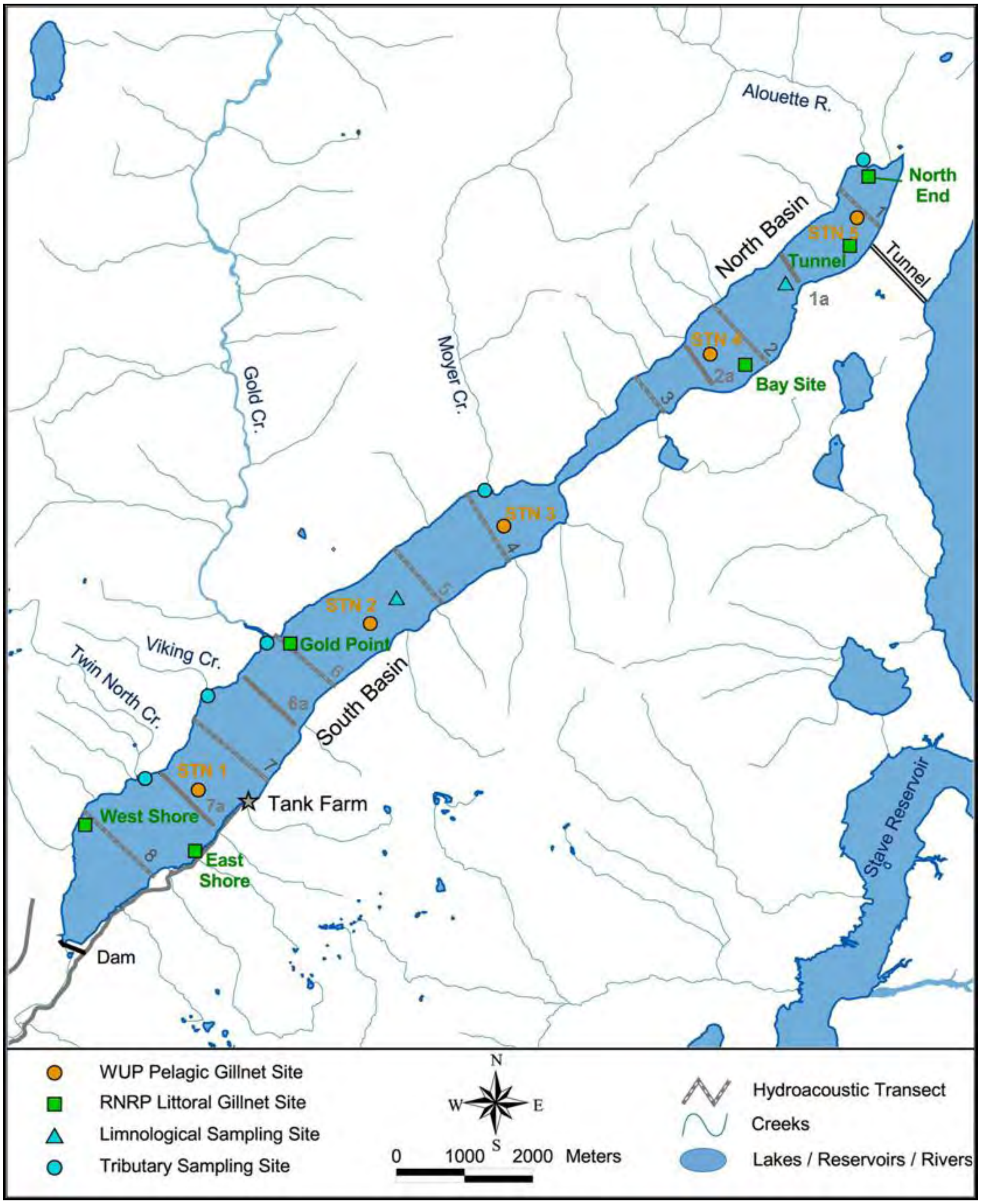


**Figure 4.** Locations for pelagic gillnetting (WUP; 2008-2012), littoral gillnetting (RNRP; 1998-2009), and limnological and tributary water sampling on the Alouette Lakes Reservoir.

### *Size-at-Age*

The gillnetting data used for assessing the influence of various factors on kokanee size-at-age were collected during 1998 to 2012. Nearshore gillnetting was completed from 1998 to 2009, as part of the reservoir nutrient restoration program (RNRP), to assess the response to fertilization (Harris et al. 2007). In the fall of 2008 and 2009, gillnetting methodology included pelagic netting overlapped by nearshore netting to assess changes in methods. The pelagic netting (WUP) methods were designed to corroborate the hydro-acoustic data in order to address the WUP management questions and this pelagic netting approach will be used in future sampling. The effect of netting methods was assessed to see if there is a difference between the two methods in their size selectivity.

Captured kokanee were aged using scales collected during 1998-2012. The actual data analyzed 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 considered 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 Harris et al. 2007).

In order to scale the size-at-age of kokanee in relation to the nutrient loading (and associated productivity) of the reservoir resulting from the fertilization program, a loading coefficient was modeled. The fertilization program commenced in 1999, so data prior to 1999 were excluded. The nutrient data quantified the kilos per year of agricultural grade liquid ammonium polyphosphate and urea-ammonium nitrate added to the system. In order to calculate the nutrient loading scalar, the ratio of added N:P was averaged over the last three years of the fertilization program in order to obtain an optimum ratio for the added fertilizers. This optimum ratio was calculated as 7.45 for the years of 2009-2012 inclusive. This is the same optimum ratio as for the previous three-year period of 2008-2010 inclusive. 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. There are several definitions that could be utilized to define the point at which standing crop stabilized in Alouette Lake Reservoir. The most logical point when a stabilized standing crop would occur would likely be the point at which the fertilizer program was refined to address the concern of nitrogen limitation in 2003 (Harris et al. 2007). However, this would leave only 9 years of data with which to fit a model with five fixed effects and two random effects, which becomes somewhat marginal. In order to maximize the data, the first year in which the nutrient loading coefficient was above 25,000 was selected. Since 2000, the nutrient loading coefficient has remained within the range of 24,000-31,935 with an average value of 28,008 therefore selecting 2000 as the starting point for analysis gives three more years of data for model fitting.

Timing and location of sampling can add substantial variation to gillnetting data. To determine if the time of year of gillnetting affected the size-at-age of kokanee captured, day of year for each date when gill netting was completed was modeled. Due to the seasonal nature of the sampling, the data for day of year were clustered during three times in the year with the bulk of the data split between two time periods rather than spread throughout the year. Inter-annual variability and sampling location were also modeled.

### *Stock-Recruitment Analysis*

Stock recruitment analysis has particular data requirements. At the most basic level, it requires an accurate and precise measure of the reproductive productivity of the mature population. The best measure of this is the number of eggs spawned, though this is rarely assessed directly (Haddon 2001). 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 (Haddon 2001; Guy and Brown 2007). All of these measures introduce uncertainty into the analysis before even beginning to assess recruitment. Stock recruitment also requires an estimate of recruitment where this can refer to either the life stage at which the fish first become vulnerable to fishing gear or the population still alive any set time after the egg stage (Haddon 2001). Similar to the estimate of the mature fish, there will be error in estimation of the recruits.

The data used to provide an estimate of the spawning population of the Alouette Lake Reservoir was obtained through hydroacoustic surveys completed on the reservoir from 2001-2012 inclusive. The hydroacoustic data collected prior to 2001 were not used as they were not considered equivalent for this purpose due the different hydroacoustic equipment (single beam) used (Dale Sebastian, MFLNRO Stock Assessment Biologist, pers. comm.). The data were interpreted from samples taken from water depths > 10 m (2001-2011) and 5 m or greater

(2012) as these data were comprised mainly of kokanee. Spawners were considered to be those fish that were classified as age-2 or age-3 fish from the size classes defined by the decibels ranging from -39 to -33 dB (2001-2012). Recruits were defined as those fish in the size classes aligned with decibels ranging from -61 to -47db for fry and 1 year old fish were those assigned to the -46 to -40 dB range for estimates derived from 2001-2012. In 2012, a slight change, recruits were defined as those fish in the size classes aligned with decibels ranging from -64 to -46db and 1 year old fish were those assigned to the -45 to -40 dB range. In order to account the proportion of kokanee recruits in the limnetic area > 10 m in depth from trawl sampling, a scaling factor of 0.75 was used to multiply the number of fish in the decibel ranges used. While there are year specific estimates for the proportion of kokanee recruits from the trawl sampling within the limnetic area (> 10 m), only the average of 0.75 was utilized for the purpose of this analysis since trawl information was not analyzed when the reporting was being conducted.

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 drops in the reservoir level over the spawning and incubation period for each year. Increases in the reservoir were not considered to be an issue since dewatering of redds and reduction of rearing habitat would not occur.

## *Analysis*

### *Size-at-Age*

Management hypothesis one states that the size-at-age of the kokanee population remains stable, or decreases with time once the standing crop has stabilized with the annual addition of fertilizer. In order to test this, the size-at-age data for three year old kokanee sampled from 1998-2012 were modeled using a generalized linear mixed effects model (GLMM) detailed in Kéry (2010). The fixed effects incorporated into the GLMM model included: day of year, the productivity of the system, sex of the fish, and the type of net. Year was also added into the model as a fixed effect in order to assess the direction of trend in size-at-age through time. A second-order polynomial was used as it provided a significantly better fit than a straight line in preliminary fitting. Third and fourth order polynomials were tested but were found to over fit the data and were not used. Year was modeled as a random effect to account for the inter-annual variation in individual lengths. The sample site where the gillnetting took place on each occasion was also treated as a random effect and was nested within year to account for spatial variation within the reservoir. Differences among sites and years were not of primary interest but would likely contribute substantially to the variability, which is why they were modeled as random effects. Once the model was initially fitted with all the fixed effects included, those effects that were not significant were removed in a stepwise fashion. After each removal, the model was refitted and changes in significance of the remaining variables were noted. Variables were removed until all explanatory variables in the model were significant at the p=0.05 level.

