Columbia River Project Water Use Plan

Arrow Lakes Reservoir Operations Management Plan

Reference: CLBMON#31

Arrow Lakes Reservoir Burbot Life History and Habitat Use (Year 5)

Study Period: May 2012 to May 2013

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Arrow Lakes Reservoir Burbot Life History and Habitat Use (Year 5)

Prepared for:

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EXECUTIVE SUMMARY

Burbot (*Lota lota*) in the Arrow Lakes Reservoir are subjected to marked daily fluctuations in flow and seasonal variations in water depth from hydro operations (especially in the upper reaches). These fluctuations may be further exacerbated by Revelstoke Dam's Unit 5, which became operational in December 2010. This report summarizes the findings of the fifth year of a five-year study commissioned by BC Hydro to develop an improved understanding of the potential effects of hydro operations at Revelstoke Dam on Burbot downstream in the reservoir.

The Year 5 field study period (March 2-18, 2013) comprised fixed-station and mobile tracking of transmitter-tagged Burbot (tagged in the Upper Arrow Lake and The Narrows between 2010 and 2012), coupled with biosampling, egg mat sampling, plankton net tows and underwater video observations, to determine Burbot movements and timing and location of spawning in the reservoir.

Continuous tracking was possible (May 2012 to May 2013) using an array of fixed-station Vemco VR2W receivers, including eight in the Revelstoke-Beaton Arm reach and one in The Narrows. In addition, a mobile tracking survey (March 2-7 & March 16, 2013) was conducted covering various areas in the Arrow Lakes Reservoir.

From May 2012 to May 2013, 93 tagged Burbot were detected.

Detection data from fixed-station receivers showed distinct seasonal movements among the areas downstream of rkm 212 (the location of a fixed-station receiver ~10 km downstream from Revelstoke). The proportion of tagged Burbot in the river reach between Salmon Rocks and Arrowhead (rkm 184) fluctuated annually, with the largest proportions in each year occurring in mid-late summer, and the smallest proportions recorded in winter or early spring. In August 2012, approximately 57% of the tagged fish were located in this reach, and by February 2013, the proportion had declined to 12%. By contrast, occupancy of the Beaton area (downstream of rkm 184), showed the opposite seasonal pattern.

As in 2012, spawning timing in 2013 in the Beaton Arm area (which appears to be the primary spawning area in the Arrow Lakes) was protracted (from mid-March onward) and spawning probably occurred mainly in deep water areas (>20 m) near the bottom. These findings are based on a considerable amount of biosampling, egg staging, and underwater video observations in areas where Burbot were concentrated.

The Status of CLBMON 31 Objectives, Management Questions and Hypotheses after Year 5.

Objectives	Management Questions	Management Hypotheses	Year 5 (2012-2013) Status
1: Identify spawning habitat of Burbot in the reservoir.	1: Where are Arrow Lakes Reservoir Burbot spawning?		In Years 2-5, we tracked the Arrow Lakes from south of Needles (Years 2 and 3) or south of Burton (Years 4 and 5) to Revelstoke at least once and then focused the remaining tracking effort on the areas of highest detected tag presence. These focus areas included Upper Arrow Lake (Beaton and Shelter Bay areas) and The Narrows (near MacDonald Creek). These areas correspond with our study objective to concentrate on the regions that were most likely to be affected by winter drawdown and Unit 5 operation. In summary, tracking during the assumed spawning period over four consecutive winters (February/March) has shown that there are consistent locations of elevated Burbot concentrations. Sampling in Years 4 and 5 confirmed that Burbot in the aggregation areas were in spawning condition, and that some (27% in Year 5) were spawned out.
2: Determine if Burbot spawning migration and/or spawning habitat is negatively affected by the Revelstoke Unit 5 Project	2: If there are spawning areas in the mid-Columbia River, does the change in flow regime due to addition of a fifth generating unit at Revelstoke Dam affect the spawning migration and spawning habitat of Burbot in the river?	H2: Spawning migration of Burbot in the mid-Columbia River does not change as a result of alterations in flow regime due to addition of a fifth generating unit at Revelstoke Dam. H3: Spawning habitat of Burbot in the mid-Columbia River does not change as a result of alterations in flow regime due to addition of a fifth generating unit at Revelstoke Dam.	No distinct change in flow regime could be detected after the fifth unit was made operational in December 2010. Thus no effects on spawning migration or habitat could be assessed. Longer-term post-operational data may be needed.
	3: Does winter drawdown of Arrow Lakes Reservoir cause the dewatering of Burbot spawning habitat and affect spawning success?	H1: Winter drawdown of Arrow Lakes Reservoir does not cause dewatering of Burbot spawning habitat.	Winter tracking has shown that Burbot move out of the parts of the Revelstoke-Arrowhead Reach that are most affected by the reservoir drawdown. Burbot do not appear to be spawning in the areas most affected by drawdown.
	4: Can modifications be made to the operation of Arrow Lakes Reservoir to protect or enhance spawning success of the Burbot population(s)?		Given the answer to Management Question 3 above, it appears that no modifications are necessary.

