Assessment of Lake Levels and their Variation on the Recruitment of Shore Spawning Kokanee Fry within the West Arm of Kootenay Lake

Report

May 29, 2012

Prepared for:

Columbia Operations Fisheries Advisory Committee (COFAC)

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Executive Summary

This report provides an examination of the hydrograph of the West Arm of Kootenay Lake in relation to the shore spawning kokanee. The hydrograph has been altered significantly following a series of hydroelectric developments over the last century. Upstream and downstream impoundment and the subsequent alteration of the natural hydrograph have had a profound ecological impact upon Kootenay Lake. Shore spawning kokanee at specific sites in the West Arm are affected due to dewatering of redds as the hydrograph declines over the fall, winter and early spring months. Analysis of the hydrograph prior to major impacts revealed that dewatered redds increased from approximately 12% on average during the 1928-1932 period to an estimated average of 70% during the last decade based on redd depth data from the 2009 and 2010 field seasons. The hydrograph is considerably more variable in the 2000-2011 period than in the 1928-1931 period with the current system configuration of dams and operational directives. The variability results in a delay in spring flood to meet flood control requirements thus leaving the West Arm littoral areas exposed with more frequent and extended periods of low water into late spring.

The operating constraints of Kootenay Lake are complex including International Joint Commission lake level regulation for flood control, Libby and Duncan Dam operations and downstream power generation. Relative to West Arm kokanee shore spawning the question arises that within these constraints what lake level regulation would improve spawning and incubation success of West Arm Kokanee shore spawners? Four operational alternatives were posed and the results of this study suggest that if these alternatives were the only options, spawning success would be optimized by placing priority on a low lake level in September as outlined in Alternative 4. Even with this operational strategy however, nearly 74% of the redds on average would still be stranded over the winter drawdown. The analysis was limited by the data available hence the estimates of dewatering may well change with more refined timing and depth data on shore spawning kokanee redds. More detailed analysis of timing of spawning and incubation and emergence could not be completed owing to lack of additional data beyond work conducted in 2010. A series of recommendations are provided to improve the data collection going forward.

Acknowledgements

BC Hydro, Fortis BC and Columbia Power Corporation are acknowledged for funding and supporting this project. The Ministry of Forests Lands and Natural resource Operations (MFLNRO) and the Department of Fisheries and Oceans also provided direction and support.

Trevor Oussoren of BC Hydro is acknowledged for edits and comments in report preparation as well as assistance in obtaining all necessary data.

Eva Schindler, Ministry of Forests Lands and Natural resource Operations (MFLNRO) Limnologist, is acknowledged for providing temperature data from the West Arm from the South Arm Kootenay Lake Nutrient Restoration Program (with funding from the Kootenai Tribe of Idaho).

Sheila Street and Jamie King of Fortis BC are acknowledged for providing data and assistance on data interpretation.

Suggested Citation: Irvine, R.L., G.F. Andrusak, and H. Andrusak. 2012. Assessment of Lake Levels and their Variation on the Recruitment of Shore Spawning Kokanee Fry within the West Arm of Kootenay Lake. Report prepared for Columbia Operations Fisheries Advisory Committee.

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Introduction

The West Arm of Kootenay Lake has undergone many changes as a result of hydroelectric development and anthropogenic influence since the area was settled. Hydroelectric developments on the lower Kootenay River began in 1897 with the construction and operation of the Lower Bonnington Dam and proceeded with several dams built and commissioned on the Kootenay River (Upper Bonnington, 1906; South Slocan, 1928; Corra Linn, 1932; Brilliant Dam, 1944; Libby Dam, 1973; Kootenay Canal, 1976 (Hirst 1991) and Brilliant Dam Expansion, 2007). Construction of the Duncan Dam on the Duncan River was completed in 1967 as partial fulfillment of the obligations under the Columbia Treaty. Corra Linn Dam affected the West Arm of Kootenay Lake as did the dredging of Grohman Narrows in 1939-1940 which was necessitated to meet the stipulations of the Kootenay Lake Order of 1938 (Hirst 1991). This Order was primarily designed to keep Corra Linn Dam from raising water levels upstream and the dredging allowed the lake levels to be lowered at the commencement of spring rise, usually early April. The hydrographic regime within Kootenay Lake has been radically altered by the operations of these various dams and the agreements that bind the operations. The impacts linked with these changes have affected the kokanee (*Oncorhynchus nerka*) population(s) within the West Arm of Kootenay Lake (Martin 1984; H. Andrusak & Northcote 1989).

Background

In 2006, large numbers of shoal spawning kokanee were observed in the West Arm of Kootenay Lake. Monitoring of spawning and egg incubation/emergence by the Ministry of Environment identified kokanee redds dewatered prior to fry emergence which resulted in fry unable to access Kootenay Lake. In 2007, this issue was raised with Columbia Operations Fish Advisory Committee (COFAC). Upon discussion with hydroelectric system operations planners it was determined that international agreements, power generation costs, available inflows from upstream dams, and cross-basin environmental and social issue trade-offs all influenced the ability to provide water levels for the protection of shore spawning kokanee. At the 20 November 2007 COFAC meeting a discussion on the complexities in operating to protect fish and fish habitat downstream of Brilliant Dam, within Kootenay Lake and downstream of Duncan Dam resulted in a recommendation of the formation of a sub-committee to review the shoal spawning kokanee issue and other related water conveyance issues (Golder 2009). A brief outline of the sequence of activities is included below:

- 2003 - onset of monitoring of KLK shore spawners - MOE;
- 2006 - large number of KLK shore spawners noted - MOE;
- 2007 - formation of the Duncan and Kootenay River Fish and Water Conveyance Sub-Committee;
- 2008/2009 - development and qualitative evaluation of operational alternatives by sub-committee;

- 2009 - development of a 5-year plan (2009 to 2013) for Kootenay Issues;
- 2009 - Finalization of the Interim Report for the sub-committee;
- 2009 –shore spawning kokanee monitoring (Redfish);
- 2010 –shore spawning kokanee monitoring (Redfish);
- 2011 – shore spawning monitoring (Redfish) and genetic analysis (UBCO - Russello);
- 2011 – COFAC recommendation to evaluate historic water levels for incubation success and refinement of life history timing (spawning, incubation and emergence);
- 2012 – COFAC receives results from analysis of historic water levels (Poisson and Redfish) and a review of the shore spawning kokanee history for new members
- 2013 – (proposed), evaluation of the results and conclusions from key studies e.g. DDM WUP, HLK WUP, BRX PAC and revise Kootenay System Issues Risk Assessment;
- 2013 – (proposed), development of a kokanee shore spawner protection strategy

West Arm kokanee are considered somewhat unique because of their unusually large size, early age at maturity (Vernon 1957; Martin 1984) and uncharacteristic fry feeding behaviour (H. Andrusak & Northcote 1989). West Arm kokanee have recently been identified as genetically distinct from the North Arm population (Russello 2012 and references therein) and preliminary results indicate that stream and shore spawners in the West Arm may also be genetically distinct ecotypes, although more sampling is required to confirm these results (Lemay & Russello 2011). Until recently, only West Arm kokanee stream spawners had been the focus of much study, but since 2003, some monitoring has been conducted on the shore spawners and since 2008 more detailed studies have been directed at the shore spawners. Andrusak et al. (2010) and Andrusak and Andrusak (2011) have assessed their abundance, spawning locations and characteristics, spawn timing and the possible impacts of lake level drawdown on spawning and egg incubation.

