Feasibility of Obtaining In-Lake Predator Estimates from Hydroacoustics on Kootenay Lake

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Prepared for:

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EXECUTIVE SUMMARY

The Fish and Wildlife Compensation Program – Columbia (FWCP) annually funds two major compensation projects on Kootenay Lake: a large scale nutrient restoration project, and the Meadow Creek kokanee spawning channel. One of the primary rationale for these projects is restoration of bull trout and Gerrard rainbow trout populations. A potential approach to estimate population size(s) with available in-lake acoustic tag data is to compare the two species vertical depth distribution data with the MFLNRO hydroacoustic data. The hydroacoustics data provides an estimate of the total number of predators based on size while the tag depth distribution data provides separation by depth of the two predator species. This study considered the feasibility of analyzing the two independent data sets in an effort to estimate the pelagic abundance for both species similar to that obtained in Idaho on Lake Pend Oreille. The benefit of obtaining these estimates would be to provide a valuable performance measure for evaluating the response of piscivorous populations to FWCP compensation efforts.

Distribution data from depth integrated acoustic tags support the notion that these two predators are spatially separated during the fall months with rainbows orientated near the surface (0-10 m) and bull trout much deeper (> 10 m). In addition, the vertical depth information indicated that both species demonstrated a preference for deeper water beginning in July through to September when the lake is stratified and surface temperatures are reaching their maximums. The apparent increase in predator depth distribution in July is probably in response to increased surface water temperatures, preference for the cooler waters of the hypolimnion, and low tolerance of warm water especially by bull trout. The acoustic tag information also suggests that July data is likely more representative of both rainbow trout and bull trout distributions whereas the September data reflects more rainbow trout than bull trout with many of the latter having migrated from the lake for spawning.

Despite the limitations of using hydroacoustic data in assessing large fish, results from this feasibility study of targets > -33 dB in July and >32 dB in September offer some cautious encouragement. First, in-lake predator (assumed to be large fish (FL ≥ 500 mm) estimates were possible from the hydroacoustics data. Secondly however, the estimates of < 7000 predators for July or September were derived from relatively low densities across all transects over the time period assessed. While it is known that predator densities are considerably lower compared to kokanee densities in the lake, the estimated densities are almost certainly underestimates due to the limited ability of hydroacoustics to detect fish near the surface (< 10 m). Moreover, the Kootenay Lake rainbow trout estimates in this study would also be particularly low since the depth integrated acoustic tags indicate that the majority of rainbow trout inhabit the upper 10 m of the water column during July and September, the very depth where hydroacoustics are limited. On the other hand, the analysis suggests September offers the best opportunity to estimate rainbow trout numbers since at that time many, possibly the majority, of large bull trout are in the spawning streams.

In summary, the data analysis and feasibility report perhaps raises more questions than answers. Hydroacoustics data can provide biased estimates of large predators on Kootenay Lake. The findings are supported by the comparison of the depth distribution data from hydroacoustic surveys and acoustic tagging data. While the acoustic tag data indicates segregation in the depth distribution between bull trout and rainbow trout. only 6 fish (2 bull trout and 4 rainbow trout), were used to determine the profile. Further investigations are warranted before any conclusions can be made on whether reliable in-lake estimates of predators can be obtained using these methods.

ACKNOWLEDGEMENTS

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Dr. Joe Thorley from Poisson Consulting Ltd is acknowledged for conducting the comparative analysis of hydroacoustic data and depth integrated acoustic tag data.

The Fish and Wildlife Compensation Program is a joint initiative between BC Hydro, the BC Ministry of Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) and Fisheries & Oceans Canada (DFO) to conserve and enhance fish and wildlife populations affected by the construction of BC Hydro dams in Canada's portion of the Columbia Basin.

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INTRODUCTION

The FWCP large lakes Action Plan (FWCP 2012 draft) identifies piscivorous rainbow trout and bull trout as high priority fish species and outlines a number of activities or actions aimed at conserving and restoring them with emphasis on Arrow Lakes Reservoir and Kootenay Lake. Lake fertilization has been the primary strategy used on both systems aimed at restoring nutrients and fish populations, especially kokanee, impacted by hydro developments (Schindler et al. 2013a, 2013b). While there are good estimates of kokanee population sizes there are no complete estimates of population size for the piscivorous populations in both systems and Ministry of Forests, Lands and Natural Resources Operation (MFLNRO) biologists rely on various indices of abundance measurements to understand trends in these populations. Spawner numbers, fishery CPUE, exploitation rates, redd counts or juvenile density estimates are commonly used to infer population status. The closest measurements of the piscivorous populations have been derived from the work over the last five decades on Kootenay Lake's Gerrard rainbow trout and the last decade on bull trout populations (Hagen and Decker 2009, Decker and Hagen 2009, Hagen et al. 2010, Andrusak and Andrusak 2012a, 2012b, Andrusak 2013a, 2013b, Andrusak and Thorley 2013).

The most important data collected on a number of BC's large lakes are estimations of kokanee abundance and biomass since these fish are the primary prey items for pelagic piscivores such as bull trout and rainbow trout. Fisheries staff in the MFLNRO have been estimating kokanee abundance and biomass using hydroacoustic technology on Okanagan, Arrow, Kootenay, Kinbasket, Revelstoke, Alouette and other lakes and reservoirs for 2-3 decades with funding from the Ministry, HCTF, BC Hydro, the Columbia Power Corporation and the Bonneville Power Administration (BPA). While the primary objective of all this work has been to estimate kokanee abundance and trends in population size these surveys also detect large size fish (> 50 cm) at low densities in the pelagic zone that are suspected to be piscivorous trout (Sebastian et al. 2005). The potential for using the existing hydroacoustic data from Kootenay Lake to estimate predator numbers was identified by Spence et al. (2005) as worthy of further investigation and that led Sebastian et al. (2005) to determine the feasibility of this approach. They determined there was potential for this data to be used to estimate predator numbers. They concluded that although the approach had potential, there were a number of technical issues needed to be resolved, including the selection of size of fish echoes used for analysis. Their report also noted that it was not possible to distinguish between rainbow trout and bull trout.

If the technical issues related to the hydroacoustics data discussed by Sebastian et al. (2005) could be resolved then estimations of all predators may be possible. Since that time there has been one potential outcome from an on-going exploitation study by Andrusak and Thorley (2013) that could possibly be applied to the acoustics data. This work has detected an apparent spatial segregation between bull trout and rainbow trout during September and early October and this data might be helpful in separating the two species within the acoustics data set. This report discusses the feasibility of using the hydroacoustic data (2008-2012) to determine the proportions of rainbow trout and bull trout based on their fall depth distribution. The proportion between the two species could then be applied to the hydroacoustic estimates of total predator numbers to estimate total numbers of catchable rainbow trout and bull trout.

Attempting to estimate predator numbers from the hydroacoustics data was foreseen by FWCP and FLNRO biologists as a "long shot" owing to many uncertainties, the most important including: the limited number of transects, inherently low densities of predator targets during surveys, especially near the surface and appropriate cut off size of the fish echoes (Sebastian et al. 2005, Taylor et al. 2005, Crockett et al. 2006, Godlewska et al. 2012).

Study objectives

The proposal intends to:

1. assess the feasibility of utilizing hydroacoustic data to estimate in-lake predators populations in Kootenay Lake by analysing existing depth and hydro-acoustic data.

2. assess uncertainty around in-lake predator estimates for rainbow trout and bull trout on Kootenay Lake (i.e. low transect abundance etc.?)

3. provide recommendations for improvements

BACKGROUND

A great deal of fisheries work has been undertaken on Kootenay Lake due to the high level of interest by the fishing public for Gerrard rainbow trout, bull trout and kokanee (Andrusak and Andrusak 2012a). The lake has undergone a number of significant ecological changes outlined by several authors including Northcote (1973), Ashley et al. (1999) and Schindler et al. (2011a). In the early 1990s a nutrient experiment began to restore lake productivity that had declined due to upstream reservoirs that were serving as nutrient sinks (Ashley et al. 1997, Larkin 1998). Since 1992 there has been an annual, comprehensive monitoring program aimed at measuring trophic level responses to lake fertilization. Monitoring of the kokanee responses to fertilization includes annual spawner estimates at the Meadow Creek spawning channel, aerial counts of the Lardeau River, trawl sampling and annual hydroacoustic estimates of in-lake kokanee abundance. Results of Kootenay Lake experimental fertilization have been documented in a number of technical reports and other publications (e.g., Ashley et al. 1997, Schindler et al. 2010). The monitoring work has been identified as core activities by the FWCP outlined in the Large Lakes Plan (FWCP 2012 draft).