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1 INTRODUCTION

Fish in the Arrow Lakes Reservoir (Figure 1) are subjected to considerable daily fluctuations in flow and seasonal variations in water depth as a result of operations of the Revelstoke and Hugh Keenleyside dams, especially in the river reach closest to Revelstoke Dam. Previously, BC Hydro operated four power-generating units at the Revelstoke Dam, but since December 2010 a new fifth unit has become operational with the capacity to increase discharge from the dam by approximately 250 cms. This additional unit has the capacity to increase the water velocity and range in daily water elevation fluctuations (mostly within ~6 km of Revelstoke Dam), and may add to the potential effects of hydro operations on fish migrations and habitats. Burbot (*Lota lota*), a valued sportfish in the reservoir system (Arndt and Baxter 2006), is one of the species that may be affected. It has been suggested by the Water Use Plan Consultative Committee that if Burbot spawn in the drawdown zone downstream of Revelstoke Dam, then the greatest potential impact of reservoir operations on spawning success and egg survival would be dewatering of nearshore areas and in the lower reaches of tributaries during winter (BC Hydro 2005).

In 2008, LGL Limited in partnership with the Canadian Columbia River Intertribal Fisheries Commission (CCRIFC) was commissioned by BC Hydro to conduct a five-year study on Burbot life history and habitat use in the Arrow Lakes Reservoir system. The aim of the five-year program is to provide an improved understanding of the potential effects of hydro operations at Revelstoke Dam on Burbot downstream in the reservoir. The results of the work completed during the first (2008-2009), second (2009-2010), third (2010-2011) and fourth (2011-2012) years of study are in Glova et al. (2009, 2010) and Robichaud et al. (2011, 2012), respectively. This report is for the findings of the fifth year of study (2012-2013).

Briefly, in Year 1, Burbot were sampled and tagged over a relatively large area of the reservoir to gather baseline information on their overall distribution/relative abundance and spawning movements. In Years 2 and 3, trapping and tagging of Burbot were limited to two areas: 1) The reach from Revelstoke to Arrowhead in the Upper Arrow Lake, which is of greatest concern to BC Hydro as it is the area most affected by changing flows and winter drawdown conditions; and 2) The vicinity of Mosquito Creek in The Narrows (Figure 1), to serve as a potential ‘control’ site as it is less affected by hydro operations and may be useful for potential impact assessment purposes. In Year 4, the areas of Burbot trapping and tagging were limited to the reach from Revelstoke to Arrowhead. In Year 5 (May 2012-May 2013), the study was limited to fixed-station and mobile tracking (from Revelstoke to Burton), with no Burbot trapping/tagging.

This report includes a description of the field and analytical methods, data summaries and analyses, GIS mapping of Burbot movements, and a brief summary of spawning-related investigations/findings in relation to BC Hydro’s key management questions and hypotheses.