### *Stock Recruitment*

To assess the effect of reservoir fluctuations on fry abundance, a stock recruitment modeling approach was utilized. The relationship between the number of spawners (age 2+ and 3+ fish as determined from the hydroacoustic data) and the response variable of numbers of fry (75% of the 0+ fish from the hydroacoustic data) was modeled. Five different models were fitted and then compared with the AIC with correction for small sample sizes ($AIC_c$) to determine which models were the best fit to the data (Burnham and Anderson 2002). The assessed models included: 1) recruitment at a constant mean level assuming fully compensatory density dependence; 2) linear regression model with number of spawners predicting the number of recruits assuming the fully density independent relationship; 3) density dependent model with the addition of the variable representing reservoir fluctuation, 4) density independent model with the addition of the variable representing reservoir fluctuations, and 5) a non-linear Beverton-Holt stock recruitment function. The influence of the reservoir fluctuations on the Beverton-Holt model was assessed by plotting the residuals from the model fit vs. the minimum reservoir elevation during the spawning and incubation period or the summed magnitude of the drops in reservoir elevation during that time.

To assess the third hypothesis of whether decreases in fry abundance persist through time and cause an impact on the abundance of mature kokanee was also assessed using stock-recruitment models where age-0 fish were the stock and age-1 fish were considered the recruits. This allowed the estimation of the carrying capacity of age-1 fish. An analogous approach as described for the above stock-recruitment modeling exercise was carried out on this relationship with a set of models fitted to the data representing the density dependent and density independent cases with or without reservoir fluctuations included and model selection with the $AIC_c$ for small sample sizes conducted. Further analysis included an assessment of the survival rates from age-0 to age-1 kokanee, using data from the 2002-2012 period in order to compare with other kokanee systems.

All analyses were conducted in R version 2.15.1 (R Development Core Team 2012) with the ggplot2 library used to create all plots in this report (Wickham 2009).

# RESULTS

## *Reservoir Elevation 2012*

Average reservoir elevation was 121.21 m (GSC) in 2012, near the long term mean of 121.7 m since 1984 (Figure 5; Appendix 2). Average reservoir drawdown was 4.4 m in 2012, slightly smaller than 5.5 m drawdown in 2011 (Appendix 2). The reservoir was at an average annual elevation of 123 m (GSC) during the months of fertilization, usually late April-September (MOE on file). Following this period and similar to previous years (Harris et al. 2011), the reservoir elevation declined precipitously. This decline in reservoir elevation during the fall coincides with the spawning and incubation period (mid-October to the end of February) for shoal spawning kokanee in the reservoir (BC Hydro 2009) as detailed in Figure 6.

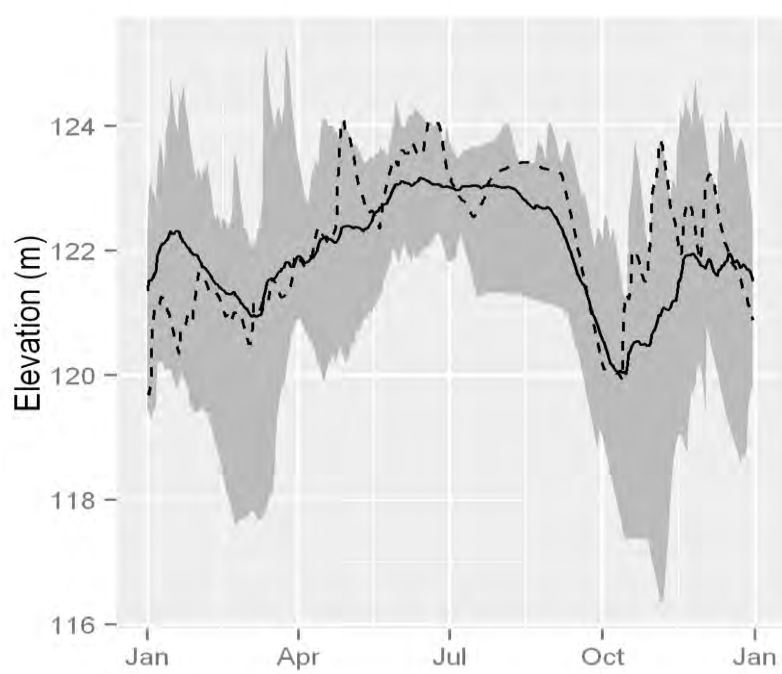


**Figure 5**. Elevation in meters vs. month in Alouette Reservoir for the 2001-2012. The minimum and maximum daily elevation are plotted with the grey band and the mean daily elevation over all years with the solid black line and the mean daily elevation in 2012 with the dashed black line.

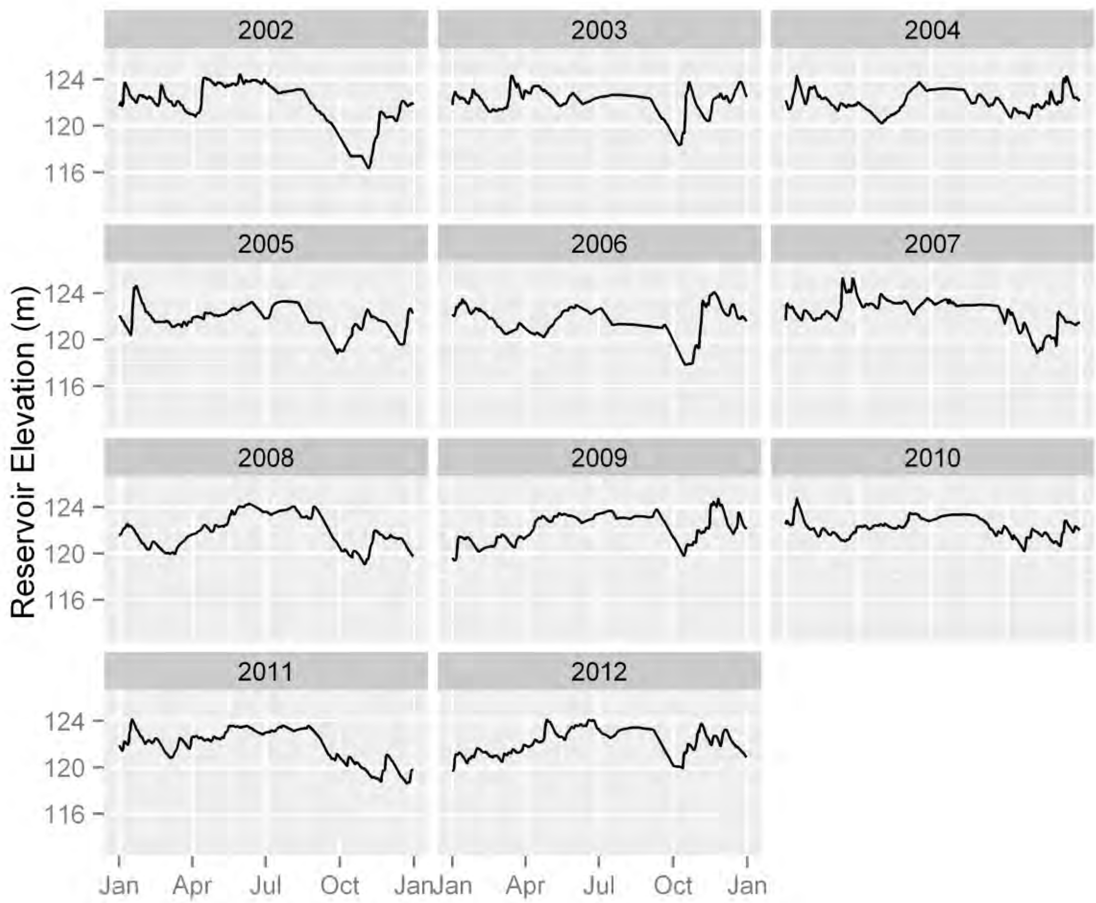


**Figure 6**. Alouette reservoir elevation in meters vs. month for the spawning and incubation season for kokanee from 2002-2012.

## *Spawner Surveys*

In order to determine spawner timing, spawner distribution, redd abundance and redd distribution, surveys were conducted around the majority of the reservoirs' shoreline. The daytime boat based surveys and nighttime snorkel surveys were employed to assess near shore areas of the ALR during October 9th to October 12th, 2012.

None of the boat surveys conducted over the three day period observed the presence of any spawning kokanee or redd construction in the near shore areas. It should be emphasized that the boat surveys were limited by the reservoir morphology and mainly confined to the south basin (Figure 7). As a result of the steep sided shoreline, large sections in the north basin were not surveyed (Figure 8). The exception in the north basin was the large alluvial fan of the upper Alouette River which was not suitable for snorkeling at night because of the vast area it covered

(Figure 8). In this particular area the boat survey method was used and no spawners or redds were observed. In most instances, boat counts were conducted to account for the large spatial area spawners could potentially occupy and increase the probability of observing them in the reservoir.

Similar to the boat surveys, nighttime snorkel surveys conducted over the same three day period did not observe the presence of spawning kokanee or construction of redds in the near-shore areas. The majority of sites were located near alluvial fans adjacent to tributaries of the reservoir (Figure 7; Figure 8). Prominent alluvial fans included surveys at Twin North Creek, Viking Creek, Gold Creek and Moyer Creek in the south basin (Appendix 1). Previous sites identified by McCusker et al. (2003) were also surveyed during the three day period. Nevertheless, these sites were often located in steep sided sections of the shoreline, with limited or no littoral zone. Detailed location of sites, including start and end points, for nighttime snorkel sites are summarized in Appendix 3. Nighttime snorkel survey site lengths ranged from 140 to 360 m (Appendix 3).