The large bull trout and rainbow trout in Kootenay Lake support popular and economically valuable sport fisheries (Redfish Consulting Ltd 2007, Andrusak and Andrusak 2012b, FWCP

2012). The approximate size of the kokanee population, the primary prey for the lakes' piscivore populations, is well documented in large part due to the hydroacoustic surveys summarized by (Schindler et al. 2013b). The bull trout and Gerrard rainbow trout population sizes are less known although some crude estimates of spawner numbers have been made based on escapements estimates (Andrusak and Brown 1987, Hagen et al. 2010). The most recent creel census on the lake indicated a high level of angler effort with most of the effort directed at the Gerrard rainbow population (Andrusak and Andrusak 2012b). The survey also indicated a high rate of release of rainbows and bull trout. An on-going exploitation study is expected to answer the question as to whether or not harvest rates are sustainable (Andrusak and Thorley 2013). A spin off benefit from this project has been the detection of differences in depth distributions of these two species during the fall months. The annual hydroacoustic surveys provide estimations of kokanee abundance and biomass and also provide detection of large size (> 50 cm) fish that are almost certainly either rainbow trout or bull trout. It is fortuitous that the fall survey occurs when most bull trout spawners are not in the lake. It was hypothesised that acoustic depth distribution of these large fish could be used to provide estimates or proportions of each species at a variety of stratified depths. This information can then be applied to the total number of predators determined by estimates from hydroacoustics for bull trout and rainbow trout. The utility of this data would provide important estimates of predator (> 50 cm) abundance within Kootenay Lake. Ultimately the data could be used to assess the "upper trophic level" response to nutrient addition to Kootenay Lake since 1992.

STUDY AREA

Kootenay Lake (395 km^2) is long and narrow, with steep sides and a narrow littoral zone. The main lake is 107 km long, approximately 4 km wide with a mean depth of 94 m and a maximum depth of 154 m (Daley et al. 1981). Two major river systems feed the lake: the Lardeau/Duncan system in the North Arm (174 km^2) and the Kootenay River in the South Arm (222 km^2). Retention time of the main lake is 1.8 years. The outlet of the main lake, at Balfour, BC, forms the upper end of the West Arm. The West Arm (40 km long) is physically and limnologically different from the main lake, comprised of a series of shallow basins (mean depth 13 m) interconnected by narrow river sections.

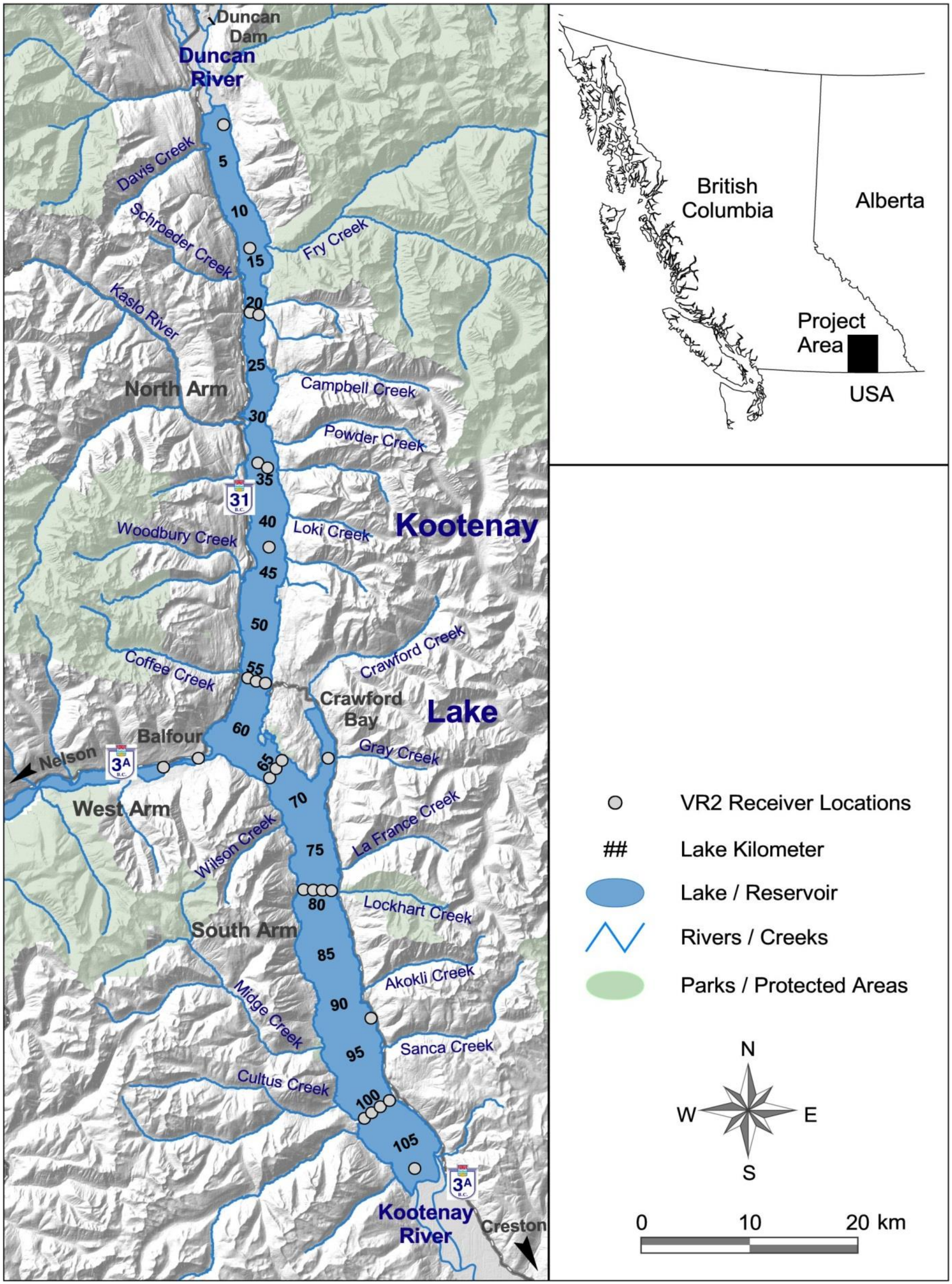

Figure 1. **Kootenay Lake and its major tributaries with the locations of the 26 VR2W receivers.**

METHODS

In-lake Acoustic Transmitters and Receivers

Acoustic Receivers

A total of 22 VR2 81 kHz acoustic receivers, from the Vemco Division of AMIRIX Systems Inc., have been distributed throughout Kootenay Lake. The existing receiver array was originally deployed in 2002 to track Kootenay white sturgeon (*Acipenser transmontanus*) movement and distribution as part of a recovery initiative (Neufeld and Spence 2004). More recently, it has been used to track burbot (*Lota lota*) movement and distribution in Kootenay Lake (Neufeld and Spence 2004). The array is a trans-boundary partnership between the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), with capital funding provided by the US Fish and Wildlife Service and the Bonneville Power Administration (BPA) through the Northwest Power and Conservation Council's Fish and Wildlife Program. Annual operation and maintenance for this project has been completed by MFLNRO and funded by the BPA through the Northwest Power and Conservation Council's Fish and Wildlife Program, in co-operation with the Idaho Department of Fish and Game (IDFG), and the Kootenai Tribe of Idaho (KTOI).

Prior to conducting the tagging project in 2008 (Andrusak and Thorley 2013), further VR2W receivers were deployed in the North Arm of Kootenay Lake in order to increase the probabilities of detecting acoustically tagged rainbow trout and bull trout. The locations of the 26 receivers are mapped in Figure 1. The Kootenay Lake receiver array data is downloaded annually in March.

Acoustic Transmitters

Annually (2008-2011), fish captured in the exploitation study (Andrusak and Thorley 2013) were implanted with V13-1L transmitters from the Vemco Division of AMIRIX Systems Inc. However, in 2010 a total of ten fish (five rainbow trout and five bull trout) were implanted with V13P-1L transmitters, which provide information on depth within the lake. All tag types had a frequency of 81 kHz and were produced by the Vemco Division of AMIRIX Systems Inc. The V13-1L transmitters have a diameter of 13 mm, length of 36 mm and weigh 11 grams in air while the V13P-1L transmitters are slightly larger with a diameter of 13 mm, length of 45 mm and weight in air of 12 grams. In 2008, the pilot study utilized V13-1L tags with a nominal pulse frequency of 60 s (30-90 s) which resulted in a tag life of just over a year. However, as the detection rate was unnecessarily high, in all subsequent years the nominal pulse rate on the V13-1L tags has been set at 120 s (60-180 s) which allows a tag life of over three years (c. 1,239 days) without compromising the detection of movements. Due to the higher energetic demands, the tag life of the V13P-1L tags which were also set to have a pulse frequency of 120 s (60-180 s) is slightly lower at just over two years (c. 836 days).