The studies on shore spawning kokanee in 2009-2010 and 2010-2011 focused on determining the abundance, distribution and success of kokanee shore spawning at select sites along the West Arm of Kootenay Lake. Shore spawning sites included; Six Mile, MacDonald's Landing, Sitkum Creek and Harrop Creek. Daytime boat and night time snorkel surveys were conducted in the September-October period to ascertain the abundance and distribution of these fish. A proportion of redds distributed within the spawning areas were marked and their depths measured and these redds were subsequently followed through incubation and emergence into the spring to determine the potential impacts of lake levels fluctuations on their success and the proportion of false redds. Key findings included: 1) kokanee shore spawners select sites influenced by groundwater, 2) shore spawning in the West Arm is associated with alluvial areas associated with tributary streams, 3) spawning substrate consisted of pea size gravel, small rocks and sand well percolated by upwelling groundwater, 4) redd depth distribution ranged between 0.5-2.0 m below the water surface at the time of spawning, 5) ATU calculations using groundwater temperatures indicate alevins and early fry development would occur by early February and fry emergence would range from mid-February until April depending upon the behavioural and biological components of emergence (Taylor et al. 2000), and 6) 84

.21% of the marked redds assessed in springtime were actual redds giving a false redd percentage of 15.8%. An additional result from the two years of study was a preliminary analysis of the proportion of redds that were dewatered using redd depth distribution and lake elevations.

In 2011, the companies involved in power generation in the Kootenay Lake watershed expressed interest in closer examination of lake levels relative to known shore spawner distributions. In order to inform the decision-making process about different operating alternatives for Kootenay Lake, an analysis of lake levels in relation to shore spawning kokanee was done. Four alternative operational strategies were generated based on previous evaluation processes (Golder Associates Ltd. 2009) and these form the basis for this evaluation of operational optimization for shore spawning kokanee. In addition, there was interest in refining the estimates of the percentage of redds dewatered through time during different operational regimes so this is also a focus of this report.

Management Questions and Hypotheses

The management questions below were generated at the 2011 COFAC meeting and refined in conjunction with members of COFAC to motivate this analysis and interpretation of the biological and environmental data from the West Arm of Kootenay Lake.

1. Considering the operating constraints of Kootenay Lake (e.g., flood control, IJC, Libby and Duncan Dam operations, downstream power generation) is it possible to improve spawning and incubation success of West Arm Kokanee shore spawners?;

Specifically, what would the relative spawning and incubation success be for the 4 defined operational alternatives (i.e., **1 – Maximize Power; 2 – Fill KLK then priority on BRD/X flows; 3 – Priority on KLK Level; 4 - Priority on KLK level in September and Brilliant Target Min Flows**)?

2. How does the spawning incubation success of the current operation of Kootenay Lake (e.g., post BRX commissioning 2007 to 2011) compare to a natural (pre-impoundment) Kootenay Lake flow regime?

The objectives linked to these management questions are as follows:

1) Graphically and numerically describe the lake level regimes in the West Arm of Kootenay Lake for the pre-impoundment period to provide a context of the natural variability in lake levels and how that variability relates to the four operational alternatives.

2) Refine the spawn timing of the kokanee based on snorkel survey data from 2008 - 2010, and any other historical data that have sufficient resolution to provide estimates of spawn timing.

3) Assess the likely window of incubation and emergence for shore spawning kokanee with confidence intervals through time in order to look at the impact of spring conditions and water temperature on recruitment. It is unlikely that there is within gravel water temperature measured in many years so the best available data will be used and assumptions made explicit.

4) Provide a comparative assessment of spawning success (measured as the proportion of redds that remain watered throughout the spawning, incubation and emergence periods) in relation to pre-impoundment conditions and the four operational alternatives.

Overview

West Arm of Kootenay Lake

The West Arm of Kootenay Lake is about 40 km long with a mean depth of only 13 m. It is physically and limnologically different from the main lake, comprised of a series of shallow basins interconnected by narrow riverine sections (Figure 1). The entire West Arm has a flushing rate of about 5-6 days (Perrin 1987; Martin and Northcote 1991). This compares with the main lake's water residence of 1.8 years, average depth of 100 m and 104 km length. A more detailed description of Kootenay Lake can be found in Northcote (1972), Northcote (1973), Daley et al. (1981) and Perrin (1987).

West Arm Kokanee

In the early 1950s, Vernon (1957) identified three racially distinct stocks of Kootenay Lake kokanee with one stock originating from the North Arm, one from the South Arm and the third from the West Arm. Martin (1984) reaffirmed the differences in growth and age of these three stocks while determining the cause of a dramatic decline of the West Arm stock in the late 1970s. Subsequently, Northcote (1991) and Martin and Northcote (1991) briefly summarized growth and food habits of West Arm kokanee, and Perrin and Levy (1990) examined kokanee fry growth under experimental conditions precipitated by the collapse of the stock and the closure of the once prominent fishery (Andrusak and Brown 1987; Redfish Consulting Ltd. 1997).

The threat of a complete collapse of Kootenay Lake kokanee in the 1980s was related to the dramatic decline in lake productivity (Daley et al. 1981) due to a combination of nutrient retention in newly formed upstream reservoirs and cessation of a major discharge of phosphorous from a phosphate fertilizer plant (Ashley et al., 1997). However, despite the implementation of a large-scale nutrient addition experiment on the lake (Ashley et al., 1997) and several small-scale experiments conducted within the West Arm (Perrin and Levy 1990), no measurable benefit to West Arm kokanee was observed. Perrin and Levy (1990) indicated that food was not a limiting factor for West Arm kokanee fry survival and concluded that other factors related to early life history of this distinct stock were affecting their survival. Andrusak and Northcote (1989) identified that West Arm kokanee fry remain on the littoral areas for over a month upon emergence and utilize benthic food items following their migration from their natal streams in the West Arm. Martin (1979) and Andrusak and Northcote (1989) suggest that changes in the hydrograph due to flood control and hydroelectric operations on Kootenay Lake have reduced survival for kokanee in the West Arm, especially since newly emergent fry rely on littoral habitat food production. All of these investigations were directed at the stream spawning component of West Arm kokanee.

Most recently, investigations have observed kokanee spawning along the shore within the West Arm of Kootenay Lake (Andrusak et al. 2010; Andrusak and Andrusak 2011). Some specific sites where shore spawning has been observed include: Six Mile south of Duhamel Creek; McDonald's Landing north of Duhamel Creek, Nine Mile near Sitkum Creek and Harrop south of Harrop Creek (Figure 2). Preliminary analysis of these fish indicates they may be genetically distinct ecotypes, but more data are needed before this distinction is conclusive (Lemay and Russello 2011). Further investigations into these shore spawning kokanee, including this study, will provide more detailed information that will assist in their management and protection.

There appears to be wide variation in timing of shore spawning kokanee in BC lakes where investigative work has been completed. In Okanagan Lake, timing varies considerably within the month of October (H. Andrusak et al. 2005). In other lakes in British Columbia, shore spawning occurs in December (Christina Lake) as in Anderson and East Barriere lakes, where shore spawning kokanee spawn during November-December at depths greater than 30m (Andrusak and Morris 2005). Wood Lake shore spawners appear at the end of October and spawn during the first two weeks of November (Andrusak 2007). The West Arm kokanee shore spawners spawn amongst the earliest of known shore spawners.