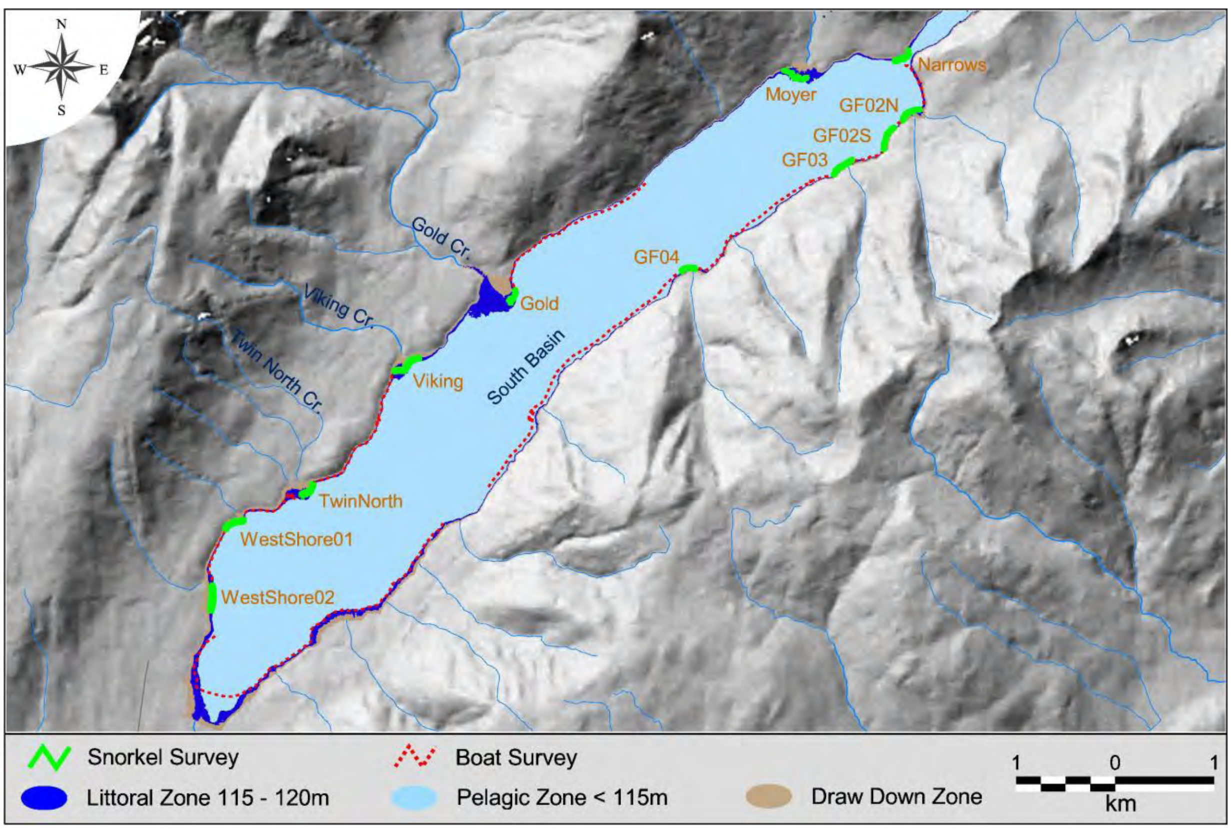


Figure 7. Daytime boat and nighttime snorkel surveys in the south basin of the Alouette Reservoir during October 9-11. Detailed location (UTM) available in Appendix 3 of this report.

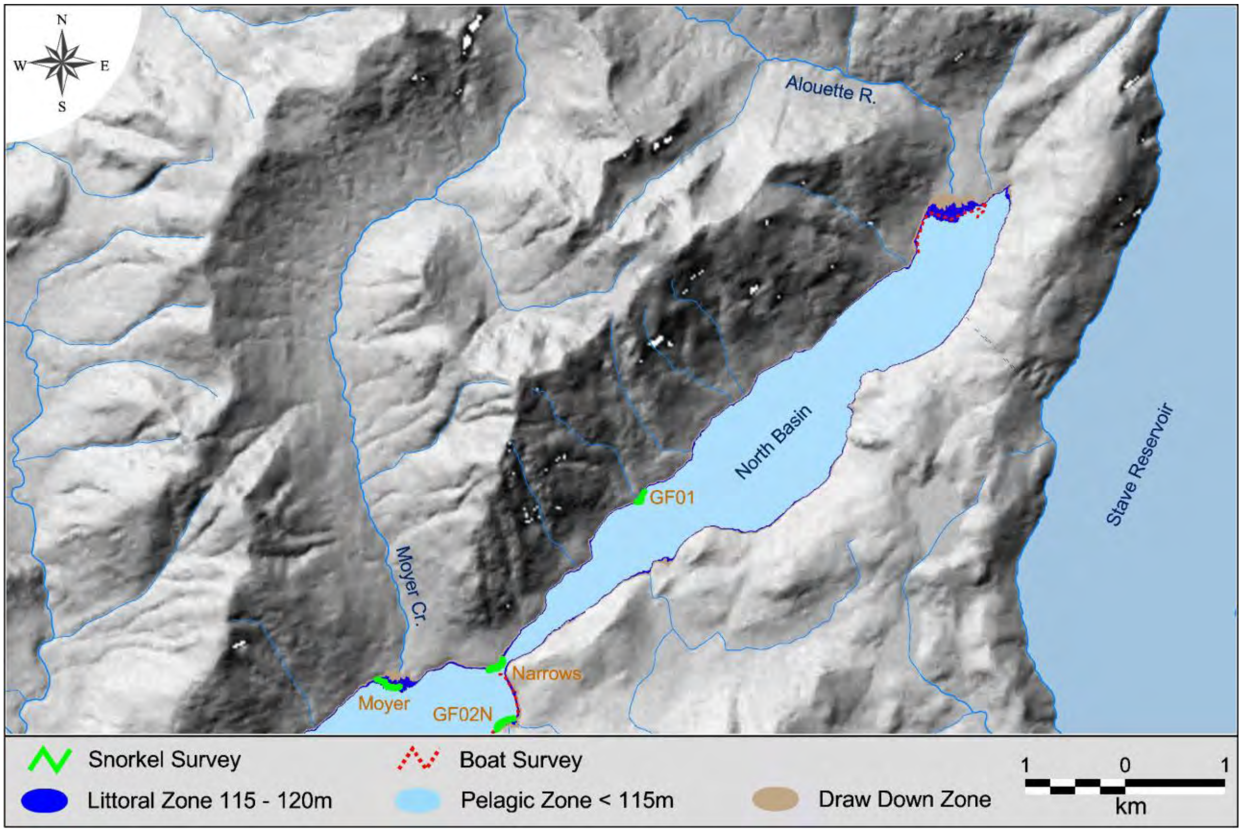


Figure 8. Daytime boat and nighttime snorkel surveys in the north basin of the Alouette Reservoir during October 9-11. Detailed location (UTM) available in Appendix 3 of this report.

## Analysis

### Size-at-Age

Length of gillnet captured kokanee were used in the size-at-age analysis for the age-3 kokanee obtained during 1998-2012, detailed in Figure 9. Analysis of this data demonstrates a downward trend immediately after the initial impressive growth at the onset of fertilization. During the last five years there has been a more stable pattern with a slight increase in 2012. (Figure 10). Model residuals indicated they were not significantly different from normal, and that model fit was adequate. The final linear mixed effects (LME) model included the net type as a fixed effect and year as a continuous variable and the random effects of year and the location of the sampling. Stepwise backward elimination removed the factors of productivity, sex of the fish, and the day of the year of the sampling event. Both the type of gillnetting and the polynomial fit of year were highly significant in the final model ($p<0.001$).

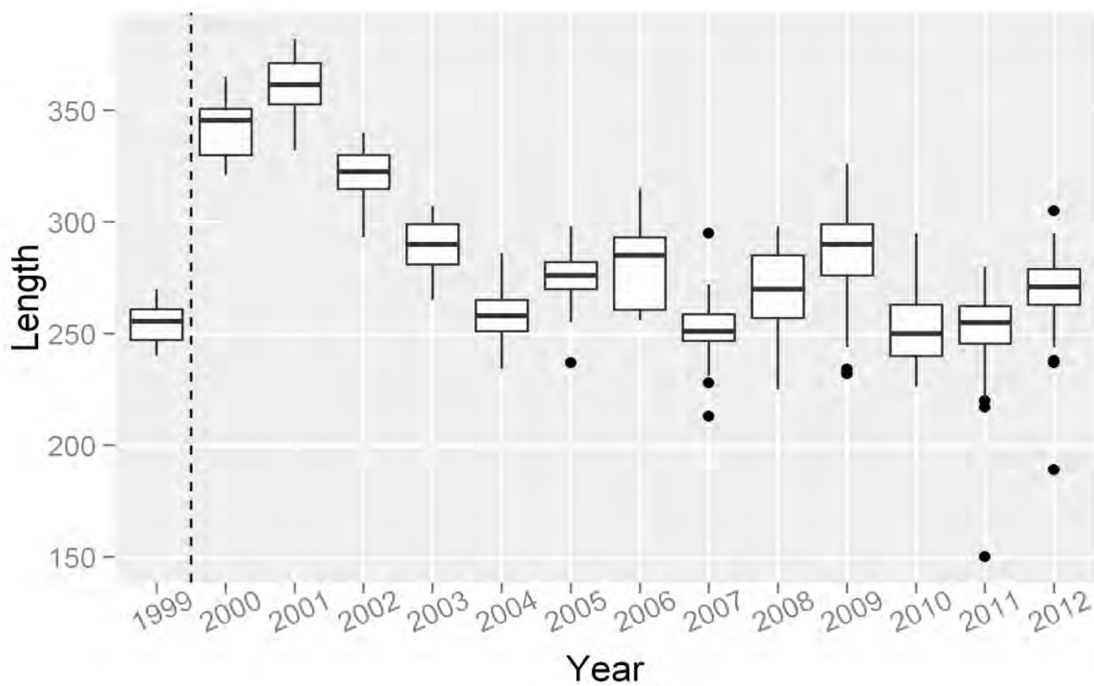


**Figure 9**. Boxplots of three year old kokanee captured with gillnets on Alouette Lake Reservoir from 1998-2012. The fertilization period begins in 1999, as indicated by the dashed line and the change in netting methods occurred in 2008. Data used in the analysis span from 2000-2012 and are to the right of the dashed line.