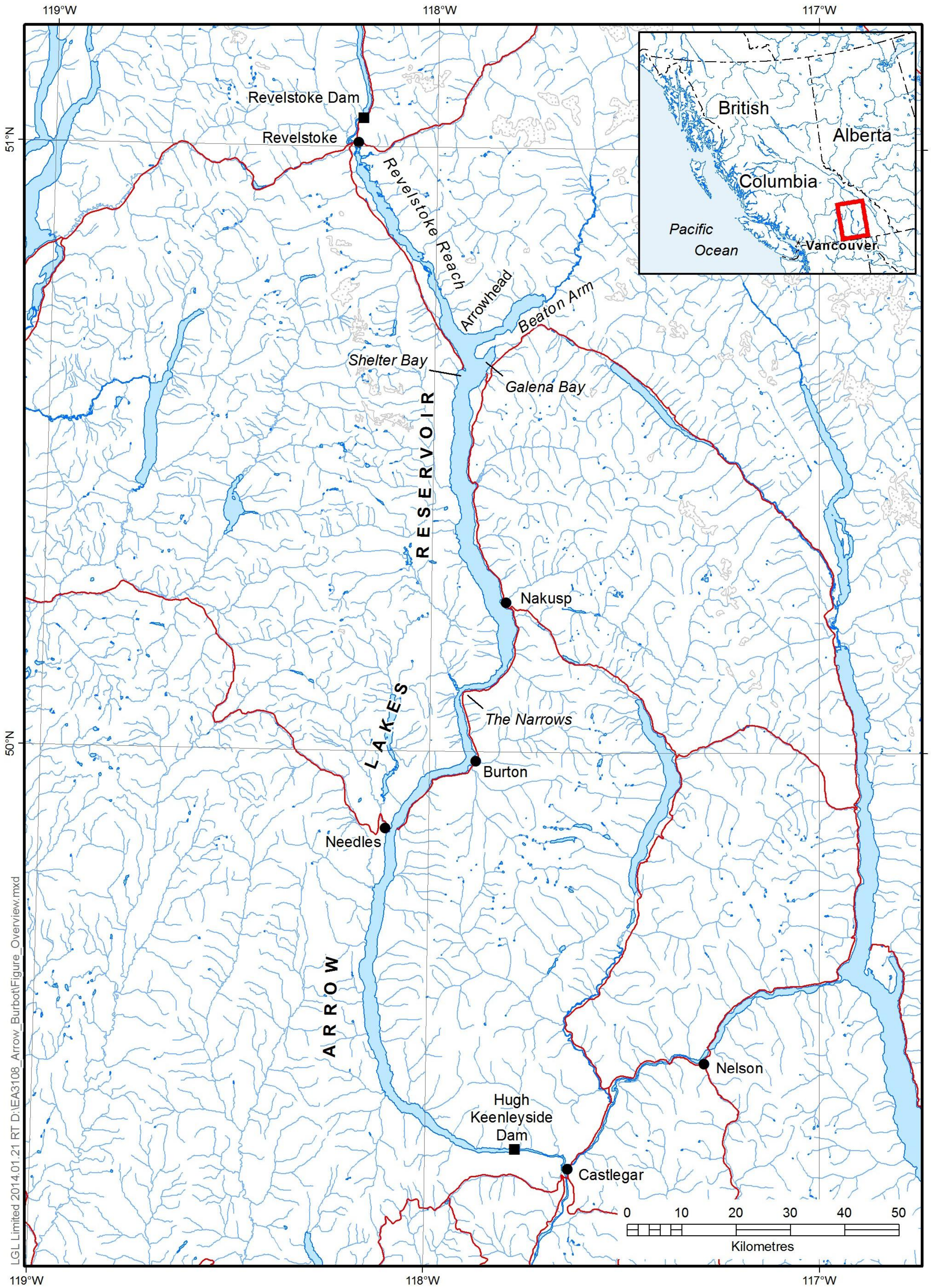

Figure 1. **Map of the mid-Columbia River watershed between Revelstoke and Hugh Keenleyside dams. Red lines show the positions of major roads.**