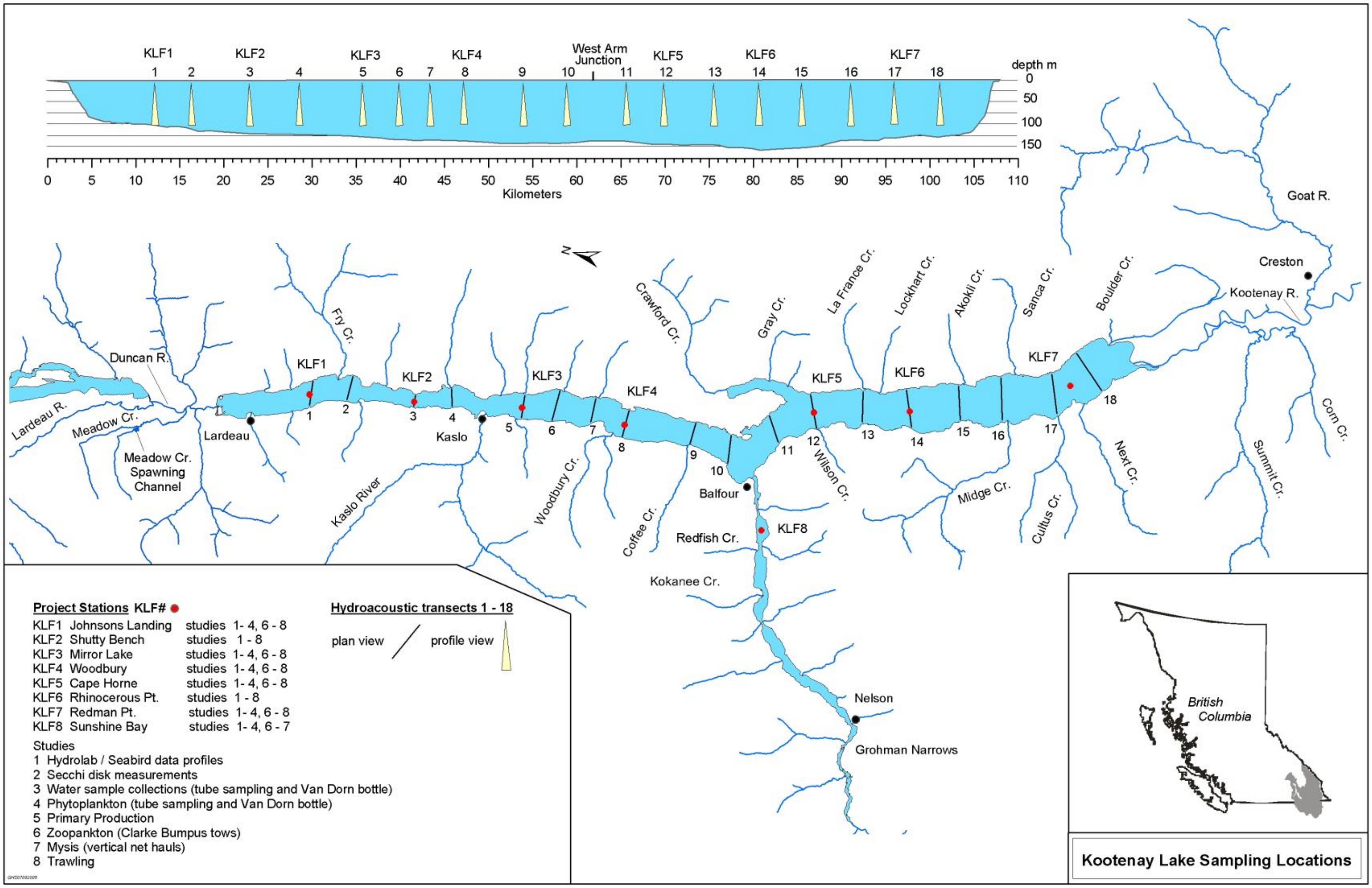

Figure 1. Sampling locations described in Schindler et al. 2010. Water temperature data for this analysis was obtained from station KLF8 in the West Arm of Kootenay Lake.

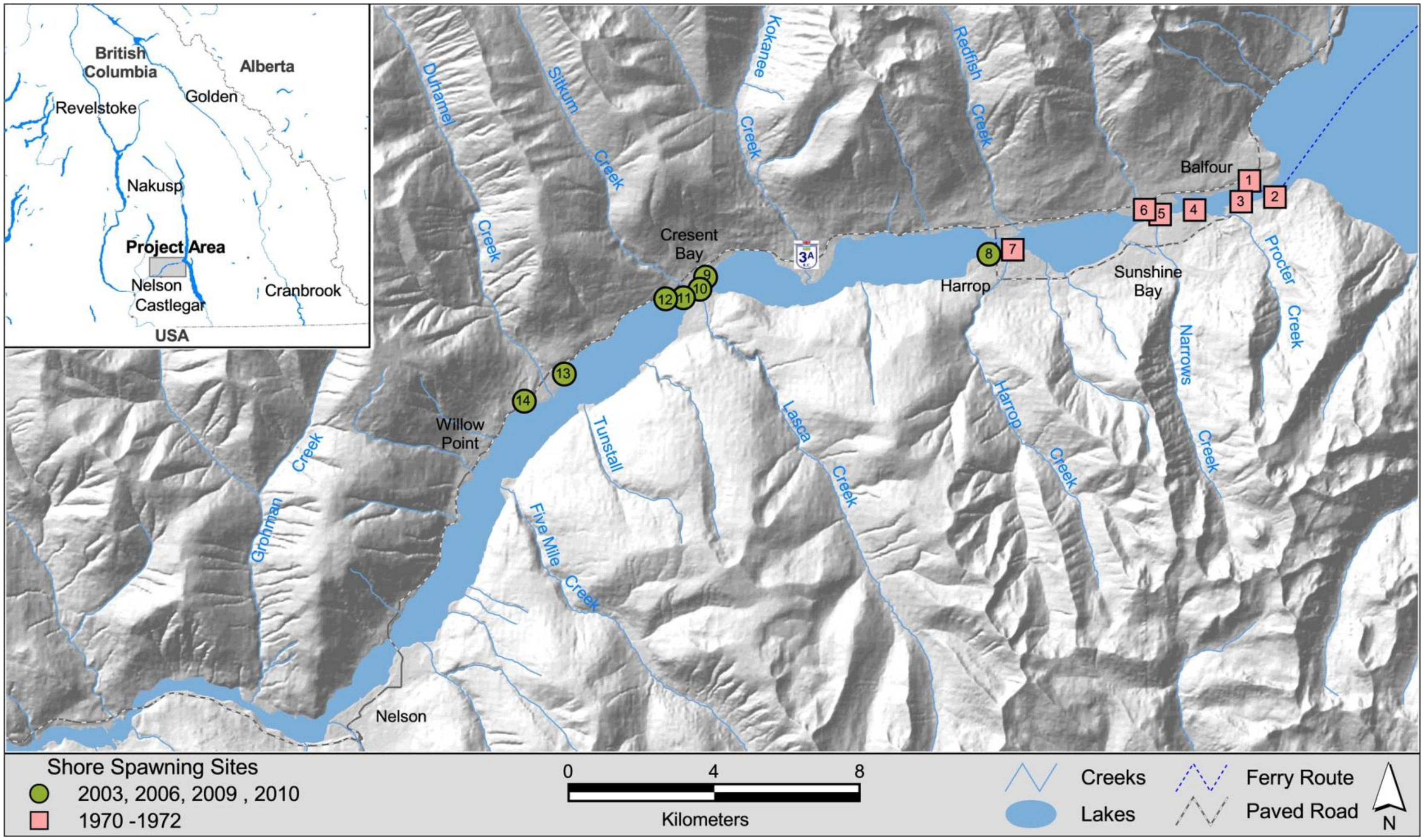

Figure 2. Overview map of the West Arm of Kootenay Lake and sites for observed kokanee shore spawning by year

Methods

Data

Lake elevation data were obtained from several sources. FortisBC (Ms. Sheila Street and Mr. Jaime King) provided data from 1928-2011 for the Queen's Bay elevation and from 1999-2011 for the Nelson Gauge. The Water Survey of Canada (WSC) provided historical data on lake elevation levels at four sites within the West Arm. Location details and years of data coverage for each of these WSC stations are provided in Table 1. The Ministry of Environment in Nelson, BC provided water temperature data for Kootenay Lake (Ms. Eva Schindler) from the work on the South Arm Kootenay Lake Nutrient Restoration Program (with funding from the Kootenai Tribe of Idaho and BC Hydro). The water temperature data are for the years 2004 to 2010 inclusive and were sampled from station KLF8 located north of Redfish Creek in the West Arm at depths from surface to 35m (Figure 1)(Schindler et al. 2010).