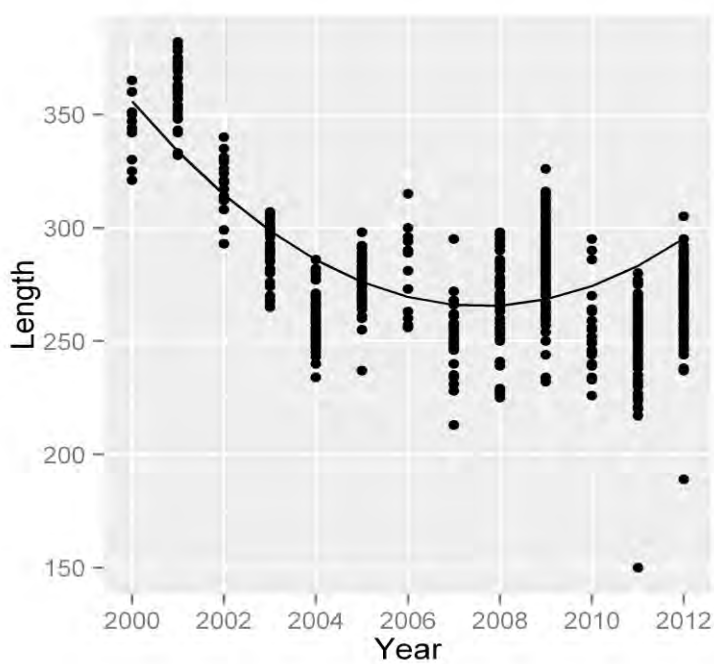


**Figure 10**. Length trend for size-at-age of three year old kokanee, 2000-2012. Observed length data are plotted with circles; fitted linear mixed effects model predictions plotted with solid line.

Hydroacoustic data from 2001-2012 suggest an increase in kokanee abundance (Figure 11). Despite the increase, kokanee abundance was not a significant predictor ($p=0.221$, $R^2=0.14$) of kokanee length over the time period (Figure 12). Nevertheless, kokanee size was larger when total abundance was lower in the reservoir, especially in 2002 and 2003. Additionally, while not displayed, linear regressions between size-at-age as measured by both length and weight, and abundance were completed and neither demonstrated a significant relationship. However, it should be mentioned that kokanee abundance data does not encompass the entire range of years due to differences between single beam (1998-2000) and split beam (2001-2012) acoustic technology.

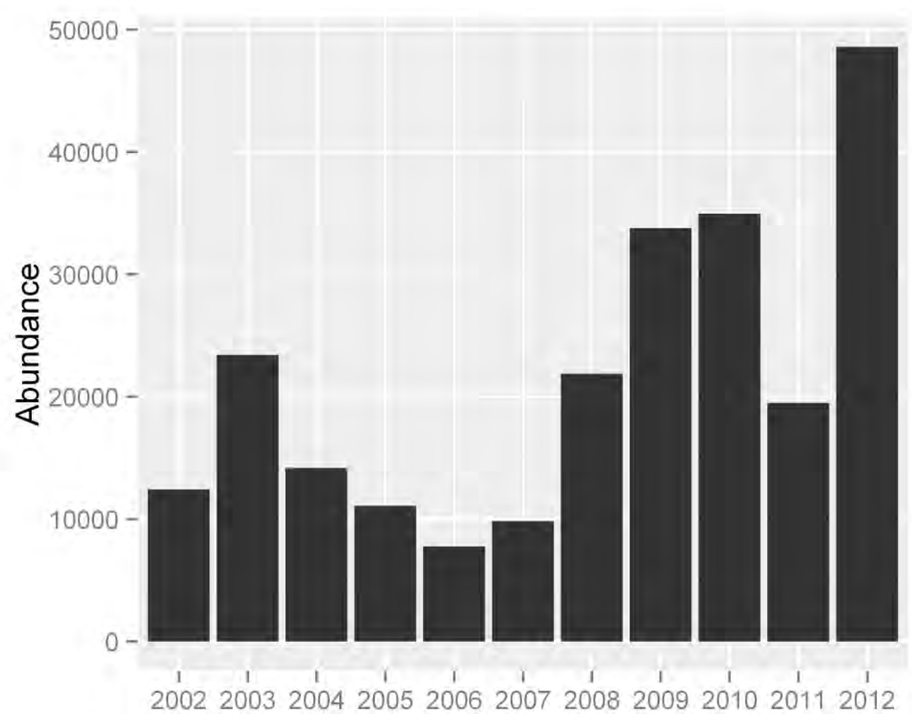


**Figure 11**. Abundance of two and three year old kokanee from 2002-2012 as assessed from hydroacoustic data.

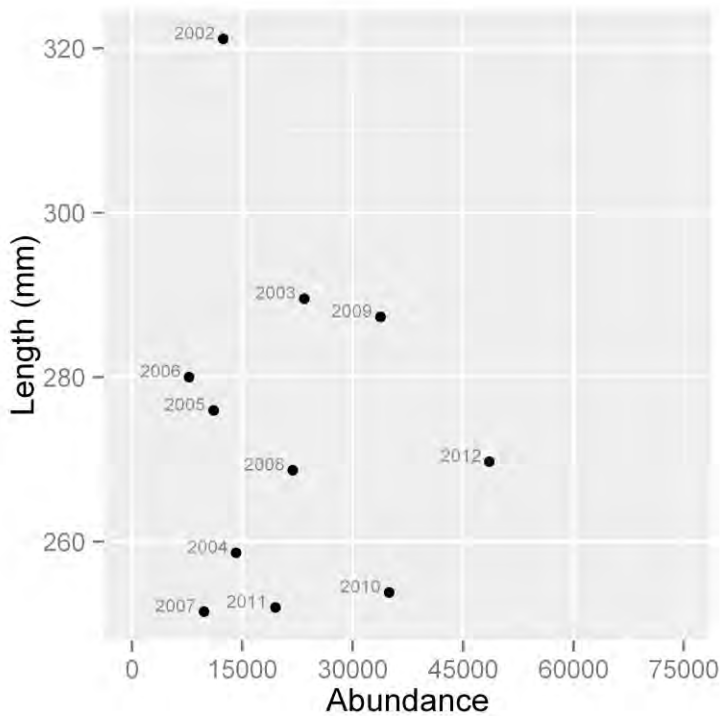


**Figure 12.** Length (mm) vs. abundance of kokanee spawners from 2002-2012 as assessed from hydroacoustic and gillnetting data.

## *Stock Recruitment*

Five stock recruitment models were fitted relative to one another, using the second-order AIC ($AIC_c$), to assess the effect of reservoir fluctuations on fry abundance. The top ranked model was the non-linear regression Beverton-Holt stock recruitment model (Table 2, Figure 13). This model assumes a density dependent response where the relationship between the spawners (2+ and 3+) and the recruits (age 0) is non-linear and reaches and asymptotic level in which recruitment does not increase with further increases in spawners (Table 2, Figure 13). The linear density independent model was the second ranked model but was greater than 4 $AIC_c$ values of the Beverton-Holt, and was not considered a good candidate model (Table 2,Figure 14). The remainder of the fitted models also had $AIC_c$ values greater than 4 $AIC_c$ values from the top model and are unlikely to represent the processes inherent in the data and will not be discussed further but are shown to emphasize that a range of models were tested (Burnham and Anderson 2002).

**Table 2**. Stock recruitment model formulations, model types and their ranking using $AIC_c$ in order to assess the spawner recruitment relationship from Age-2 and -3 fish (spawners) to Age-0 fish (recruits) for kokanee in Alouette Lake Reservoir.

| Model | Model Type | Rank | $AIC_c$ | $\Delta AIC_c$ |
|---|---|---|---|---|
| Recruits~(a*Spawners)/(1+b*Spawners) | Beverton-Holt, Non-linear | 1 | 243.85 | 0 |
| Recruits ~ Spawners | Density independent, Linear | 2 | 249.78 | 5.93 |
| Recruits ~ 1 | Density dependent, Linear | 3 | 249.92 | 6.07 |
| Recruits ~ Sum of Reductions | Density dependent, Linear | 4 | 252.57 | 8.72 |
| Recruits ~ Spawners+ Sum of Reductions | Density independent, Linear | 5 | 253.45 | 9.6 |

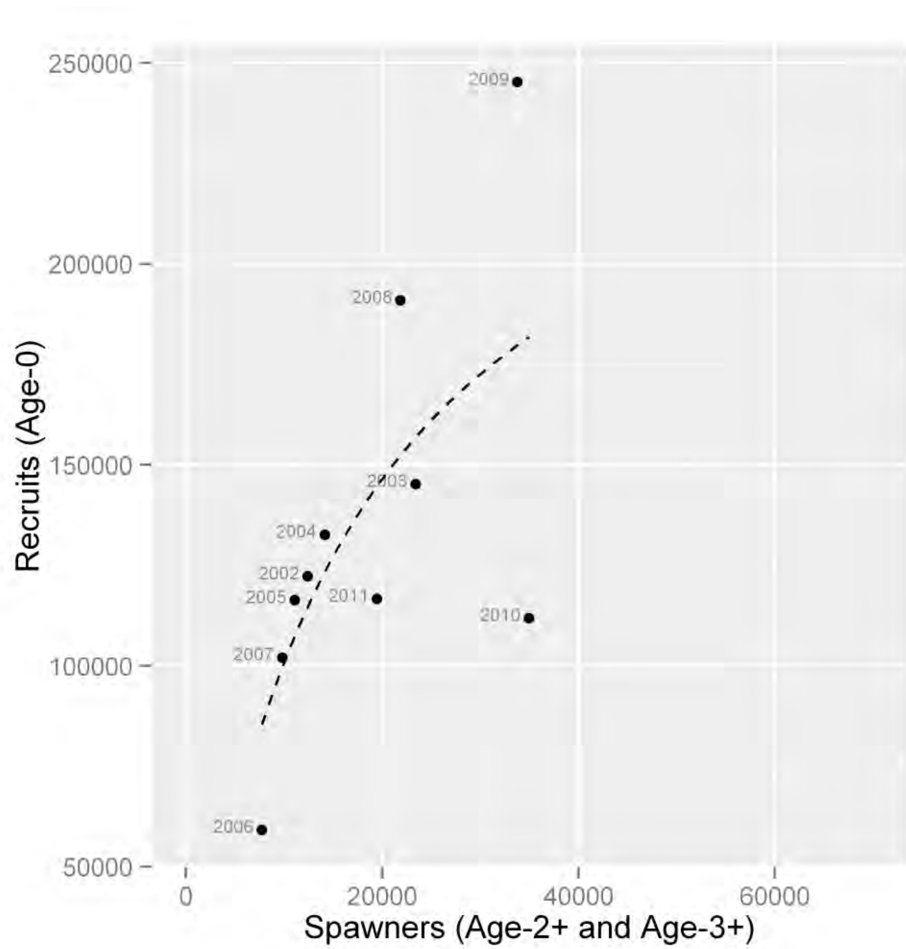


Figure 13. Alouette Reservoir kokanee stock recruitment data fitted with Beverton-Holt non-linear regression model (dashed line). Points are labeled with the year in which sampling for the spawners occurred.