Hydroacoustic Surveys

As part of this feasibility study, four years of hydroacoustic data (2009-2012) was used in the analysis (MFLNRO on file). In general, nighttime surveys of the limnetic habitat in Kootenay Lake have been conducted during the new moon phase in September since the early 1990s. In addition, acoustic surveys have been conducted in early July since 2004 following emergence and migration of kokanee fry. Acoustic data are collected at 18 transect locations evenly spaced along the length of the main lake, including both North and South Arms (Figure 1, APPENDIX 1).

Acoustic data from 2009-12 were collected using a Simrad model EK60 120 KHz split beam system. The downward looking transducer was towed on a planer alongside the boat at a depth of 1 m, and data were collected continuously along survey lines at 2-5 $\text{pings}\cdot\text{s}^{-1}$ while cruising at ~2 $\text{m}\cdot\text{s}^{-1}$. Navigation was by radar, GPS, and a 1:75,000 Canadian Hydrographics bathymetric chart. Echograms for each transect were analyzed from surface to 50 m depth in 10 equal depth layers (allowing an exclusion zone of surface to 3 m in the shallowest layer). The fish densities in $\text{number}\cdot\text{ha}^{-1}$ for each transect and depth strata were output in 1-decibel (dB) size groups and compiled on an Excel spreadsheet. Echo counting was the method used to generate target densities for unit area by depth stratum for years 2011 and 2012, while echo integration was determined to be the most suitable method in 2009 and 2010. The analysis method chosen by year was based on target densities; under the lower densities found on average in Kootenay Lake echo counting is expected to be the most appropriate method, whereas under the record high densities found in 2009 and 2010 echo integration was deemed more appropriate. Detailed year specific field and analysis settings and methods are described by Schindler et al. (2013b) and (2014 *in Prep.*) for survey years 2009 & 10 and 2011 & 12 respectively.

Decibel bin cut-offs chosen to isolate the predators were based on visual inspection of the target strength (TS) distribution to determine where the point of inflection occurs at the top end of the kokanee distribution. When a clear inflection point occurs it is expected that the vast majority of targets larger than the chosen cut off will be predators with ideally no influence by the kokanee which exist in vastly higher densities. Inclusion of even a small proportion of the largest kokanee targets could have a dramatic impact on the 'predator' estimates. In most cases >-33 dB appears to exclude the kokanee distribution, although the -33dB bin is more prone to inclusion of KO target echoes than is the -32 dB bin. To demonstrate the differences that can occur acoustic data were analysed using both >-32 dB and >-33 dB cut offs. These decibel bins are expected to relate to fish fork lengths of ~466-525 mm and 413-465 mm for -32 dB and -33 dB respectively based on Love (1977) dorsal aspect empirical equation for a 120 KHz echosounder. These size ranges in theory exclude the smaller kokanee targets and roughly equate to the 500mm fork length separating piscivorous (>500 mm) from non-piscivorous (<500 mm) rainbow trout in BC large lakes.

Analysis of Distribution, Density and Abundance

For the purpose of this feasibility study, hydroacoustic distribution data from targets > -33 dB in July and >32 dB in September assumed to be large fish (FL ≥ 500 mm) was compared with the depth distribution information from the acoustically tagged fish. The hydroacoustic data was provided by MFLNRO and the acoustic tag depth data from the Kootenay Lake Exploitation Study (Andrusak and Thorley 2013).

Model

Hierarchical Bayesian models were fitted to the hydroacoustic density data and acoustic tag depth detection for Kootenay Lake using R version 3.0.2 (R Core Development Team 2013) and JAGS 3.3.0 (Plummer 2003) which interfaced with each other via the jaggernaut (Thorley 2014; APPENDIX 2) R package. For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011).

Unless specified, the models assumed vague (low information) prior distributions (Kery and Schaub 2011; APPENDIX 2). The posterior distributions were estimated from a minimum of 1,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kery and Schaub 2011). Model convergence was confirmed by ensuring that Rhat (Kery and Schaub 2011) was less than 1.1 for each of the parameters in the model (Kery and Schaub, 2011).

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

The results were displayed graphically by plotting the modeled relationship between the particular variable(s) and the response (with 95% credible intervals) with the remaining variables held constant (APPENDIX 3). In general, continuous and discrete fixed variables were held constant at their mean and first level values respectively while random variables were held constant at their typical values (expected values of the underlying hyper-distributions) (Kery and Schaub 2011). Where informative the influence of particular variables was expressed in terms of the effect size (i.e., percent change in the response variable) with 95% credible intervals (Bradford et al. 2005). Plots were produced using the ggplot2 R package (Wickham 2009).

Acoustic tag data

The depth tag data from the Kootenay Lake Exploitation Study were analysed using a Bayesian polynomial model. Key assumptions of the depth tag model included:

1. Relative use varies as a third-order polynomial of the standardised depth.
2. Relative use is log-normally distributed.
3. Only detections in less than 50 m of water during the hours of darkness were included in the model.
4. The number of fish and number of detections are tabulated by month and species below.

Table 1. Total detections from bull trout and rainbow trout by month from 2009-2012

Month	Species	Fish	Detections
July	Bull Trout	2	179
July	Rainbow Trout	4	889
September	Bull Trout	2	338
September	Rainbow Trout	4	890

Hydroacoustic survey data

The hydroacoustic survey data were analysed using a hierarchical Bayesian zero-inflated (Kery and Schaub 2011) log-normal polynomial model. Key assumptions of the hydroacoustic model included:

1. Positive densities (one or more fish detected) vary with year.
2. Positive densities vary randomly with respect to transect.
3. Zero-inflation varies as a third order polynomial of the standardized depth.
4. Density is zero-inflated log-normally distributed.
5. Only detections in less than 50 m of water were included in the model. The surveys were conducted during the hours of darkness.
6. The data consisted of detection densities by decibel cut-off from 18 transects spanning 4 years.

RESULTS

Vertical depth distribution- acoustic tagged fish

Vertical distribution patterns were obtained from a total of eight tagged fish (FL ≥ 500 mm) in the spring of 2010 with depth integrated acoustic transmitters (V13P-1L) and tracked within the lake (Andrusak and Thorley 2013). Summarized tracking information includes data from 2010-2012 from the six acoustically tagged fish, separated by species.

Acoustic tracking information suggests a substantial difference in the vertical depth distribution between rainbow trout and bull trout during 2010-2012 (Figure 2). Firstly, bull trout appear to have a much greater range in depth distribution compared to rainbow trout. Secondly, over the entire year rainbow trout were distributed closer to the lake surface compared to bull trout (Figure 3). With the exception of the summer months (July-September), rainbow trout were typically within 20 m of the surface. Meanwhile, with the exception of the spring (May-June), bull trout were almost exclusively in water deeper than 15 m with vertical migrations often exceeding 100 m in depth. It should be noted that these results are reflective of a total of six fish tagged and are assumed to represent the temporal and spatial migration patterns of the greater population of each species. Additional acoustic tracking (i.e. 2012-2013) information was not available at the time of report preparation.

Vertical depth distribution- hydroacoustic and acoustic tagged fish

Hydroacoustic distribution data from targets > -33 dB and >32 dB in July and September are believed to be large fish (FL ≥ 500 mm) and these were compared with the distribution information from the acoustically tagged fish.

The depth distribution from the integrated acoustic tags data in July and September when compared with the hydroacoustics data illustrated in Figure 4 suggests only a small overlap. Depth information from acoustically tagged fish indicates that the majority are distributed near the surface (< 10 m) compared to the acoustic distribution data which indicates a distribution ≥ 20 m (see Discussion). However, the overlap in distribution does appear slightly better in July compared to September (Figure 4). Not displayed in this report, but an analysis of the diurnal pattern (i.e. day vs night) in depth distribution compared with the hydroacoustic data also revealed a non-overlapping distribution. As well, while limited to a total of six tagged fish, separation of depth information by species did not improve the distribution pattern.