Table 1. ***Locations and date ranges for Kootenay Lake elevation data obtained from the Water Survey of Canada (WSC).***

Gauge No.	General Location	Gauge Name	Date Range	UTM Grid	Easting	Northing	Actual Data
12	Kootenay Lake Near Nelson	08NJ077	1929 - 1948	11U	482746	5490295	1929, 1930, 1931, 1945, 1946, 1947, 1948
13	Kootenay Lake Near Nelson	08NJ078	1929 - 1948	11U	484377	5491896	1929 to 1932; 1945 to 1949
14	Kootenay Lake Near Nelson	08NJ079	1929 - 1948	11U	487113	5493803	1929 to 1932; 1945 to 1949
15	Kootenay Lake Near Nelson	08NJ084	1929 - 1948	11U	488359	5494542	1929 to 1931; 1945 to 1949

The time series of elevation data measured at the Nelson gauge were regressed against the time series at Queen's Bay for dates when data were recorded at both stations in order to determine a predictive relationship between the water levels measured at the two gauges. The elevation time series measured at WSC Gauge 15 were also regressed against the time series at Queen's Bay to determine a linear predictive relationship between the two gauges.

Data on kokanee spawner counts, redd counts, redd depths and surface and groundwater temperatures from selected spawning sites throughout the spawning, incubation and emergence period were provided by Redfish Consulting Ltd.

Data on four operational alternatives that are under consideration for use on Kootenay Lake in order to balance the needs of different fish and fish habitat use concerns in the system were provided by T. Oussoren of BC Hydro. This hydrological data was used to compare the operational alternatives with the historical and current Kootenay Lake levels and with the needs and habitat use of the shore spawning kokanee.

All data were compiled into a customized Access 2007 database prior to analysis and plotting in order to provide standardization of formatting for this and future work.

Analysis

The data were plotted extensively in order to look for outliers or errors and to assess patterns in variation through season and among years and for patterns and trends through time as development in the region increased. Elevations, temperature, redd depth and redd and adult spawner count data were assessed.

In order to determine the percent of redds dewatered for each year for which there were elevation data (1928-2011) the minimum elevation the lake would reach during the spawning, incubation and emergence period (1 September to 30 April) was calculated for each year. The elevation for each day of year within each year in the period of record was extracted. The redd depths measured in the 2009-2010 and the 2010-2011 studies on the West Arm were converted to feet since all historical elevation data were recorded in feet. Redd elevations for each day in each year were calculated by subtracting the absolute depth of the redd (e.g., 3 ft) from the elevation on that day. For example, if in 2009, a kokanee on September 15th, created a redd at 3 feet underwater and the elevation was hypothetically 1743ft, the redd's absolute elevation would be 1740 ft. for that year. This depth data would then be transposed to another year by subtracting the redd depth data from the elevation on the same day in a different year. To continue with the above example, the depth on September 15th in 1930 was approximately 1741 ft. so the redd's absolute elevation for that year would be 1738ft. Because there are only two years of depth data for redds, and due to the fact that the biology in other systems with shore spawning kokanee show a high degree of consistency in the depths they select for spawning (e.g., Okanagan Lake kokanee spawn predominantly in 0.25-1.0m of water in each year they have been studied over multiple years (H. Andrusak et al. 2005), it was assumed that selected depths would be the same from year to year. The spawn timing was assumed to be the same as well in the absence of any consistent temperature time series for the West Arm of Kootenay Lake or any additional spawner count data. Photoperiod is the predominant driver of spawn timing in salmonids, but temperature determines final sexual maturation and spawn initiation (Wang et al. 2010). The absolute redd elevation was then compared to the annual minimum elevation during the spawning, incubation and emergence period and if it was higher than the minimum elevation, the redd was considered dewatered. The four operational alternatives were then compared using the same method.

This analysis method differs from the method used by Poisson Consulting Ltd. in the previous studies (G. F. Andrusak & H. Andrusak 2011; G. F. Andrusak et al. 2010) in that the previous analysis used absolute lake elevations of the kokanee redds and did not take into account variation in lake level fluctuations from year to year. This approach was appropriate for the previous purposes since it was not trying to extrapolate to a wide range of years with different regimes; the current approach is considered more accurate and appropriate for the range of operations assessed.

The analyses and plotting of data was performed using R 2.14.1 (R Development Core Team 2011) and ggplot2 library (Wickham 2009). The plotting of elevation was consistently completed in feet since all reference material and documents used this system. The constructed database includes elevation in feet and metres so the plots could easily be regenerated in the metric system if desired.

Results

The linear regression between the water elevation at the Nelson gauge and Queen's Bay had over 4000 data points with which to relate the two gauges and the regression was very tight with an adjusted R^2 of 0.96 (Figure 3). The regression equation relating the elevations at the two gauges is:

$$Nelson_{elev}=218.2 + 0.8744*Queen's\ Bay_{elev}$$

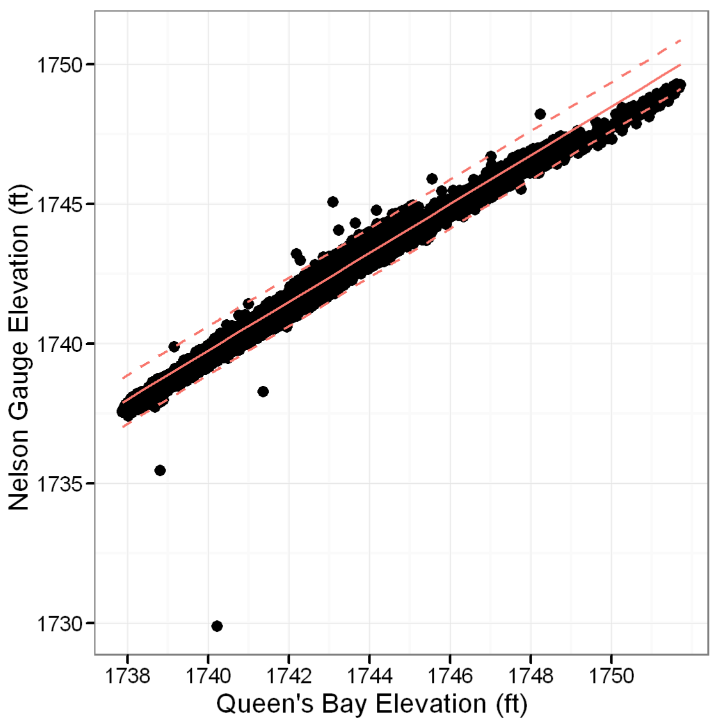

Figure 3. West Arm of Kootenay Lake water elevation (ft) measured at the Nelson gauge as predicted by elevation measured at the Queen's Bay gauge, 2004-2011. Raw data is plotted in black, the linear regression fit is shown with the solid red line and prediction intervals are plotted in the red dashed lines.