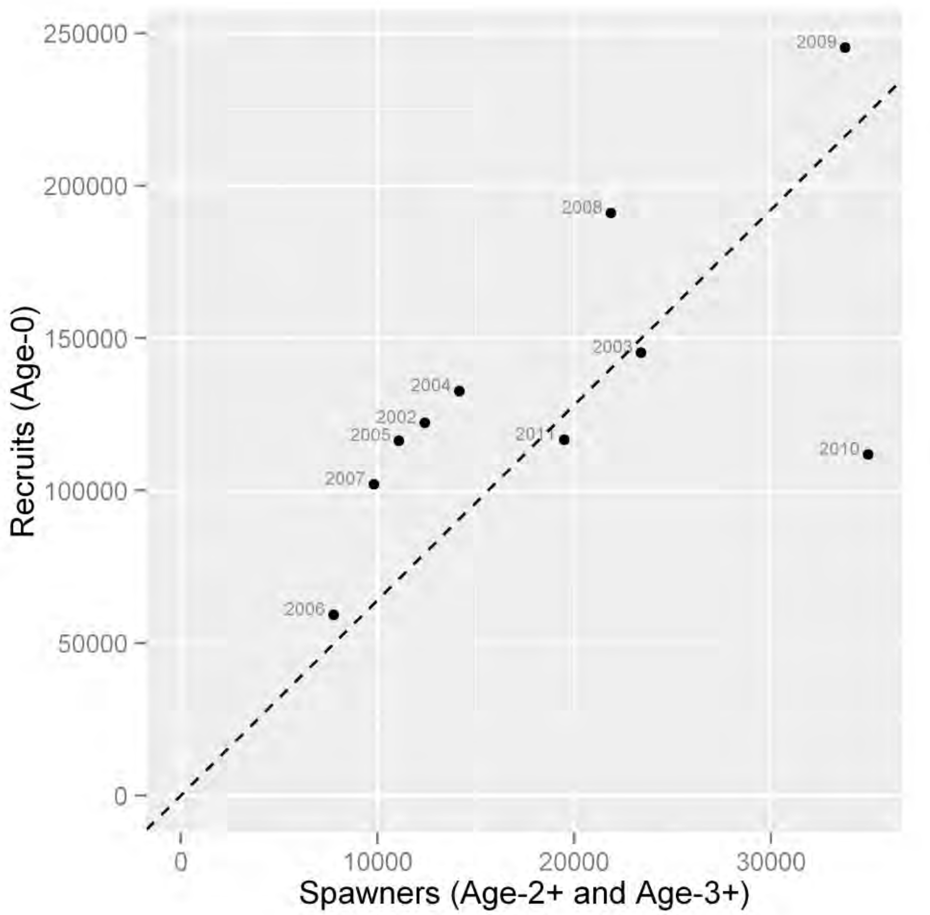


**Figure 14.** Alouette Reservoir kokanee stock recruitment data fitted with the linear density independent model (dashed line). Points are labeled with the year in which sampling for the spawners occurred.

Four stock recruitment models were fitted to assess the mechanisms driving the recruitment of age-1 fish from age-0 fish are ranked and described in Table 3. The top ranked model ($AIC_c$) was the null model that assumed fully compensatory density dependence. This model assumes a density dependent response where the relationship between the age 0 and age 1+ is linear and predicts an average recruitment value for age-1 fish of 24,926 (±SE=2,562; Table 3; Figure 15). The linear density independent model was the second ranked model and was within 4 $AIC_c$ values of the full density dependent model, and cannot be discounted as a viable model. All other models were greater than 4 $AIC_c$ values from the top model so are considered less likely to be good models for the data. Nonetheless, the fully density independent and density dependent model, using the variability in the reservoir as the predictive variable of the age-0 fish predicting the age-1 fish were very close to 4 $AIC_c$ values from the top model (Table 3).

The proportion of fish surviving from age-0 to age-1 fish was assessed for the years from 2002-2011. Relative survival was derived using age-1 fish from the following year divided into the number of age-0 fish from the year to estimate survival by year (survival=age 1/age 0). Relative survival was estimated to be 29.7% in 2011. From 2001-2011, the mean survival was 20.2%, maximum was 29.8% in 2005, and minimum was 10.8% in 2003 (Figure 16). There also appears to be an increase in survival in 2006-2007 when a large number of age 1+ fish emigrated from the reservoir (Mathews and Bocking 2011).

**Table 3.** Linear regression models and their ranking using $AIC_c$ in order to assess the spawner recruitment relationship from Age-0 to Age-1 fish for kokanee in Alouette Lake Reservoir

| Model | Model Type | Rank | $AIC_c$ | $\Delta AIC_c$ |
|---|---|---|---|---|
| Recruits (Age 1)~1 (Null) | Density dependent, Linear regression | 1 | 213.03 | 0 |
| Age 1 ~ Age 0 | Density independent, Linear regression | 2 | 216.21 | 3.2 |
| Age 1 ~ Sum of Reductions | Density dependent, Linear regression | 3 | 217.3 | 4.3 |
| Age 1 ~ Age 0 + Sum of Reductions | Density independent, Linear regression | 4 | 222.2 | 9.2 |

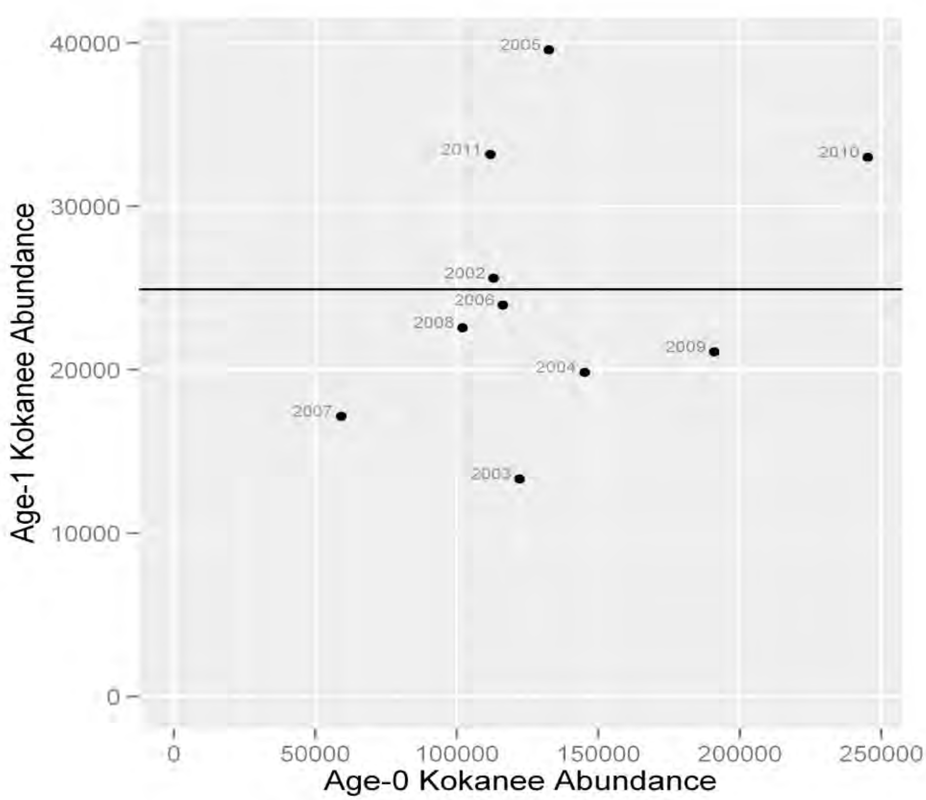


**Figure 15.** Alouette Reservoir kokanee data for age-1 vs. age-0 fish. The year label is for the year in which the age-0 fish were enumerated and the age-1 fish are from the subsequent year. The null model prediction assuming full density dependence is plotted with the solid line.

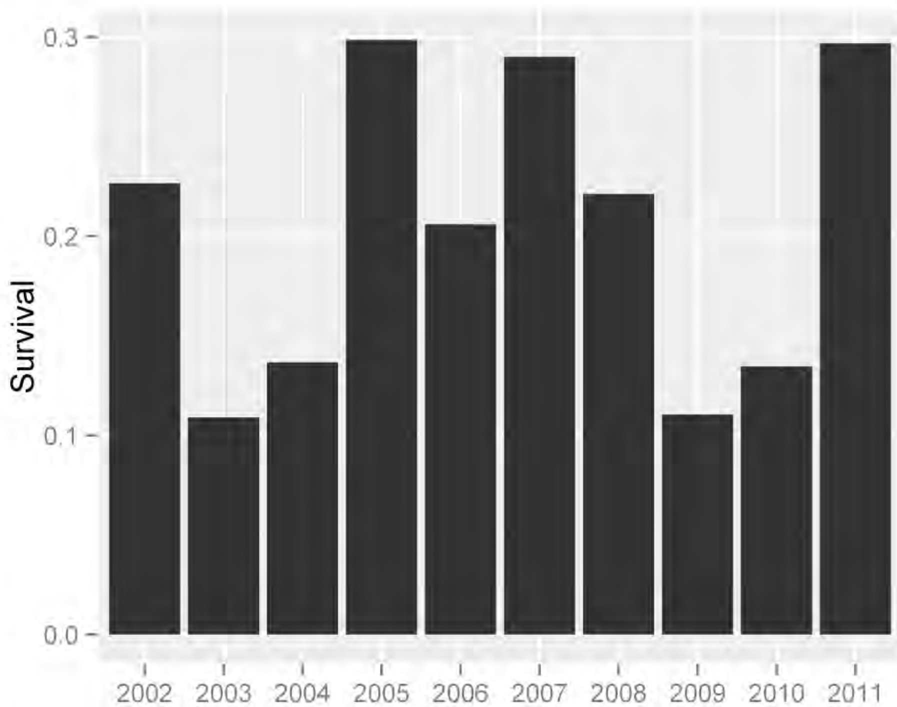


**Figure 16.** Estimated survival from age-0 to age-1 fish by year for kokanee of the Alouette Reservoir. The year is the year in which fish were aged 0.