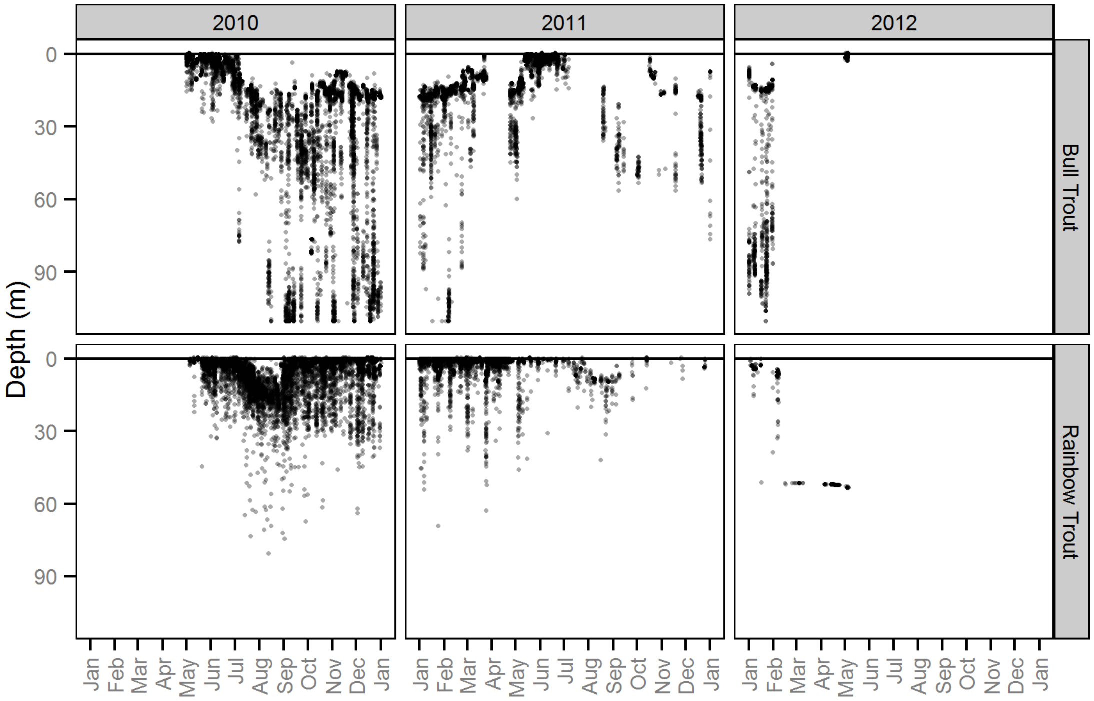

Figure 2. Depth detections of large (FL ≥ 500 mm) acoustically tagged bull trout and rainbow trout in Kootenay Lake by date and year from 2010 to 2012.

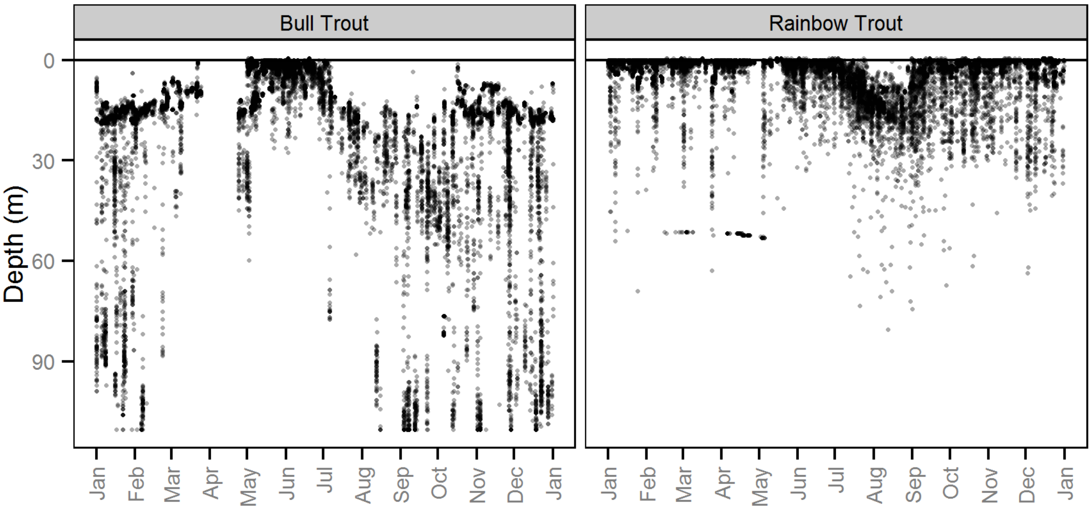

Figure 3. Depth detections of large (FL ≥ 500 mm) acoustically tagged bull trout and rainbow trout in Kootenay Lake by date from 2010 to 2012.

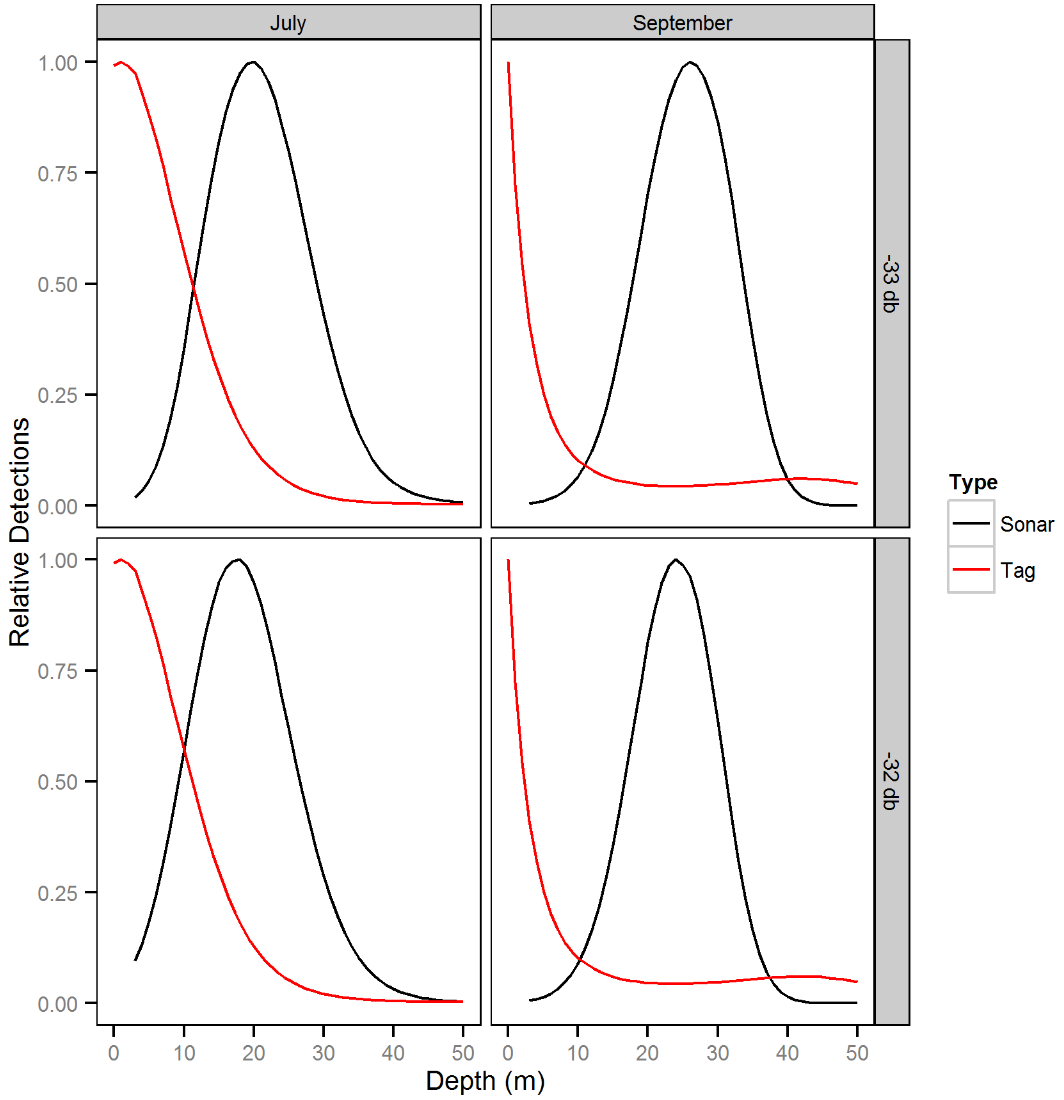

Figure 4. **Depth distribution information from hydroacoustic data from targets > -33 dB (July) and >32 dB (September) assumed to be large fish (FL ≥ 500 mm) and the distribution information from fish with depth integrated acoustic tags. Note the lack of overlap.**

Density and Abundance

Using a hierarchical Bayesian zero-inflated model, both estimates of density by transect and abundance were derived for the years 2009-2012 on Kootenay Lake. Similar to the depth distribution information, hydroacoustic survey data was analysed using target strengths of > -33 dB and >32 dB in July and September, both bin sizes considered to be large fish (FL ≥ 500 mm).