The linear regression between the water elevation at the Water Survey of Canada Gauge 15 (see Table 1 for location) and Queen's Bay was very good with an adjusted R^2 of 0.98 (Figure 4). The regression equation relating the elevations at the two gauges is:

$$WSC15_{elev}=245.8 + 0.8588*Queen's\ Bay_{elev}$$

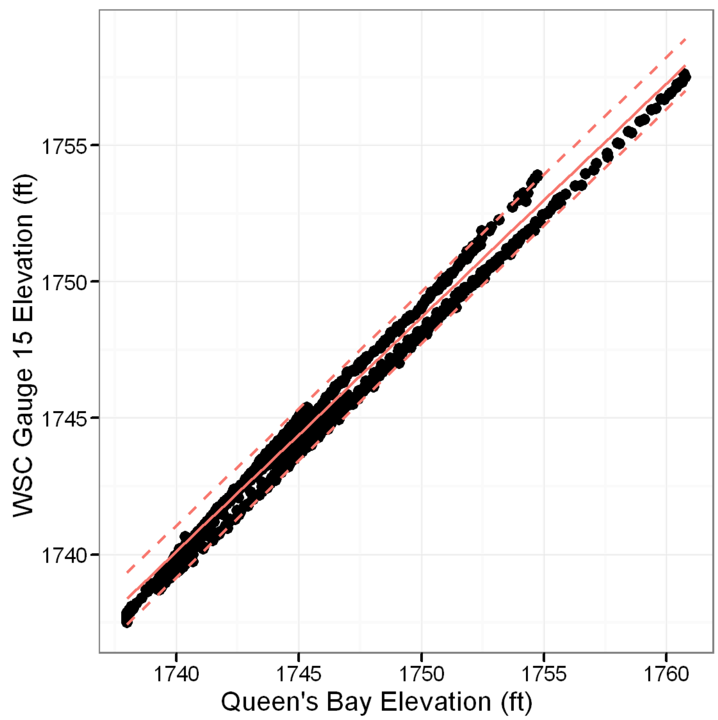

Figure 4. West Arm of Kootenay Lake water elevation (ft) measured at the Water Survey of Canada Gauge 15 as predicted by elevation measured at the Queen's Bay gauge, 1929-1930 and 1945-1949. Raw data is plotted in black, the linear regression fit is shown with the solid red line and prediction intervals are plotted in the red dashed lines.

Kootenay Lake elevations at Queen's Bay and the Water Survey of Canada Gauge 15 in the 1928-1931 period is plotted in Figure 5. Although there was already some hydro-electric development prior to this time, it is the closest data available to natural West Arm elevation levels and is prior to: 1) completion of Corra Linn Dam in 1932, 2) to the Kootenay Lake Order in 1938, and 3) the dredging of Grohman Narrows in 1939-1940.

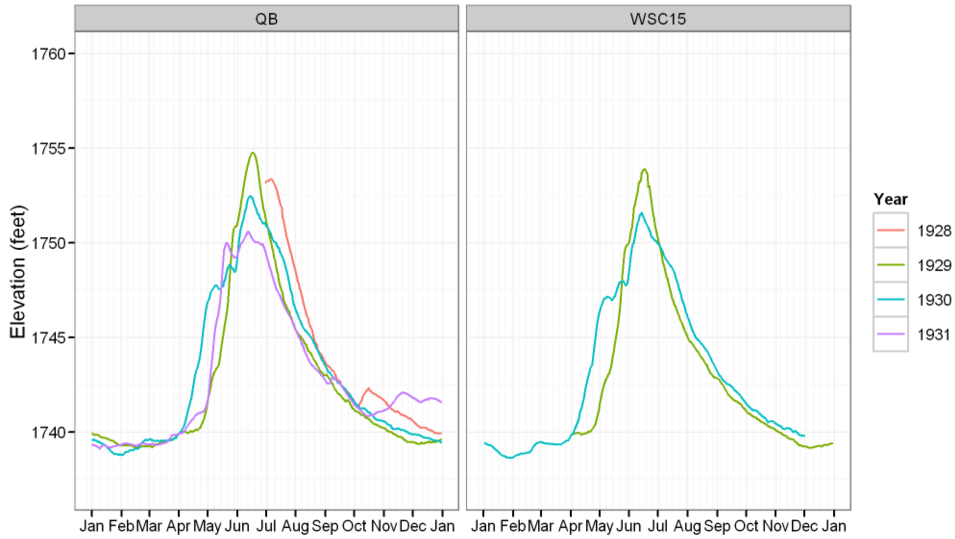

Figure 5 West Arm of Kootenay Lake water elevation (ft) measured at the Queen's Bay gauge and the Water Survey of Canada Gauge 15, 1928-1931.

The Kootenay Lake Order was instituted in 1938. The plot of the same two gauges throughout the 1940s illustrates the differences in hydrologic regime by this point in regional hydro development (Figure 6). This is prior to the construction and operation of Libby Dam, Duncan Dam and Kootenay Canal.

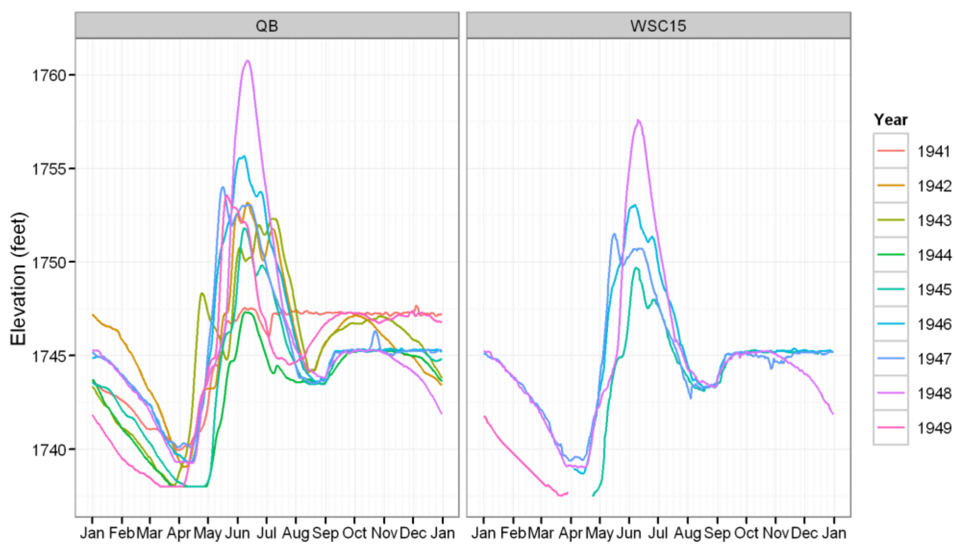

Figure 6 West Arm of Kootenay Lake water elevation (ft) measured at the Queen's Bay gauge and the Water Survey of Canada Gauge 15, 1940-1949.

The minimum Kootenay Lake elevation, mean and maximum elevations in the 1928-1931 period (Figure 7 upper panel) and the most recent decade, 2000-2011 (Figure 7 lower panel) are plotted for comparison of the lakes' elevations over the annual cycle between the predominantly pre-development period and today.