# DISCUSSION

Similar to many reservoirs throughout BC, hydroelectric development and operations have the potential to have adverse effects on fish distribution and abundance. (Ney 1996; Ashley et al., 1997; Stockner et al. 2000; Stockner et al. 2005). Impacts can be evidenced from both footprint and operational impacts associated with the impoundment/inundation phase and with the water regulation phase of hydroelectric operations. Understanding both footprint and operational impacts on fish populations can be often obscure and unclear. Due to the large spatial and temporal aspects of these systems, they often require years of information to determine real impacts.

Neither the boat based surveys nor the nighttime snorkel surveys conducted over the three day period in October 2012 observed the presence of spawning kokanee or redd construction in the near-shore areas of the reservoir. Maximum depth of observations by either method did not exceed 5 m. Acoustic tagging information from adult sockeye re-introduced into the reservoir suggest that spawning is occurring at depths >10 m, well beyond the visible range (Shannon Harris pers. comm. MOE biologist), similar to that observed on Seton-Anderson Reservoir

(Morris and Caverly 2004). Despite this information, based on the spatial extent of the reservoir and the concern over the temporal timing of observing kokanee spawners, it is recommended that further boat based surveys be continued systematically during September and October.

Analysis of the size-at-age modeling indicates potential compensatory mechanisms regulating age 3+ kokanee in the ALR. Kokanee populations, similar to other nerkid populations, are often regulated by density dependent processes (Hyatt and Stockner 1985, Rieman and Myers 1992; Myers et al. 1997, Myers 2001; Rose et al. 2001). However, assessing the direct mechanisms related to compensatory increases in growth, survival and reproduction in relation to stock density can often prove difficult and somewhat obscure. Nonetheless, the kokanee population has demonstrated a substantial increase since 2000, meanwhile the average kokanee size from 2000 to 2004 has subsequently declined and appears to be stabilizing at the present level around which there are inter-annual fluctuations (Andrusak and Irvine 2011; Andrusak and Irvine 2012). Despite these observations, the relation between abundance and size of kokanee in the reservoir is relatively weak and not significant ($p=0.221$, $R^2=0.14$) and this suggests that other factors related to the reservoir productivity and/or food quality may be influencing the compensatory mechanisms (Rieman and Myers 1992; Harris et al. 2011). To understand more completely the mechanisms and processes driving the patterns in size-at-age requires a more in-depth modeling exercise. This would involve measuring the growth of kokanee from cohort to cohort that could be modeled for each year in relation to the productivity and fish numbers.

Stock recruitment relationships are essential in assessing stock dynamics and defining biologically important reference points for many species of fish (Myers 2001). A kokanee stock recruitment relationship on ALR was developed to assess 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, was the top ranked model and the best predictor of the kokanee dynamics within the reservoir. Likewise, analyses also indicated that density dependent factors likely regulate the population abundance of both age-0 and age-1 fish. While it was difficult to predict the peak recruitment of age 0+ from the selected model, the fully compensatory density dependent model predicted a peak recruitment of 24,926 (95% CI=19,904-29,947) age1+. As with previous years, these estimates are considered conservative since separation of age classes from hydroacoustic data may not be reliable, 75% of the 0+ fish acoustically identified were used as recruits and the analysis was limited to a depth layer between 10 to 50 m from 2001-2011 and 5-50 m in 2012 (*see Limitations and Data Assumptions*).

Additional analysis of the survival between age-0 and age-1 fish demonstrated that the model, assuming fully compensatory density dependence, was the best candidate model. The relative survival from age-0 to age-1 fish was estimated to be 29.7% in 2011, considerably higher than the mean survival of 20.2% from 2001-2011 (range=10.8-29.8%). These estimates are substantially less than that inaccurately reported in Andrusak and Irvine (2012). It is presently unclear as to the mechanisms driving the variable rates of relative survival in ALR. However, there is some indication of an increase in survival in 2007 when densities of age-0 fish were the lowest in the reservoir and in part due to a large outmigration of age 1 the spring (Mathews and Bocking 2011, Harris et al. 2011). The low densities in this year class coincide with a large out-migration (n=62,923) of juvenile kokanee from the reservoir during surface flow releases from the Alouette Dam, mostly age-1 kokanee (Mathews and Bocking 2011; Table 4). Nonetheless, it is believed that the direct loss of kokanee through the spillway provided some compensatory increase in survival for kokanee remaining in the reservoir, since densities were dramatically reduced. Future assessment of large out-migrations of kokanee from the reservoir may be beneficial in understanding the underlying mechanisms regulating the kokanee population on ALR while providing important answers for addressing water management questions.

Table 4. Mark-recapture estimates of *O. nerka* out-migrating the Alouette Reservoir from Mathews and Bocking (2011).

| Year | Estimate | 95% CI | % of Age 1 | % Age 2 & 3 |
|---|---|---|---|---|
| 2005 | 7,900 | na | 96% | 4% |
| 2006 | 5,064 | na | 94% | 6% |
| 2007 | 62,923 | 48,436 – 77,410 | 91% | 9% |
| 2008 | 7,712 | 6,682 – 8,742 | 72% | 28% |
| 2009 | 4,287 | 3,833 – 4,741 | 95% | 5% |
| 2010 | 14,201 | 13,624 – 14,778 | 68% | 32% |
| 2011 | 35,542 | 34,034 - 37051 | na | na |
| 2012 | 720 | 344-1,096 | na | na |

While preliminary analysis combined with spawner assessment surveys suggests that reservoir operations may not be constraining kokanee recruitment and/or incubation success in the reservoir, it is believed that age 1 kokanee population could potentially be impacted by spring surface flow releases from the Alouette Dam. Spillway releases from the dam during the spring have occurred since 2005 and were implemented to determine the volitional migration success of *O. nerka* from the reservoir (Mathews and Bocking 2011). Despite the low number of out-migrants in 2012 (n=720), on average of ~17,000 nerkids per year have emigrated from ALR since 2005 (Table 4). Moreover, based on age proportions in their study, the majority (>80%) appear to be age-1 fish (Table 4). Large out migration events similar to that observed in 2007, and to a lesser extent in 2011, could influence factors regulating the kokanee population in the reservoir. It is recommended that the out-migration monitoring be continued and that data be incorporated into the modeling efforts in future years of the study program.

The oligotrophic nature of the Alouette Lake Reservoir also implies the system has a low productive capacity, comparable to other lakes and reservoirs in BC; a capacity, that ultimately determines fish production. Theoretical kokanee spawner estimates derived from both the in-lake biomass density biostandard (5 kg/ha) and a photosynthetic rate (PR) model (Hume et al. 1996, Shortreed et al. 2000) indicated 9,000-30,000 spawners could potentially be supported in the reservoir (Andrusak and Irvine 2012). Much of the information used in deriving the theoretical estimates have been established from other large lakes (e.g., Kootenay, Arrow, Okanagan, upper Columbia reservoirs) monitored throughout BC and provide good approximations of kokanee abundance, age structure and age proportions for the Alouette Reservoir in light of data gaps. Similarly, use of kokanee spawner information was used to derive theoretical estimates of fry production for the reservoir (Andrusak and Irvine 2012). Assuming a 10% egg to fry survival rate (Redfish Consulting Ltd. 1999), 104,000-311,000 fry might be produced annually. While the PR model indicate a fry production estimates of ~300,000 for the ALR, the fully density dependent model suggested an estimate of >140,000 fry can be supported in ALR. The main point of these estimations and models of fry production is to demonstrate that kokanee fry numbers are likely quite low in ALR (i.e. < ~ 0.5 million). Consequently, the overall in-lake population estimate (all ages) of kokanee likely doesn't exceed one million fish.

Analysis of data suggests that the ALR kokanee population is likely regulated by compensatory mechanisms, similar to other kokanee populations. 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 decreases under higher lake productivity. As well, the stock-recruitment analyses also failed to reject hypotheses two ($H_0 2$) and three ($H_0 3$) under management questions two and three. While it appears that the reservoir is not limiting incubation success and/or recruitment, large emigrations of kokanee (primarily age 1+)

through the spillway during volitional migration success studies may impact the kokanee population which likely persists through that cohort's life stage. However, it is acknowledged that there is considerable uncertainty in modeling the kokanee data provided which can ultimately limit inferences of reservoir impacts on kokanee. Moreover, limited spawning habitat in this reservoir also cannot be ruled out due as a limiting factor to kokanee recruitment within ALR. In summary, incorporation of more data will assist in supporting the models for analyses and assessing mechanisms regulating the kokanee population on ALR.

In summary, preliminary assessments and analysis indicate that reservoir operations may have a limited impact upon the kokanee population within the Alouette Lake Reservoir. Results from analysis combined with boat and snorkel spawner assessment surveys suggest that reservoir operations may have a minimal impact upon incubation success and recruitment presumably because spawning occurs at deeper depths. While the findings would be considered preliminary, it appears that key management questions in the Alouette WUP can be addressed through field assessments and the modeling of kokanee data.