Data analysis for July (2009-2012) using the > -32 dB target strength indicate an in-lake estimate of 500-1000 large fish (Figure 5). These estimates are based on relatively low densities across all transects for this size distribution (Figure 6). By way of comparison, analysis of the July 2009-2012 data using the > -33 dB target strength indicate an in-lake estimate of 1,800-5,800 fish (Figure 7). Once again, these estimates are based on relatively low densities across all transects (Figure 8) for this size distribution but are slightly higher than the >-32 dB distributions.

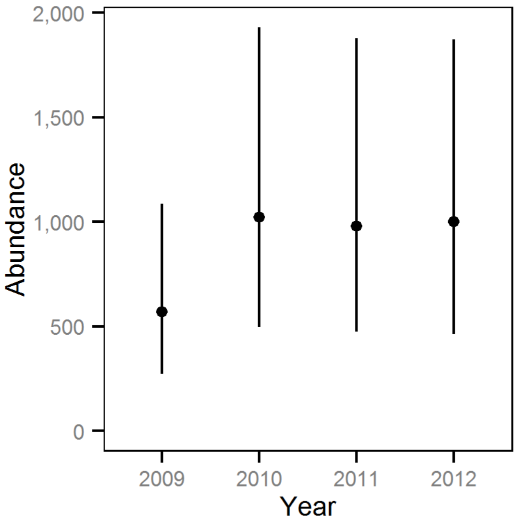

Figure 5. **Derived in-lake abundance estimates from > -32 dB target strength from hydroacoustic data in July on Kootenay Lake**

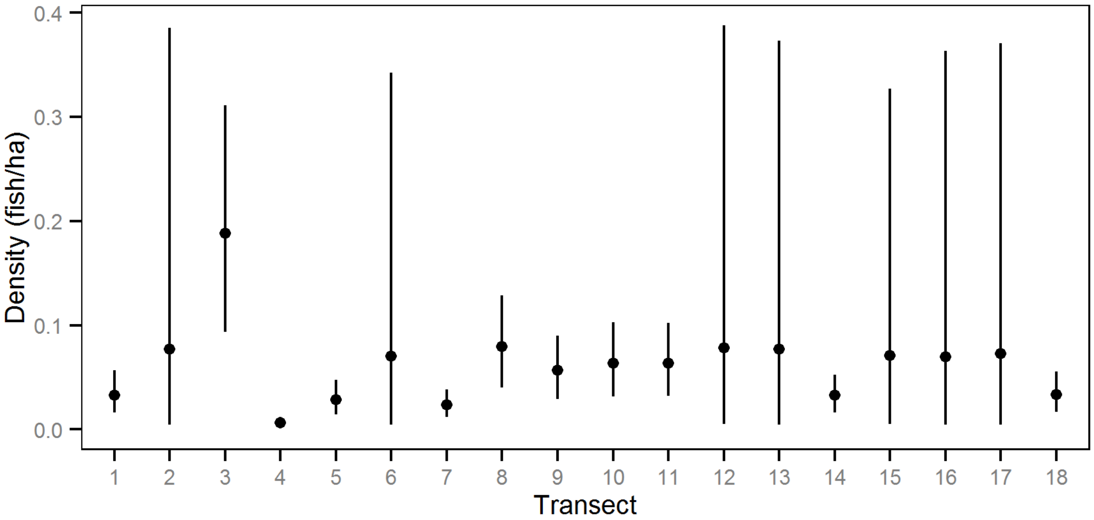

Figure 6. **Density (fish/ha) derived from (> -32 dB) hydroacoustic data in July on Kootenay Lake 2009-2012**

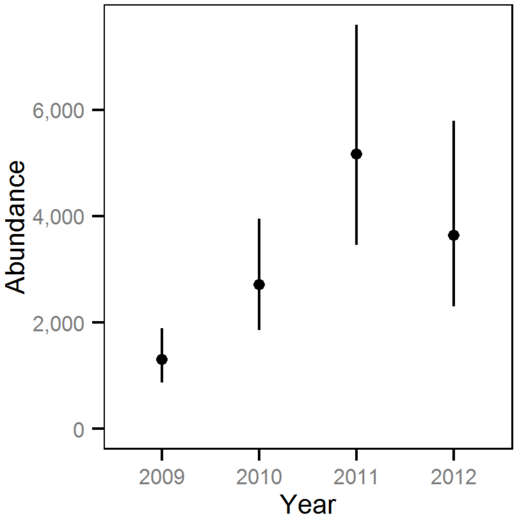

Figure 7. **Derived in-lake abundance estimates from > -33 dB target strength from hydroacoustic data in July on Kootenay Lake from 2009-2012.**

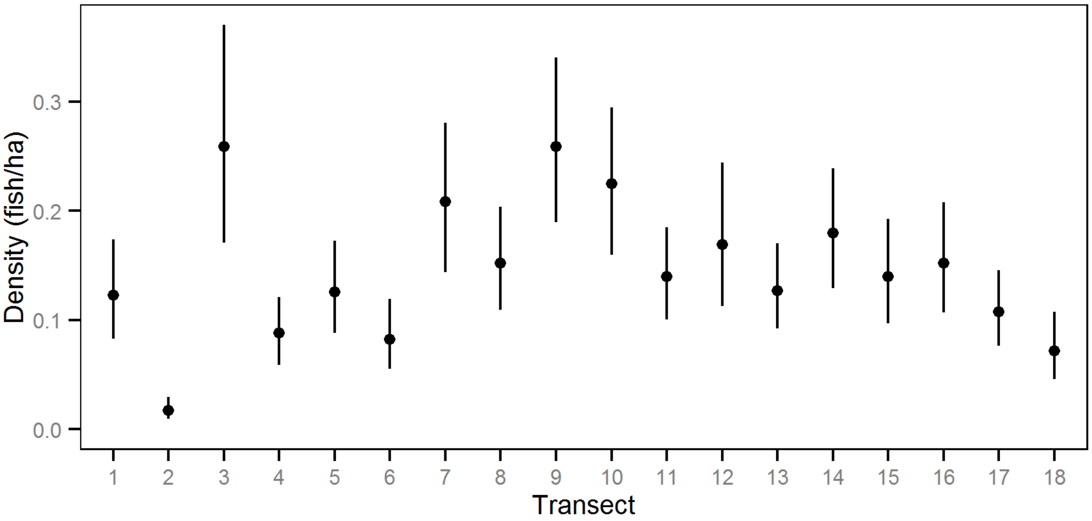

Figure 8. **Density (fish/ha) derived from (> -33 dB) hydroacoustic data in July on Kootenay Lake 2009-2012**

Data analysis results from September (2009-2012) using the > -32 dB target strength indicate an in-lake estimate of 600-1,500 fish (Figure 9). These estimates are based on relatively low densities across all transects (Figure 10) for this size distribution but are slightly higher than the July estimates for the same target strength. In contrast, results from September 2009-2012 data using the > -33 dB target strength indicate an in-lake estimate of 2,400-6,800 fish (Figure 11). The estimates are based on densities across all transects for this bin size (Figure 12).