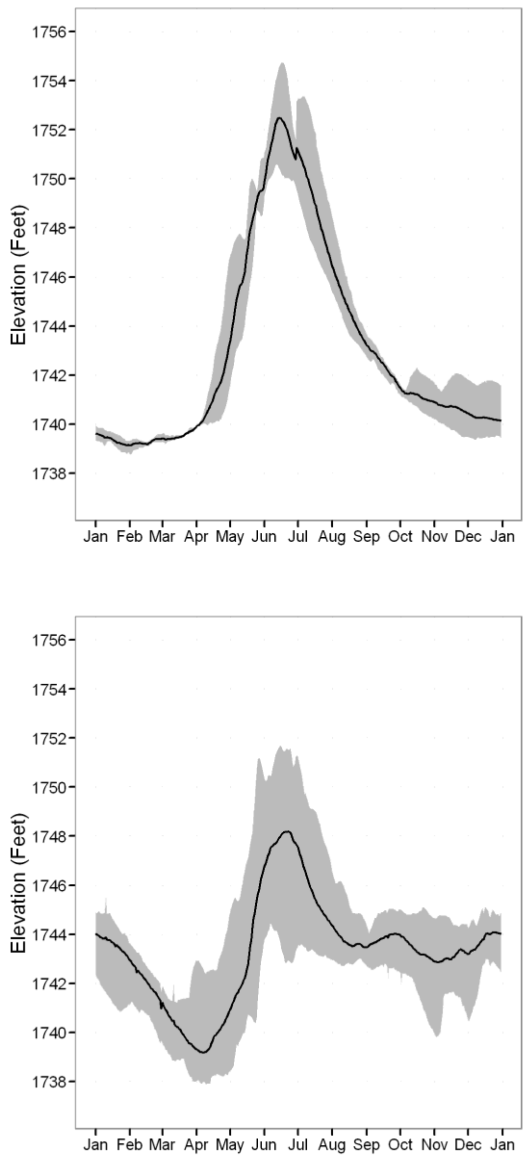

Figure 7 West Arm of Kootenay Lake water elevation (ft) measured at the Queen's Bay gauge during 1928-1931 (top plot) and 2000-2011 (bottom plot). Mean elevation by day is plotted with the black line and minimum and maximum elevations for each day averaged over all years are shown with the grey ribbon.

Adult kokanee and redd counts through time for each of the two years of study and allocated to time of day are plotted in Figure 8. On the first night of the snorkel survey on September 22, 2009, approximately 400 fish were counted at all the sites with decreasing numbers observed after that date. The number of redds counted increased up to over 1000 redds at all surveyed sites on the final survey on October 21, 2009. The total number of fish and redds was quite low in 2010 with only 110 adults counted over all five night snorkel surveys and 176 redds counted in daytime surveys (Figure 8).

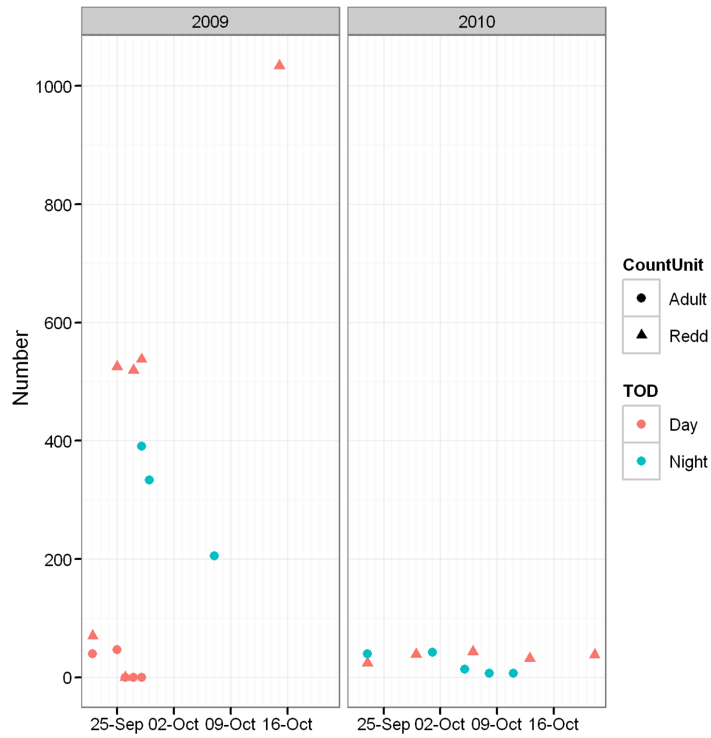

Figure 8 Number of adult kokanee spawners (circle) and redds (triangle) counted in either day (pink) or night (blue) over all sites in the two years of study, 2009-2010.

With respect to water temperature, the best data collected to date for refining the timing of the incubation and emergence of kokanee fry is the groundwater temperature measured during the 2009-2010 spawning season which had an average groundwater temperature of 6.74°C (G. F. Andrusak & H. Andrusak 2011). There was very little variation in the groundwater temperatures (Figure 9) at the Six Mile and Harrop sites while the Sitkum Creek logger was considered to have been affected by surface water (G. F. Andrusak & H. Andrusak 2011). The attainment of 1000 ATUs is used as a general guideline for the number of thermal units required by kokanee to attain emergence or the absorption of most of the yolk (Taylor et al. 2000). Given the groundwater temperatures in the identified shore spawning sites in the West Arm, the eggs would require 148.5 days on average to reach 1000 ATUs.

The water temperatures of the West Arm obtained from the MOE (Figure 10) allowed a longer term assessment of the date at which the lake surface temperature dropped below 13°C, which is thought to be an initiation temperature for shore spawning kokanee in Okanagan Lake (H.

Andrusak et al. 2005). Based on the MOE data, the temperature of 13°C is usually attained in either the last week of September of the first week of October (Figure 10).

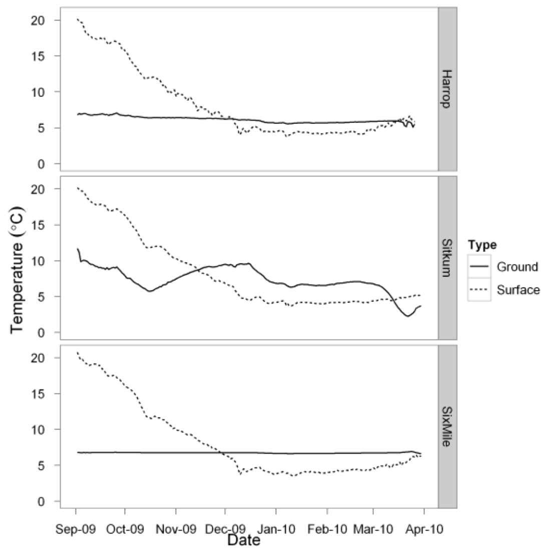

Figure 9 Ground and surface water temperatures through time at three identified shore spawning sites for West Arm kokanee, 2009-2010.

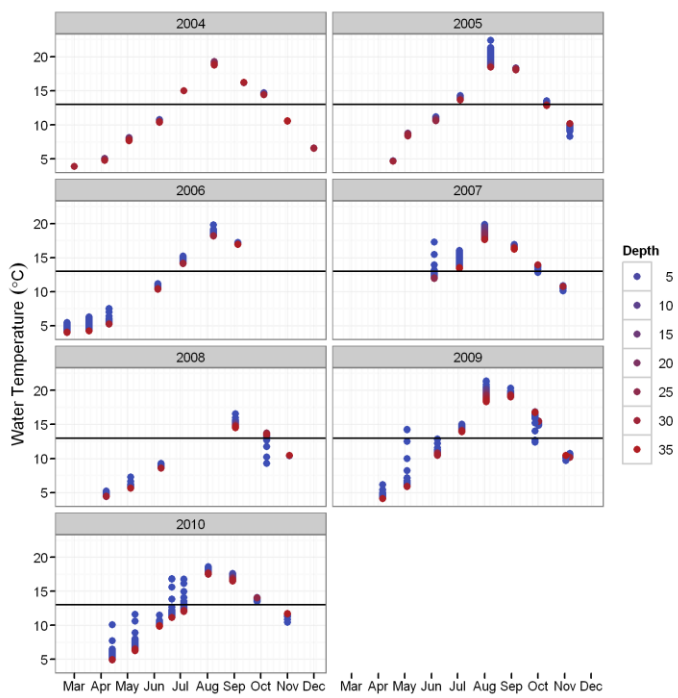

Figure 10 West Arm water temperatures by month and depth, 2004-2010. The horizontal black line marks 13°C believed to be the temperature at which kokanee initiate shore spawning.