# RECOMMENDATIONS

A number of data gaps have been identified and recommended actions to address these gaps are outlined in brief below. These include:

- Fisheries work should be directed at determining kokanee spawner numbers, size-at-maturity and fecundity. Fecundity information can also be derived using the length-fecundity regression established for kokanee based on a large dataset accumulated throughout the province.
- Spawning distribution information could then be used with the digital elevation model (DEM) for modeling the hydrologic impacts on the kokanee population.
- In the BC Hydro TOR, a study plan was proposed where gillnet sampling would only occur every other year (BC Hydro 2009). It is strongly recommended that this study design not be implemented. Annual information is important for answering the questions of interest about recruitment and the carrying capacity of the system.
- Future analyses of these data would benefit from operating in a hierarchical Bayesian framework where model fits are robust to low sample sizes, confidence intervals are more readily calculated and prior information can be incorporated.
- Pelagic trawl sampling should continue to allow for the discernment of species composition and proportions of kokanee by depth. This work should continue so more accurate estimates of kokanee numbers and ages can be incorporated into the analysis
- In the analysis assessing whether kokanee size-at-age is stable or decreasing, the start point for the data could be shifted to 2003 when the nutrient addition program was refined to address the problems with nitrogen limitation that were identified in 2002 (Harris et al. 2007) to better reflect the 'stable state' when there are sufficient years of data to do so. Kokanee density information could also be incorporated in future years of analysis to model some of the variability in size-at-age.
- Entrainment losses through the spillway and the tunnel may need to be estimated in order to correct for biomass lost from the reservoir in the analyses. This currently could be partially addressed by incorporating the information from reports documenting the outmigration of kokanee and other species through the spillway (Mathews and Bocking 2010), but no data currently exist assessing the loss of fish through the northern tunnel. It is critical to institute a method for determining the fish species, sizes and ages entrained through the northern end of the reservoir or to derive a basic estimation process in order to improve the assessment of the stock-recruitment relationships

- To obtain a better understanding of the mechanisms and processes driving the patterns in the size-at-age data, growth information from kokanee cohorts should be modeled for each year in relation to the productivity and fish numbers in the system
- Refinement of the proportion of kokanee below 10 m (2001-2011) and or 5 m (2012) depth from trawl information is needed to further reduce the uncertainty in the abundance estimates used in the stock recruitment relationship and is recommended for future reporting and analysis

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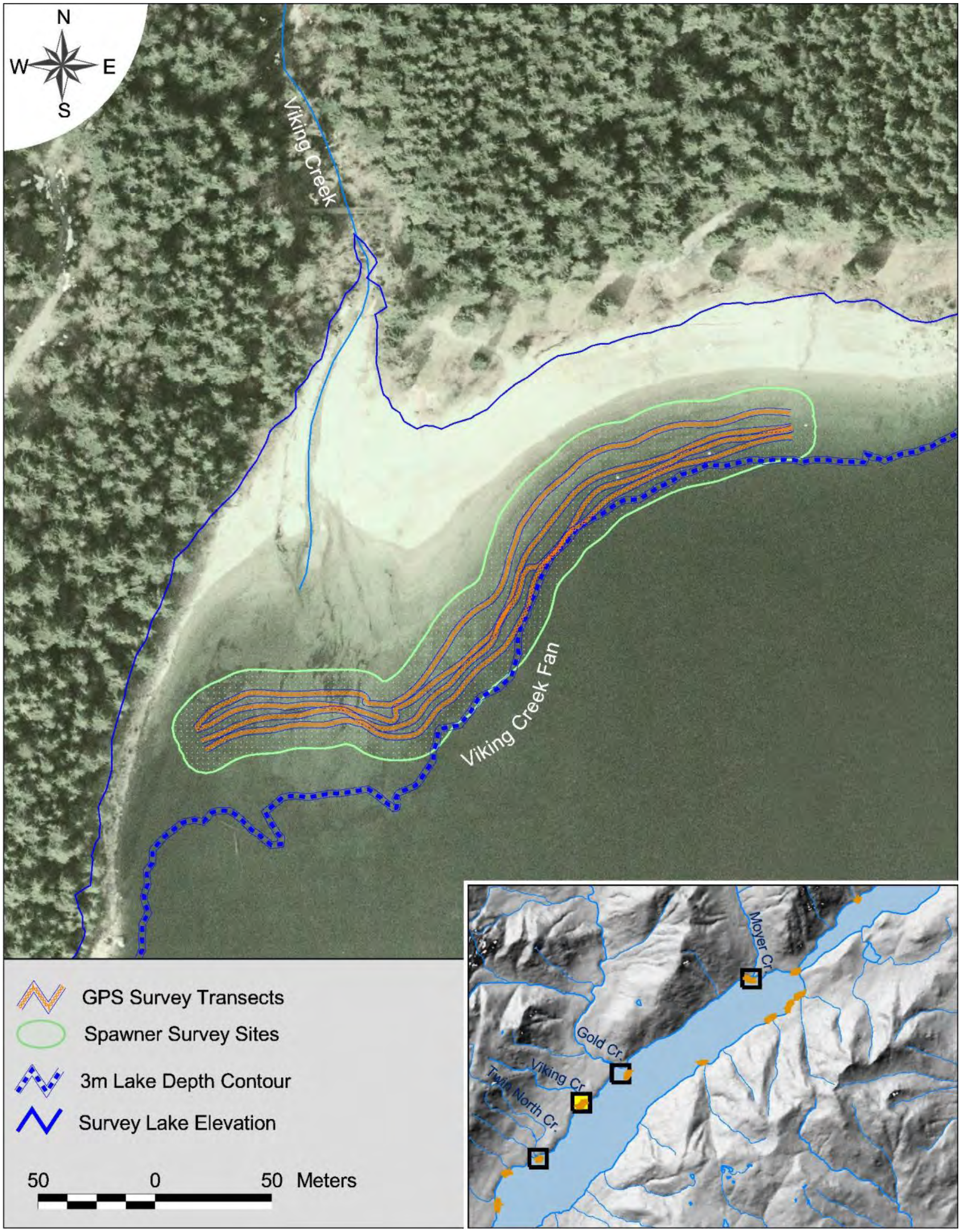
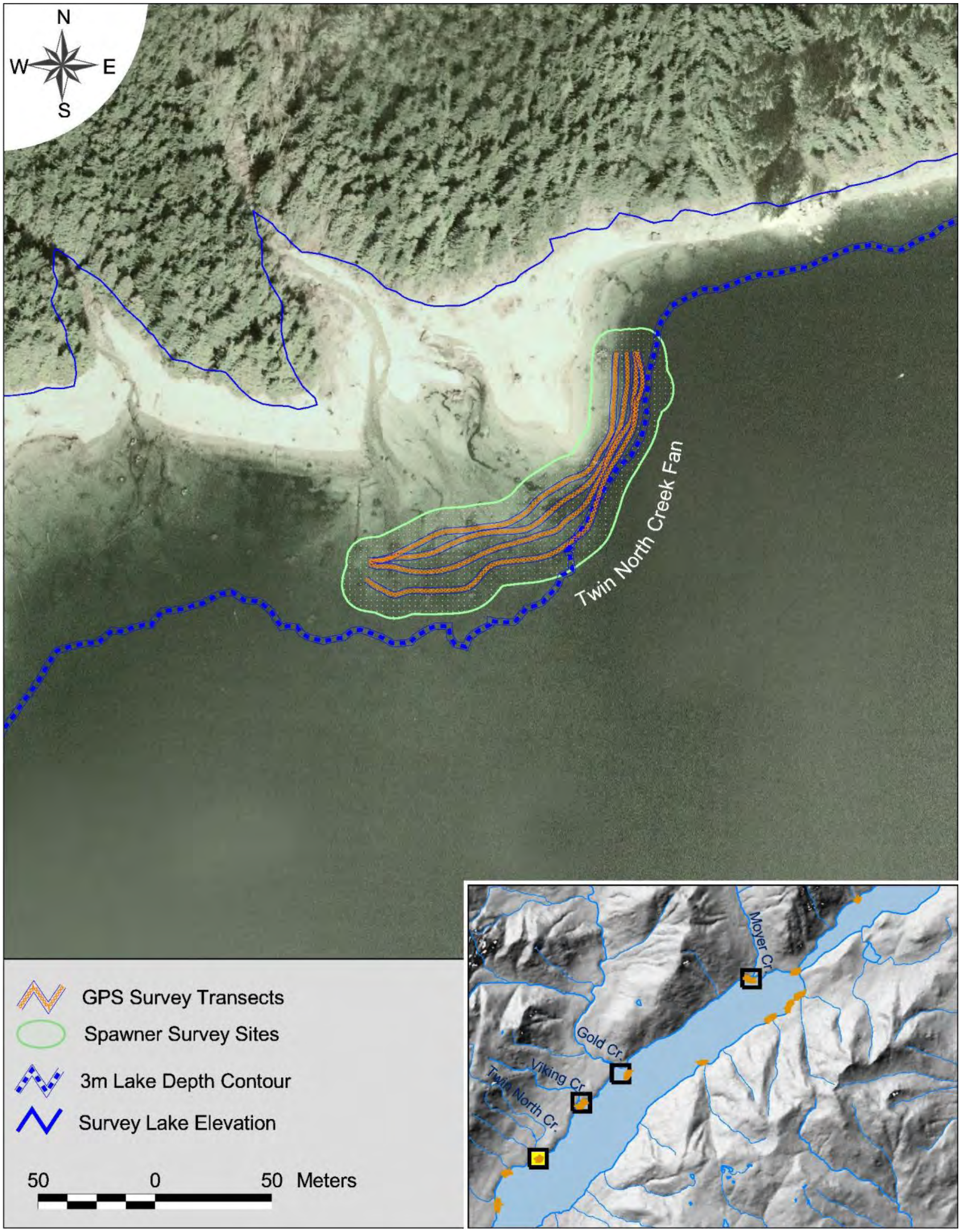
# APPENDIX 1. Alluvial fan sites using nighttime snorkel