1.1 MANAGEMENT QUESTIONS AND HYPOTHESES

According to the Terms of Reference for the CLBMON-31 project, the key management questions that BC Hydro wishes to answer from the findings of this five-year Burbot life history and habitat use monitoring program are:

1. Where do Arrow Lakes Reservoir Burbot spawn?
2. If spawning occurs in the mid-Columbia River, will the change in flow regime due to the addition of the fifth generating unit at Revelstoke Dam affect Burbot spawning migration and habitat in the river?
3. Does winter drawdown of the reservoir cause dewatering of Burbot spawning habitat and affect spawning success?
4. Can operation of the Arrow Lakes Reservoir be modified to protect or enhance spawning success of Burbot?

The hypotheses to be tested with the baseline information gathered on Burbot movements and habitat during the course of this monitoring program are:

- H_1: Winter drawdown does not cause dewatering of Burbot spawning habitat.
- H_2: Spawning migration of Burbot in the mid-Columbia River does not change as a result of alterations in flow regime due to the addition of the fifth generating unit at Revelstoke Dam.
- H_3: Spawning habitat of Burbot in the mid-Columbia River does not change as a result of alterations in flow regime due to the addition of the fifth generating unit at Revelstoke Dam.

2 METHODS

The fifth year of the monitoring program consisted of three main tasks: 1) Tracking (with the use of mobile and fixed-station receivers) tagged Burbot to find patterns of migration and to locate potential spawning areas (based on Burbot aggregation during the spawning season); 2) assessment of gonadal development (via biosampling) of Burbot found in the presumed spawning areas; 3) assessment of the maturity stage of Burbot eggs collected from Burbot biosampling, plankton nets and egg mats, deployed at the timing and location of presumed spawning events; and 4) collection of underwater video in presumed spawning areas, in order to see if Burbot spawning behaviours could be observed.

2.1 STUDY AREA

The sampling program was designed to address the management questions and provide baseline information to test the management hypotheses. Accordingly, emphasis was placed on the areas that will be most affected by winter drawdown conditions and by the change in flow that may result from the addition of the fifth generating unit at Revelstoke Dam. The areas of emphasis and the rest of the Arrow Lakes Reservoir (downstream to Hugh Keenleyside Dam) comprise the study area (Figure 1).

The study area was divided into zones, the delineations of which are shown in Figure 2. The area from Revelstoke to Arrowhead was divided into five zones of approximately