The percentage of shore spawning kokanee redds that would be annually dewatered is plotted in Figure 11. In the earliest years for which there are data and there was minimal hydroelectric development (1928-1935), the percentage dewatered ranged from 0-20% (Figure 11). In the 1940s until the 1970s the dewatered percentage was very high, often reaching 100% and usually higher than 90% (Figure 11). In more recent times, the percentage of dewatered redds has ranged from a low value of 37% in 2002 to 100% in 2000 and 2001. The best three years for minimizing the percentage of dewatered redds during 1990-2011 were: 1994 (47% dewatered), 2002 (37% dewatered), and 2010 (50% dewatered) (Figure 11). All of these predictions use elevation data from Queen's Bay. The average percentage over the entire time period is ~80%, denoted by the horizontal black line on the plot (Figure 11). Because the absolute difference in the lake level for each year and the depth of the redd was used, there would be no difference in the predicted percentage of dewatered redds between Queen's Bay and other sites. There certainly could be differences, but these would result from differences in lake bathymetry and dewatering timing or redd site selection variation amongst sites. Since such data were not available, only the Queen's Bay results are presented as broadly representative of the system.

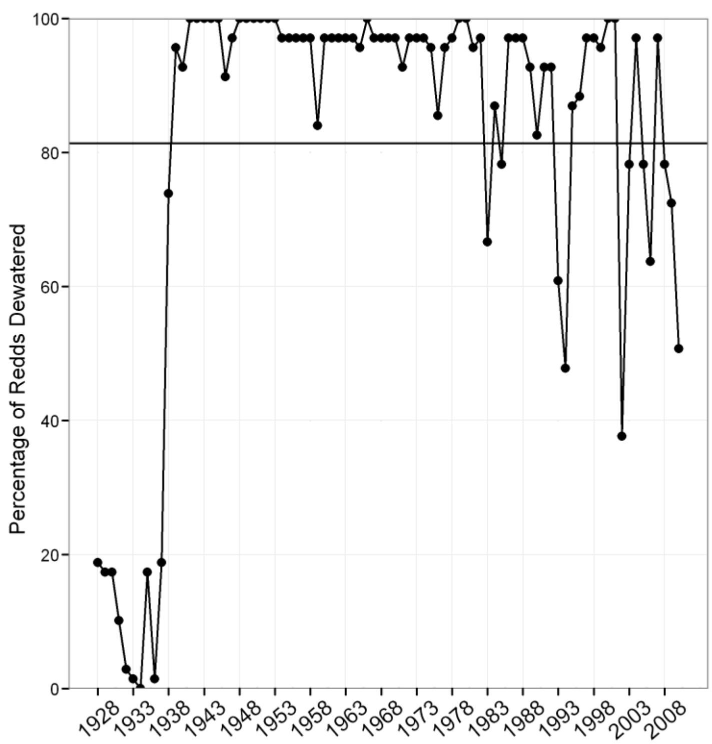

Figure 11 The percentage of shore spawning kokanee redds that would be dewatered during the spawning, incubation and emergence periods (September 1 to April 30), 1928-2010. The horizontal black line indicates the mean percentage of redds dewatered over the entire period.

The four operational alternatives provided by BC Hydro were then compared using the same analytic method to see what percentage of redds would be dewatered using each drawdown strategy. Alternative 4 (Priority on Kootenay Lake level in September and Brilliant Target

Minimum Flows) has the lowest dewatering potential given the existing data with 73.9% of redds dewatered and Alternative 1 (Maximize Power) has the highest dewatering potential at 95.7% (Figure 12).

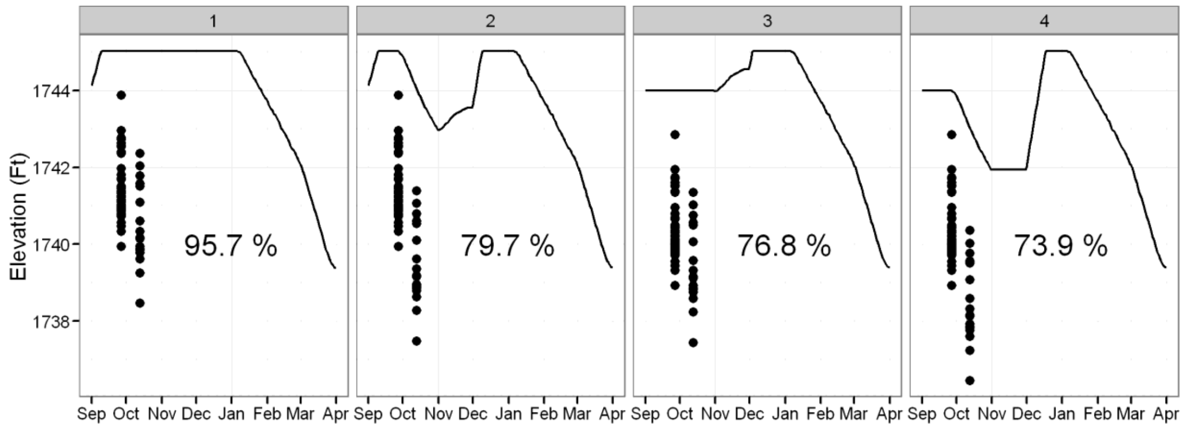

Figure 12 Percentage of shore spawning kokanee redds that would be dewatered during the spawning, incubation and emergence periods (September 1 to April 30) if Kootenay Lake was operated according to one of the four operational alternatives. The line plots the elevation of Kootenay Lake, the points are the absolute heights of kokanee redds with overall percentage of dewatered redds superimposed on each plot.

Discussion

The following discussion addresses each of the project objectives.

1) *Graphically and numerically describe the lake level regimes in the west arm of Kootenay Lake for the pre-impoundment period to provide a context of the natural variability in lake levels and how that variability relates to the four operational alternatives.*

The advent of hydroelectric development in the Kootenay Lake watershed has had a profound effect on Kootenay Lake level regimes that in turn impacts the percentage of redds dewatered during the spawning, incubation and emergence period for shore spawning kokanee. Data analysis indicates the percentage of dewatered redds increased from ~12% on average during the 1928-1932 period to an average of ~70% during the last decade (Figure 11). The lake level data suggests the shape of the annual elevation curve for the West Arm of Kootenay Lake during the 1928-1932 period was at approximately 1742 ft. in the September-October period with a gradual lowering of lake levels until February or March by approximately 3 ft. A gradual refilling of the lake until April or May would then occur and a steep increase would begin sometime in spring associated with commencement of freshet (Figure 5). In contrast, the current annual elevation curve (1976 to present) shows an average elevation of ~1744 ft. in the September-October period when spawning occurs, a decrease in lake levels almost immediately during November to December, an increase in January and a relatively steep decline from January to April or May with an average decrease of 5 ft. (Figure 7).