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Twin North Creek Fan
GPS Survey Transects
Spawner Survey Sites
3m Lake Depth Contour
Survey Lake Elevation
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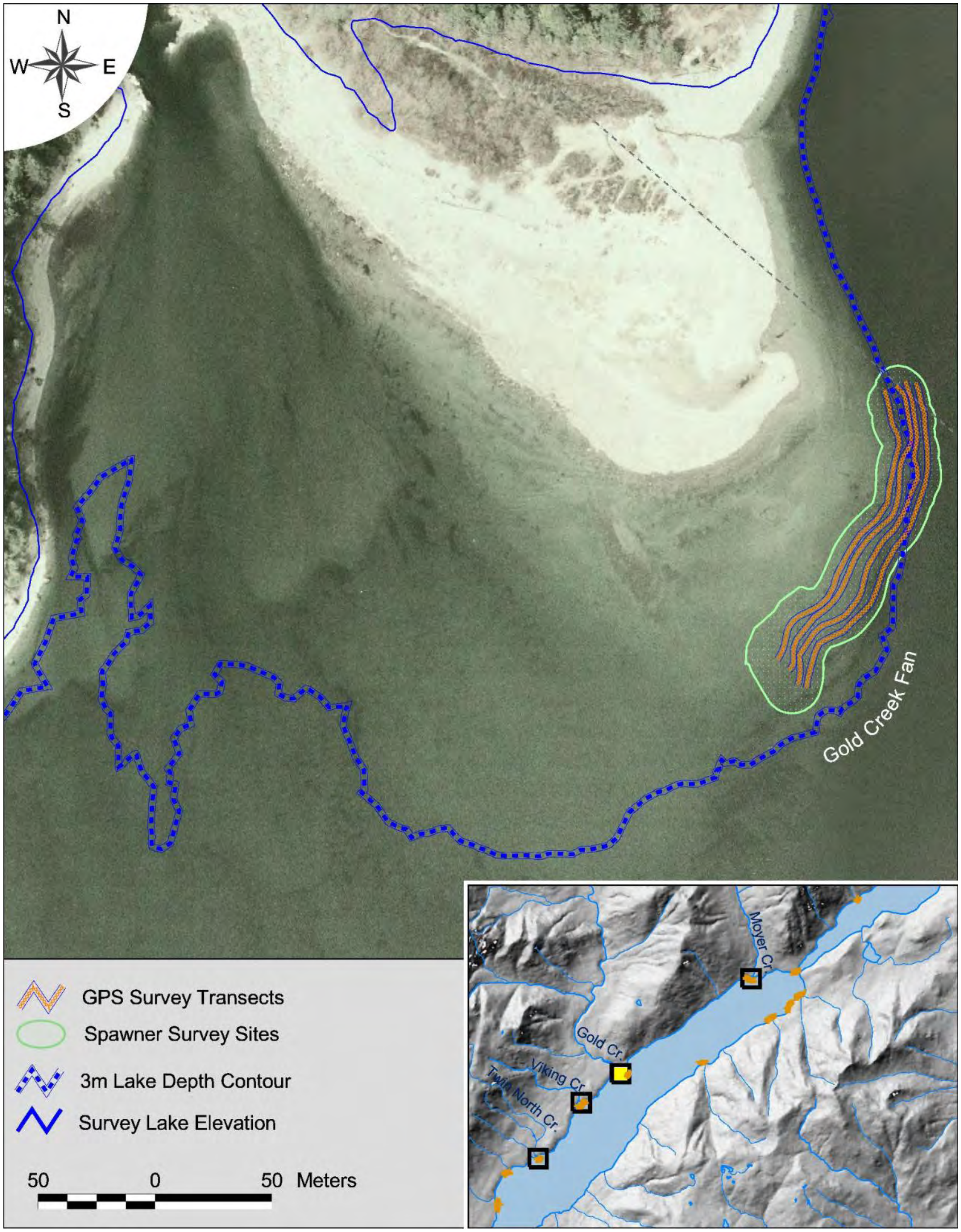
Meters
Moyer Cr.
Gold Cr.
Viking Cr.
Twin North Cr.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Gold Creek Fan
GPS Survey Transects
Spawner Survey Sites
3m Lake Depth Contour
Survey Lake Elevation
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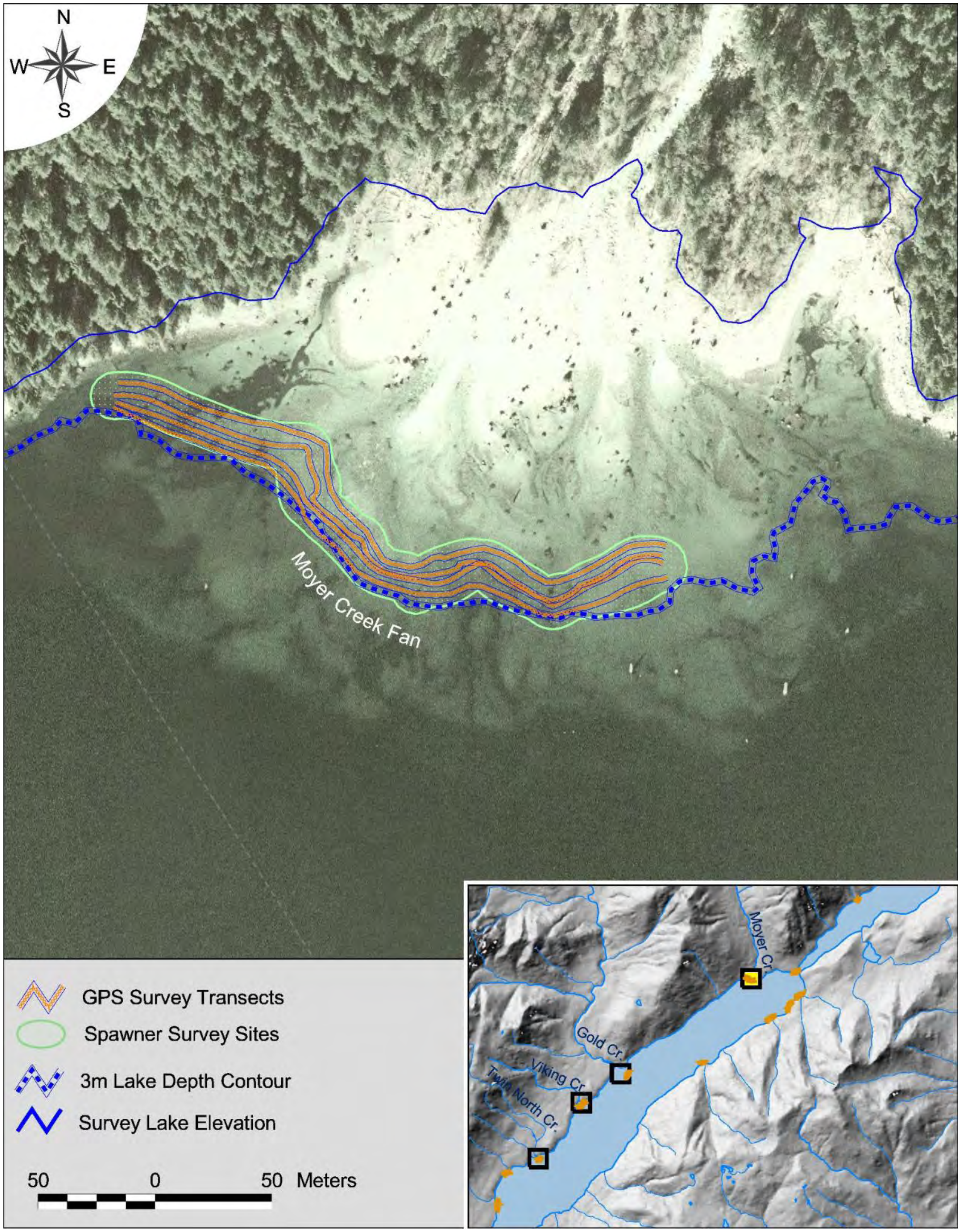
Moyer Cr.
Gold Cr.
Viking Cr.
Twin North Cr.



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Moyer Creek Fan
GPS Survey Transects
Spawner Survey Sites
3m Lake Depth Contour
Survey Lake Elevation
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Meters
Moyer Cr.
Gold Cr.
Viking Cr.
Twin North Cr.

# APPENDIX 2. ALR Elevation 1984-2012

| 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 | 8.70 | 120.25 | 2.20 |
| 1991 | 124.24 | 116.10 | 8.14 | 119.95 | 2.19 |
| 1992 | 122.77 | 116.00 | 6.77 | 118.90 | 1.98 |
| 1993 | 124.89 | 116.18 | 8.72 | 120.10 | 2.69 |
| 1994 | 125.27 | 117.07 | 8.20 | 121.88 | 2.09 |
| 1995 | 126.14 | 119.21 | 6.93 | 122.96 | 1.30 |
| 1996 | 124.64 | 120.70 | 3.94 | 122.13 | 0.62 |
| 1997 | 125.08 | 120.11 | 4.97 | 122.50 | 1.08 |
| 1998 | 124.03 | 117.24 | 6.79 | 121.81 | 1.51 |
| 1999 | 124.45 | 119.50 | 4.95 | 122.40 | 1.09 |
| 2000 | 124.43 | 118.92 | 5.51 | 121.27 | 1.46 |
| 2001 | 123.95 | 117.62 | 6.33 | 121.33 | 1.60 |
| 2002 | 124.39 | 116.37 | 8.02 | 121.76 | 1.95 |
| 2003 | 124.30 | 118.34 | 5.96 | 122.13 | 1.06 |
| 2004 | 124.32 | 120.22 | 4.10 | 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 | 122.40 | 1.19 |
| 2008 | 124.27 | 119.09 | 5.18 | 121.96 | 1.40 |
| 2009 | 124.72 | 119.41 | 5.31 | 122.27 | 1.18 |
| 2010 | 124.74 | 120.22 | 4.52 | 122.30 | 0.80 |
| 2011 | 124.12 | 118.61 | 5.51 | 121.92 | 1.43 |
| 2012 | 124.09 | 119.69 | 4.40 | 122.21 | 1.09 |

# APPENDIX 3. Nighttime snorkel site locations

| ID | Site Name | Length of site(m) | Start UTM | | End UTM | |
|---|---|---|---|---|---|---|
| | | | sXn83z10u | sYn83z10u | eXn83z10u | eYn83z10u |
| 1 | WestShore02 | 306 | 537349 | 5460643 | 537351 | 5460888 |
| 2 | WestShore01 | 226 | 537495 | 5461471 | 537685 | 5461556 |
| 3 | Twin North | 192 | 538269 | 5461828 | 538382 | 5461917 |
| 4 | Viking | 321 | 539203 | 5463061 | 539457 | 5463196 |
| 5 | Gold | 211 | 540371 | 5463764 | 540422 | 5463881 |
| 6 | GF04 | 186 | 542243 | 5464097 | 542105 | 5464065 |
| 7 | GF03 | 212 | 543779 | 5465157 | 543646 | 5465045 |
| 8 | GF02S | 266 | 544252 | 5465512 | 544147 | 5465298 |
| 9 | GF02N | 278 | 544507 | 5465698 | 544337 | 5465590 |
| 10 | Moyer | 292 | 543133 | 5466093 | 543369 | 5466029 |
| 11 | Narrows | 268 | 544252 | 5466189 | 544394 | 5466300 |
| 12 | GF01 | 140 | 545736 | 5467868 | 545815 | 5467969 |