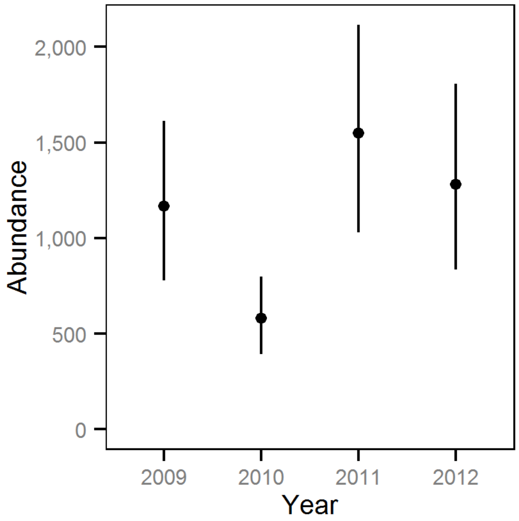

Figure 9. **Derived in-lake abundance estimates from > -32 dB target strength from hydroacoustic data in September on Kootenay Lake from 2009-2012.**

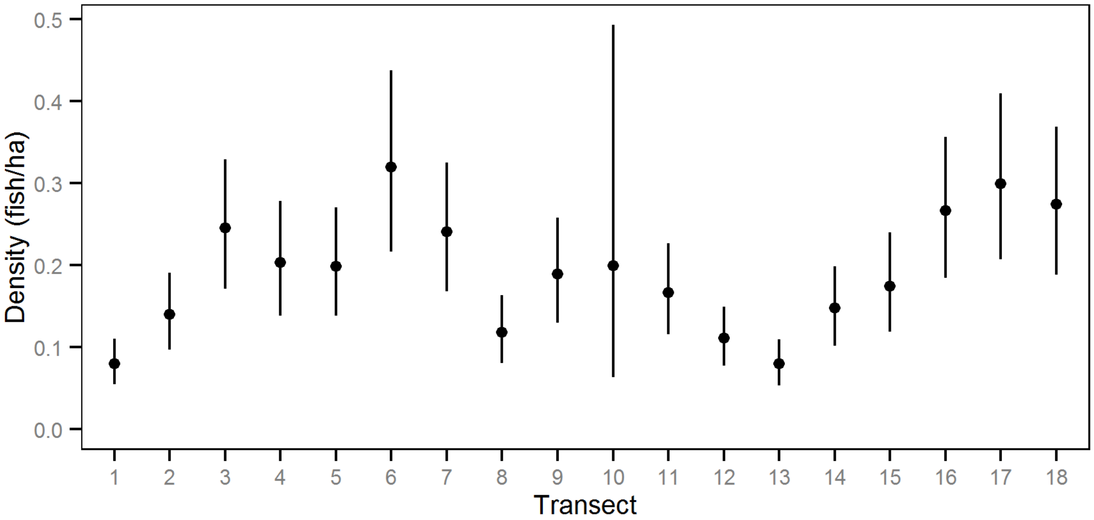

Figure 10. **Density (fish/ha) derived from (> -32 dB) hydroacoustic data in September on Kootenay Lake 2009-2012**

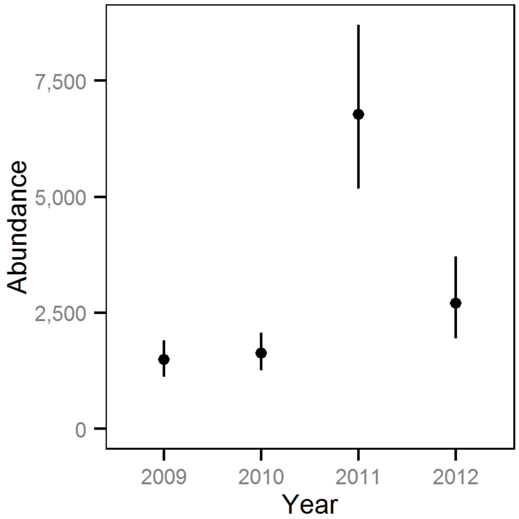

Figure 11. **Derived in-lake abundance estimates from > -33 dB target strength from hydroacoustic data in September on Kootenay Lake from 2009-2012.**

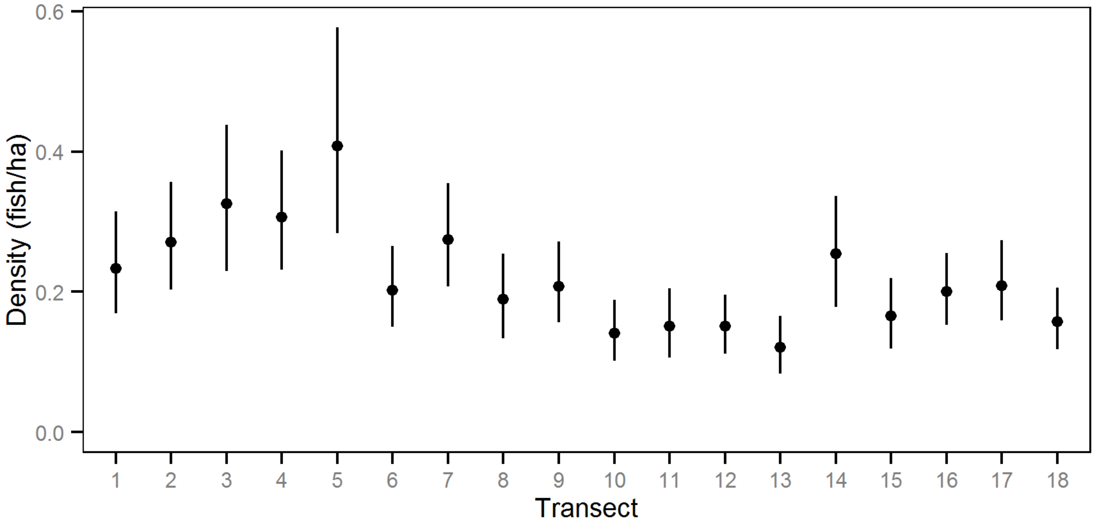

Figure 12. **Density (fish/ha) derived from (> -33 dB) hydroacoustic data in September on Kootenay Lake 2009-2012**

DISCUSSION

The FWCP annually funds two major compensation projects on Kootenay Lake: a large scale nutrient restoration project, and the Meadow Creek kokanee spawning channel. One of the primary rationale for these projects is restoration of bull trout and Gerrard rainbow trout populations (FWCP 2012 draft). Obtaining in lake estimates of the predator population would provide a valuable performance measure for evaluating the benefits of lake fertilization. Other than the escapement index at Gerrard, there have been no estimates of population size of the piscivorous rainbows in Kootenay Lake. The adfluvial bull trout data are even sparser with escapement estimates initially made only within the last three years (Andrusak and Andrusak 2012a, 2013b). There is a wealth of hydroacoustic data and Sebastian et al. (2005) discuss the merits and limitations of using this data to estimate predator numbers, also detailed in Simmonds (2005). A potential approach to estimate population size(s) with available in-lake acoustic data is to compare the two species vertical depth distribution data of Andrusak and Thorley (2013) with the MFLNRO hydroacoustic data. The hydroacoustics data provides an estimate of total number of predators based on size while the tag depth distribution data provides separation by depth of the two predator species. This study considered the feasibility of analyzing the two independent data sets in an effort to estimate the pelagic abundance for both species similar to that obtained in Idaho on Lake Pend Oreille, detailed in Maiolie et al. (2007). Undoubtedly, aside from being informative for fisheries managers, obtaining these estimates would provide a valuable performance measure for evaluating the response of piscivorous populations to FWCP compensation efforts.

The ability to obtain in-lake estimates of the two predator species using hydroacoustics data alone is confounded by the fact that both rainbow trout and bull trout inhabit the lake and overlap in their distribution and habitat use within the limnetic area. Furthermore, hydroacoustics present multiple sources of variation in target strength that complicate the target strength–fish size relationship, especially for larger sized fish (Crockett et al. 2006). This uncertainty may substantially bias population size estimates, especially for piscivores that are greatly outnumbered by other species (Crockett et al. 2006). Nonetheless, distribution data from depth integrated acoustic tags (Andrusak and Thorley 2013) support the notion that these two predators are spatially separated during the fall months with rainbows orientated near the surface (0-10 m) and bull trout much deeper (> 10 m). In addition, the vertical depth information indicated that both species demonstrated a preference for deeper water beginning in July through to September when the lake is stratified and surface temperatures near or above 20°C (Schindler et al. 2011, 2013b). The apparent increase in predator depth distribution in July is probably in response to increased surface water temperatures and preference for cooler hypolimnion as well as low tolerance of warm water especially by bull trout (Sebastian et al. 2005, McPhail 2007). The July data probably is more representative of both rainbow trout and bull trout whereas the September data reflects more rainbow trout than bull trout with many of the latter have migrated from the lake for spawning (Andrusak and Thorley 2013). Based on the limited information it is plausible that conducting hydroacoustic surveys in August may provide more informative estimates of the rainbow trout inhabiting the lake, since they appear to utilize deeper depths where they can be detected.