The considerable increase in predicted percentage of dewatered kokanee redds from the 1928-1932 period to the current state of operations can result from redds being dewatered throughout the incubation period. Firstly they can be dewatered immediately after spawning; secondly dewatering may occur during early winter when the lake level is lowered; or thirdly, the redds may be dewatered as the fry are hatching and prior to their emergence and migration to the lake in the February – April period.

Operational restrictions (i.e. IJC) in the spring months mean that the only time period when lake level regulation can be used to decrease dewatering of redds is during the fall months. The discussion on different operational strategies is guided by the four alternatives that are currently under discussion as part of the Duncan and Kootenay Rivers Fish and Water Conveyance Issues Sub-Committee (Figure 12) (Golder Associates Ltd. 2009). The best case scenario for shore spawning kokanee within these constraints is to: 1) keep the lake levels as low as possible prior to the spawning period so that the redds are inundated with water as long as possible in spring as the lake levels decrease, and 2) only implement increases in the lake levels after the spawning period during autumn. This scenario is best represented by a combination of Alternative 3 and Alternative 4, ideally with the fall decrease in Alternative 4 occurring approximately 2 weeks earlier than it is presently outlined (Figure 12). This does make the assumption that the habitat suitable for kokanee shore spawning would still be available and accessible even with lower water levels.

2) *Refine the spawn timing of the kokanee based on snorkel survey data from 2008 - 2010, and any other historical data that have sufficient resolution to provide estimates of spawn timing.*

The spawn timing could not be refined in this project as additional data were not available beyond that from 2009 and 2010 (G. F. Andrusak & H. Andrusak 2011; G. F. Andrusak et al. 2010). The only other research done on the West Arm shore spawners was a diving survey in the early 1970s (August 1970 and September 1971). The main goal of that project was to identify habitat types and geographical areas where shore spawning occurred throughout the West Arm. The report, in fact, does not have dates of observations, but only locations and numbers of kokanee observed (H. Andrusak 1972).

Area under the curve analysis in order to refine spawn timing of the shore spawning kokanee could not be completed on the 2009 and 2010 data due to the following: 1) the numbers of shore spawning kokanee were overall very low in 2010 and therefore there is really only one year of data of redd and adult counts, 2) the field surveys for the two projects commenced after spawning had already begun (due to funding timing) so the ascending limb of the curve for defining spawn timing is lacking, 3) the daytime observations are not comparable to the night data since shore spawners appear to mainly spawn at night.

3) *Assess the likely window of incubation and emergence for shore spawning kokanee with confidence intervals through time in order to look at the impact of spring conditions and water temperature on recruitment. It is unlikely that there is within gravel water temperature measured in many years so the best available data will be used and assumptions made explicit.*

There were no further data with which to refine the incubation and emergence periods for shore spawning kokanee in the West Arm. The only groundwater temperatures were measured with Tidbit loggers in the 2009-2010 period. The mean groundwater temperature averaged over time and between the Six Mile and Harrop Creek sites was 6.74°C which would require 148.5 days for kokanee to reach 1000 ATUs. The periods of spawning, incubation and emergence based on these groundwater data have been summarized in the 2011 report and cannot be refined without further data (G. F. Andrusak & H. Andrusak 2011).

Water temperature data for the West Arm of Kootenay Lake are sparse and discontinuous with no long term data similar to the elevation data which are available from 1928-present day. The temperature data that were available from Schindler et al. (2010) were plotted to determine the date at which the lake temperatures dropped below 13°C since this is considered a temperature cue to initiate spawning in Okanagan lake where a distinct genetic shore spawning ecotype of kokanee exists (H. Andrusak et al. 2005). This temperature cue can only be tested for its veracity in Kootenay Lake with further fish surveys and additional temperature data so that the date of spawning commencement can be compared over a long time period with the water temperature in the West Arm. Currently, the temperature usually drops below 13°C in the last week of September or the first week of October and shore spawning was observed before that time in both years of study thus it may not be a defined cue.

4)-*Provide a comparative assessment of spawning success (measured as the proportion of redds that remain watered throughout the spawning, incubation and emergence periods) in relation to pre-impoundment conditions and the four operational alternatives.*

In the context of this analysis, the four proposed alternative operational strategies for Kootenay Lake were tested and Alternative 4 was found to be the best, although it still would strand ~74% of the shore spawning kokanee redds. Alternatives 3 and 4 only differ by ~3% so the ranking of the alternatives with respect to which is best for minimizing shore spawning kokanee dewatering may alter with more refined timing and depth data on shore spawning kokanee redds. Redd depths were recorded on one date in each year of the previous studies: September 27, 2009 and October 13, 2010. This current analysis would increase in accuracy and refinement if redd depth measurements were done the day that the fresh redd was observed because this would give both timing and spatial (depth) data with which to further test alternatives. The current data is an excellent start to further assess the operational alternatives since all redds measured to date were clearly constructed prior to that date.

Conclusion

The Kootenay lake hydrograph has been altered significantly following a succession of hydroelectric developments over the last century. Upstream impoundment and the subsequent alteration of the natural hydrograph have had a profound ecological impact upon Kootenay Lake (Ashley et al. 1997) and similar to that detailed throughout the Columbia Basin (Moody et al. 2007; Utzig & Schmidt 2011). With respect to the West Arm of the lake and the subsequent impact in relation to kokanee, the major change in the discharge regime appears to have occurred post 1938 to the present. The altered hydrograph is considerably more variable than in past, resulting in a delay in spring flood to meet flood control and hydro generation requirements and leaving the West Arm littoral areas exposed with more frequent and extended periods of low water into late spring. Important littoral areas in the West Arm remain dewatered and unavailable to kokanee fry at a potentially critical time following emergence. The findings cited within this report demonstrate an effect of the altered hydrograph on shore spawning kokanee.

Recommendations

Recommendations for future field studies in order to address the data gaps outlined in this report are listed below, grouped by variable:

Temperature

- obtain groundwater and surface water temperatures for multiple years to assess the variation in temperature and refine the emergence timing
- ensure the water temperature is collected throughout the entire year or at least during the entire kokanee spawn to emergence window
- ideally, temperature data would be collected over the long term with a permanent set of locations recording year round in the West Arm of Kootenay Lake

Elevation

- the broad predictions of the model are based on the elevations at Queen's Bay. If a more refined estimate of stranding of redds is required for important spawning sites such as Six Mile, it is recommended that a Barologger and Levellogger be installed in order to see how the water level actually drops given the bathymetry of the site

Kokanee Surveys

- survey the extent of shore spawning within the West Arm, using night spotlighting boat based reconnaissance surveys

- commence weekly surveys in each year by the end of the first week of September in order to capture the beginning of the spawning window
- increase the frequency of the night snorkel surveys (e.g., every 3-5 days) once the first spawning fish are observed to obtain good data outlining the curve of spawner abundance through time
- in conjunction with night time spawner counts, conduct daytime redd surveys and measure the depth of fresh redds as they are encountered to provide a comparison with spawner counts to minimize overestimation due to double counting
- if funding is limited, restrict the surveys to one site (Six Mile), one time of day, and one type of count unit (i.e., fish or redds) so that all data within a year are comparable
- commit to four consecutive years of data collection in order to capture the variability in timing and in numbers inherent in a population with peaks and lows in abundance
- the extent of suitable spawning habitat should be assessed to determine the minimum elevation of the lake that would still provide adequate habitat

Closure

This report is to the best of my knowledge accurate and correct. If there are any questions regarding its contents please contact one of the undersigned.

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