Hydroacoustic surveys are typically directed at estimating abundance of forage fishes in large limnetic systems such as kokanee that are often distributed near the thermocline (Sebastian et al. 2005; Taylor et al. 2005). A major shortcoming of hydroacoustic surveys is their limited ability to assess near surface and shallow water depths (Sebastian et al. 2005; Godlewska et al. 2012). Consequently, the difficulty in obtaining in-lake predator estimates is associated with the inherent limitations in hydroacoustic technology in shallow water and sources of uncertainty outlined by Sebastian et al. (2005) and recently discussed further with Dale Sebastian (former MFLNRO acoustic biologist specialist Victoria BC pers. comm.). The uncertainty relates to the fact that hydroacoustic data does not directly represent numbers of fish but rather numbers of individual echoes by target strength (bin size) of fish. Echo numbers have to be converted to fish numbers and selection of bin size is critical to correct interpretation of predator numbers. For this reason bin sizes of >-33 dB and >-32 dB were used in this study for estimating predator numbers simply to illustrate the considerable differences. It is possible that these cut-offs include the upper size range in kokanee in some years (Tyler Weir, MFLNRO, pers comm.), which could substantially bias estimates. An additional consideration and uncertainty is that most large fish targets are hit numerous times and target strength from an individual track can vary considerably as the transducer passes overhead. Therefore assessing and understanding the beam angle is another important variant in obtaining fish size and abundance estimates i.e. bigger fish are seen further out on the beam so beam angle increases with fish size -thus using nominal beam angle is therefore a compromise and will tend to over-estimate density of big fish. Additional aspects of the strengths and limitations of acoustic surveys can be found in (Simmonds 2005). The number of transects surveyed on Kootenay Lake is also problematic given low predator densities and considerable distances between transects. Increasing transect numbers especially where highest densities of kokanee occur would improve the precision of predator estimates (Sebastian et al 2005).

Despite the limitations of using hydroacoustic data in assessing large fish (Sebastian et al. 2005; Taylor et al. 2005), results from this feasibility study of targets >-33 dB in July and >-32 dB and September offer some cautious encouragement. First, in-lake predator (assumed to be large fish (FL ≥ 500 mm) estimates were possible from the acoustics data. Secondly however, the estimates of < 7000 predators for July or September were derived from relatively low densities across all transects over the time period assessed. While it is known that predator densities are considerably lower compared to kokanee densities in the lake (Sebastian et al. 2000, 2005, Schindler et al. 2013b), the estimated densities are almost certainly underestimates based on known escapement information and due to the limited ability of hydroacoustics to detect fish near the surface [< 10 m] (Harris et al. 2013). The Kootenay Lake rainbow trout estimates in this study would also be particularly low since the depth integrated acoustic tags indicate that the majority of rainbow trout inhabit the upper 10 m of the water column during July and September, the very depth where hydroacoustics are limited (Sebastian et al. 2005, Godlewska et al. 2012). On the other hand, the analysis suggests September offers the best opportunity to estimate rainbow trout numbers since at that time many, possibly the majority, of large bull trout are in the spawning in tributaries to the lake(Andrusak and Andrusak 2012a).

While the conceptual idea for this study was similar to work proposed on Lake Pend Oreille (Maiolie et al. 2007), the data analysis and report perhaps raises more questions than answers. Yes, hydroacoustics data can provide an estimate, albeit an underestimate, of predator numbers. This notion is supported by the lack of overlap in the depth distribution data from the tagged fish that suggests the majority are distributed near the surface (< 10 m) compared to the acoustic distribution data which indicates a distribution ≥ 20 m. These findings are contrary to those of Sebastian et al. (2005) that found predators were not surface orientated. The acoustic tag data suggest a potential segregation in the depth distribution between bull trout and rainbow trout. However, since the depth distribution from tagged fish is based on only 6 fish (2 bull trout and 4 rainbow trout), more tagging to determine the vertical depth distribution by species is warranted particularly if the FWCP wants to pursue this method of estimating predator numbers from hydroacoustic data.

RECOMMENDATIONS

- Proceed with acoustic depth tagging of approximately 20 large rainbow trout and 20 large bull trout to confirm depth distributions;
- Due to the low density of predators and the ability of the current design to detect their presence (Sebastian et al. 2005), increase the number of transects for any future hydroacoustic surveys dedicated to predator assessment;
- Investigate a horizontal looking sonar which would be complimentary to the existing hardware (Kubecka and Wittingerova 1998), and/or upward looking hydroacoustics collected via submersible ROV;and.
- Continue the discussion with acoustic specialists (MFLNRO) with the goal of concluding on an innovative approach in methods.

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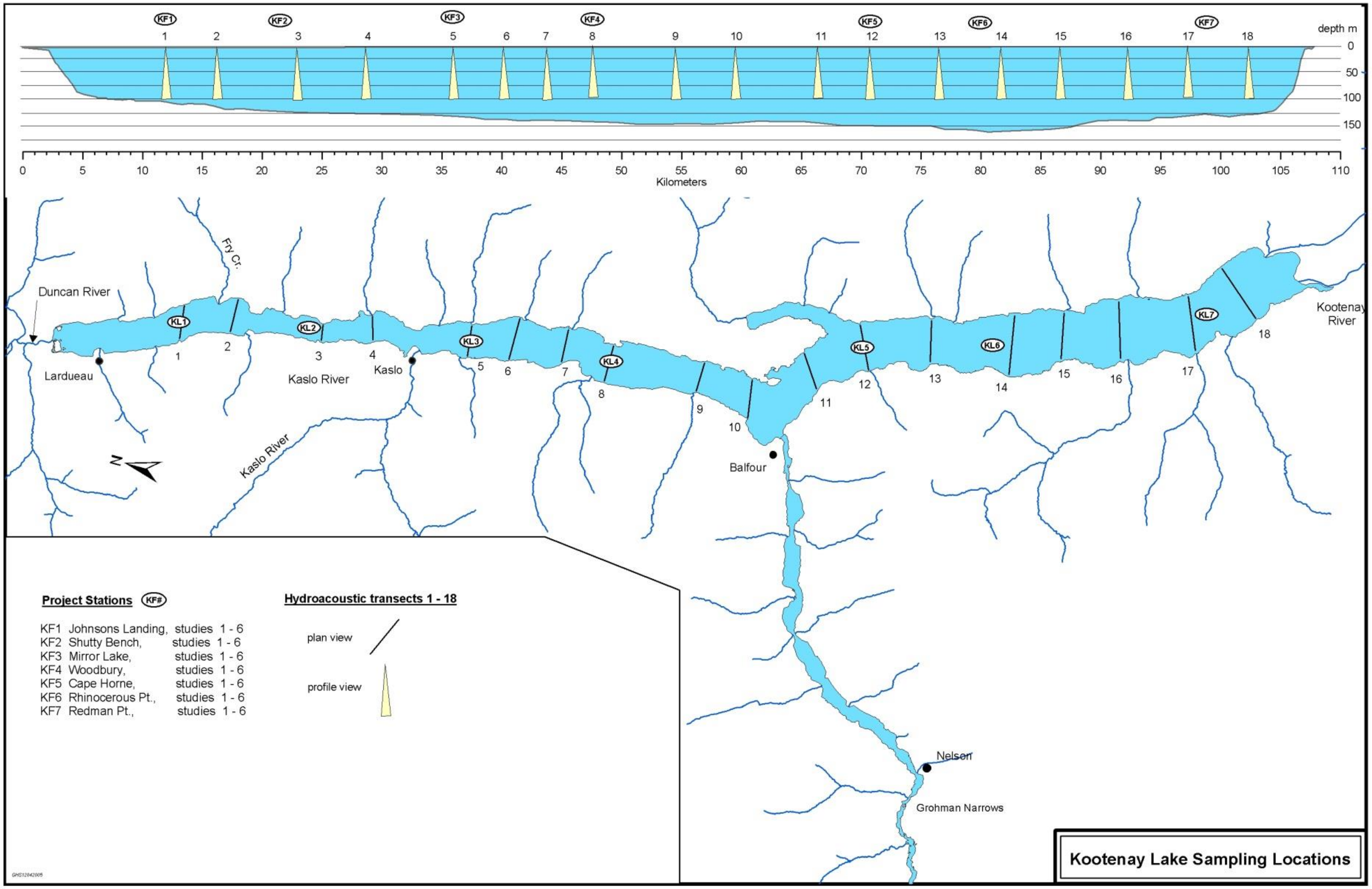
APPENDIX 1. Kootenay Lake hydroacoustic sampling transects.



APPENDIX 2. Model code

JAGS Distributions

JAGS distributions, functions and operators used in the models are defined in the following three tables. For additional information on the JAGS dialect of the BUGS language see the JAGS User Manual (Plummer 2003).

Distribution	Description
dbern(p)	Bernoulli distribution
dlnorm(mu, sd^-2)	Log-normal distribution
dnorm(mu, sd^-2)	Normal distribution
dunif(a, b)	Uniform distribution

JAGS Functions

Function	Description
`ifelse(x, a, b)`	If x then a else b
`length(x)`	Length of vector x
`logit(x)`	Log odds of x

JAGS Operators

Operator	Description
`<-`	Deterministic relationship
`~`	Stochastic relationship
`1:n`	Vector of integers from 1 to n
`a[1:n]`	Subset of first n values in a
`for (i in 1:n) {...}`	Repeat ... for 1 to n times incrementing `i` each time
`x^y`	Power where x is raised to the power of y

The following sections provide the variable and parameter definitions and JAGS model code for the analyses. By convention variables are named using `CamelCase` and the number of levels of a discrete variable `Factor` is referenced by `nFactor`.

Depth Tags

Variable/Parameter	Description
bDepth0	Intercept for log relative use
bDepth1	Effect of standardised depth on bDepth0
bDepth2	Effect of standardised depth squared on bDepth0
bDepth3	Effect of standardised depth cubed on bDepth0
Depth[i]	Depth of ith depth bin
eLogUse[i]	Expected log relative use at i^th depth bin
sUse	S.D. of the residual log relative use
Use[i]	Observed relative use at i^th depth bin

Depth Tags - Model 1

```
model {
    sUse ~ dunif(0, 5)
    bDepth0 ~ dnorm(0, 5^-2)
    bDepth1 ~ dnorm(0, 5^-2)
    bDepth2 ~ dnorm(0, 5^-2)
    bDepth3 ~ dnorm(0, 5^-2)
    for (i in 1:length(Depth)) {
     eLogUse[i] <- bDepth0 + bDepth1 * Depth[i]
        + bDepth2 * Depth[i]^2 + bDepth3 * Depth[i]^3
      Use[i] ~ dlnorm(eLogUse[i], sUse^-2)
  }
```

Hydroacoustic Surveys

Variable/Parameter	Description
`Area[i]`	Area of transect on `i`^th depth-transect visit
`bDepth`	Effect of standardised depth on `bSuitable`
`bDepth2`	Effect of standardised depth squared on `bSuitable`
`bDepth3`	Effect of standardised depth cubed on `bSuitable`
`bIntercept`	Intercept for log positive density
`bSuitable`	Intercept for log odds of probability of positive density
`bTransect[tr]`	Effect of `tr`^th transect on `bIntercept`
`bYear[yr]`	Effect of `yr`^th year on `bIntercept`
`Density[i]`	Observed density on `i`^th depth-transect visit
`eLogDensity[i]`	Expected log density on `i`^th visit
`eSuitability[i]`	Expected probability of positive density on `i`^th visit
`sDensity`	S.D. of the log-normal density distribtion
`sTransect`	S.D. of the random effect of transect on `bSuitable`

Hydroacoustic Surveys - Model 1

```
 model {
  bIntercept ~ dnorm(0, 2^-2)
  bSuitable ~ dnorm(0, 2^-2)

  sDensity ~ dunif(0, 2)

  bYear[1] <- 0
  for(yr in 2:nYear) {
    bYear[yr] ~ dnorm(0, 2^-2)
  }

  bDepth ~ dnorm(0, 2^-2)
  bDepth2 ~ dnorm(0, 2^-2)
  bDepth3 ~ dnorm(0, 2^-2)

  sTransect ~ dunif(0, 2)
  for(tr in 1:nTransect) {
    bTransect[tr] ~ dnorm(0, sTransect^-2)
  }

  for (i in 1:length(Depth)) {
    eLogDensity[i] <- bIntercept + bYear[Year[i]]  + bTransect[Trans
ect[i]]
    logit(eSuitable[i]) <- bSuitable + bDepth * Depth[i]
      + bDepth2 * Depth[i]^2 + bDepth3 * Depth[i]^3

    dFish[i] ~ dbern(eSuitable[i])
    dLogDensity[i] <- ifelse(dFish[i], eLogDensity[i], log(0.00001))
    Density[i] ~ dlnorm(dLogDensity[i], sDensity^-2)
  }
}
```

APPENDIX 3. Parameter Estimates

The posterior distributions for the *fixed* (Kery and Schaub 2011 p. 75) parameters in each model are summarised below.

Depth Tags - July

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDepth0	-4.7957	-5.0634	-4.5291	0.13705	6	0.0000
bDepth1	-2.6458	-3.0815	-2.2328	0.22277	16	0.0000
bDepth2	-0.0119	-0.2331	0.2193	0.11249	1901	0.9022
bDepth3	0.6926	0.4807	0.9211	0.11232	32	0.0000
sUse	0.5703	0.4531	0.7362	0.07226	25	0.0000

Depth Tags - September

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDepth0	-5.1710	-5.4910	-4.85531	0.1626	6	0.0000
bDepth1	0.0808	-0.4601	0.58420	0.2662	646	0.7525
bDepth2	0.5632	0.3234	0.80308	0.1216	43	0.0000
bDepth3	-0.3498	-0.6151	-0.07659	0.1350	77	0.0180
sUse	0.7476	0.6110	0.91796	0.0789	21	0.0000

Hydroacoustic Surveys - July - -33 Decibels

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDepth	-1.8033	-2.52230	-1.0699	0.370650	40	0.0000
bDepth2	-2.1369	-2.81402	-1.5521	0.323180	30	0.0000
bDepth3	0.7775	0.03492	1.4304	0.344780	90	0.0379
bIntercept	-0.7290	-1.09462	-0.3612	0.182280	50	0.0000
bSuitable	-0.9951	-1.34131	-0.7030	0.164530	32	0.0000
bYear[2]	0.7341	0.58320	0.8828	0.077983	20	0.0000
bYear[3]	1.3768	1.23617	1.5233	0.075969	10	0.0000
bYear[4]	1.0164	0.73771	1.3046	0.148530	28	0.0000
sDensity	0.2331	0.22256	0.2448	0.005738	5	0.0000
sTransect	0.6931	0.46332	1.0175	0.145530	40	0.0000

Hydroacoustic Surveys - July - -32 Decibels

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDepth	-2.01608	-3.37031	-0.75880	0.660740	65	0.0000
bDepth2	-1.66246	-2.98013	-0.72550	0.553370	68	0.0000
bDepth3	0.51071	-0.57459	1.45855	0.520380	199	0.3072
bIntercept	-0.31265	-0.84010	0.26592	0.308940	177	0.3498
bSuitable	-2.84400	-3.51732	-2.28938	0.307000	22	0.0000
bYear[2]	0.58501	0.47008	0.70451	0.059740	20	0.0000
bYear[3]	0.54197	0.42181	0.66805	0.061617	23	0.0000
bYear[4]	0.55857	0.31891	0.79469	0.118180	43	0.0000
sDensity	0.08402	0.08007	0.08839	0.002148	5	0.0000
sTransect	0.96926	0.60838	1.56124	0.239070	49	0.0000

Hydroacoustic Surveys - September - -33 Decibels

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDepth	0.53101	-0.2222	1.3505	0.410850	148	0.1936
bDepth2	-3.44685	-4.3541	-2.6280	0.439780	25	0.0000
bDepth3	-0.63124	-1.7505	0.4658	0.574580	176	0.2874
bIntercept	-0.60551	-0.8043	-0.4124	0.101940	32	0.0000
bSuitable	-0.48413	-0.7801	-0.1949	0.147290	60	0.0060
bYear[2]	0.08771	-0.0595	0.2243	0.069976	162	0.2116
bYear[3]	1.51410	1.3505	1.6640	0.081539	10	0.0000
bYear[4]	0.59134	0.3473	0.8333	0.124540	41	0.0000
sDensity	0.24535	0.2341	0.2580	0.006253	5	0.0000
sTransect	0.36754	0.2404	0.5499	0.077297	42	0.0000

Hydroacoustic Surveys - September - -32 Decibels

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDepth	-0.43852	-1.60497	0.61084	0.565930	253	0.4290
bDepth2	-3.81101	-5.38164	-2.49603	0.743030	38	0.0000
bDepth3	-0.53423	-2.12642	1.09748	0.831900	302	0.4908
bIntercept	-0.09416	-0.35094	0.16003	0.125920	271	0.4309
bSuitable	-1.42946	-1.84198	-1.06056	0.200880	27	0.0000
bYear[2]	-0.69404	-0.76953	-0.61378	0.039188	11	0.0000
bYear[3]	0.28385	0.19054	0.37437	0.048683	32	0.0000
bYear[4]	0.09459	-0.00848	0.20825	0.054347	115	0.0773
sDensity	0.07548	0.07191	0.07941	0.001931	5	0.0000
sTransect	0.46874	0.32598	0.68769	0.092371	39	0.0000