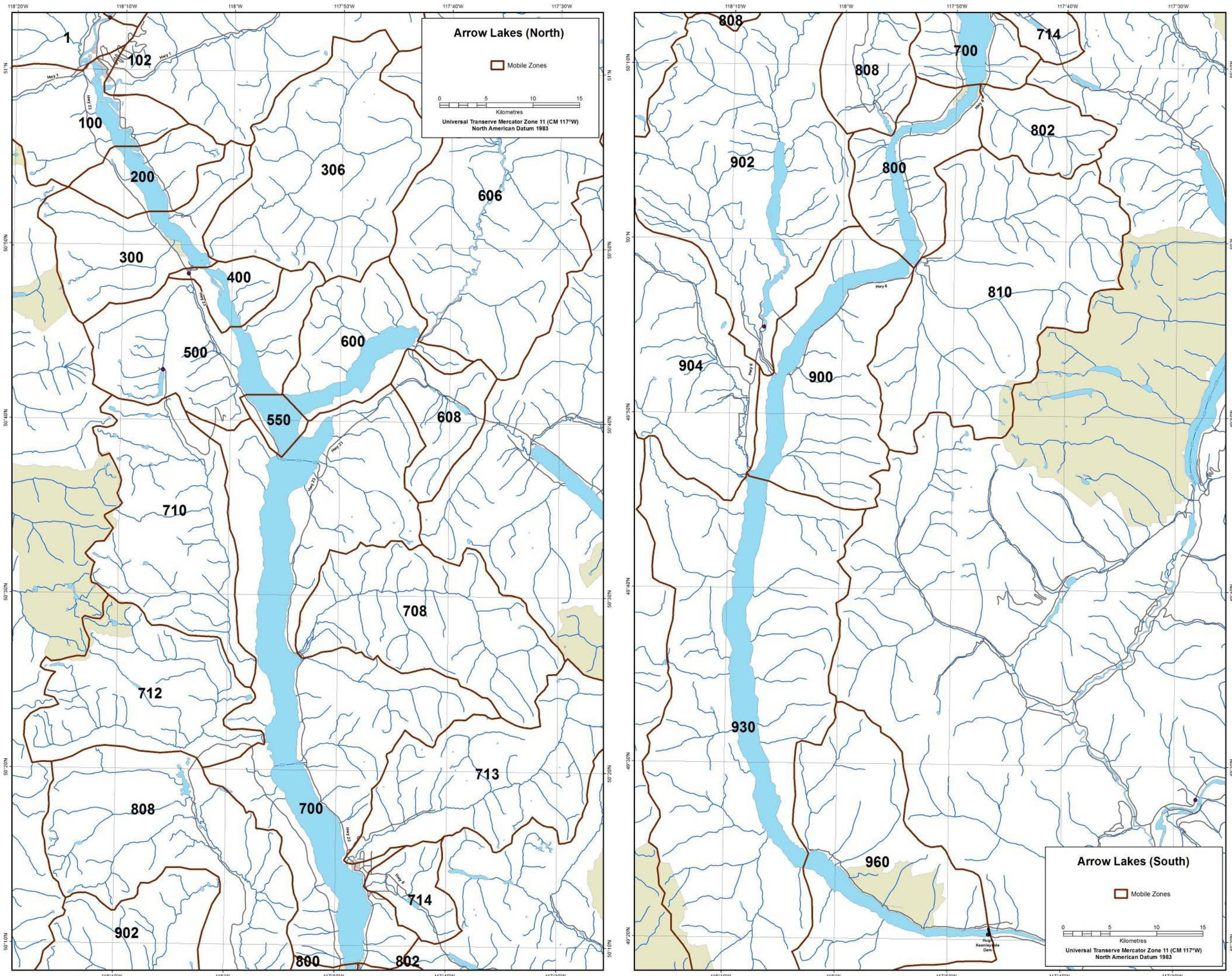

Figure 2. **Numbered zones of the Arrow Lakes Reservoir system.**

equal length. Other zones were delineated by reservoir topography, and the positions of the fixed-station receivers. Each zone was numbered with an arbitrary value starting with low values in the north, and increasing southwards. These numbered zones were used during automated telemetry data processing as they allowed mobile tracking detections to be grouped into discrete bins (i.e., 'zones'). The zone delineations were also useful to ensure tagging effort was divided evenly throughout the Revelstoke to Arrowhead reach.

2.2 TRACKING METHODS

Transmitters ('tags') were surgically implanted into Burbot each fall (Oct/Nov) from 2008 to 2011. Details of these tags and their deployment are available elsewhere (Glova et al. 2009, 2010; Robichaud et al. 2011, 2012). The transmitters were coded such that all tags were unique and receivers could distinguish individual fish. Because of limited battery life, only those implanted in 2010 and 2011 were available for detection during Year 5.

In Year 5, tags were tracked using a combination of fixed-station receivers and mobile tracking.

2.2.1 Fixed-Station Tracking

The tagged fish were tracked using an array of Vemco VR2W fixed-station telemetry receivers deployed in the reach from Revelstoke to Beaton Arm, and in The Narrows (Figure 3). A more extensive array had been maintained by BC Hydro (April 2007 to May 2011) to track acoustic-tagged juvenile sturgeon (Robichaud et al. 2011). Starting in Year 4 (May 2011), a reduced (i.e., fewer receivers) array was maintained by LGL Limited for the sole purpose of tracking Burbot around presumed spawning areas. The use of the reduced array continued through the end of Year 5.

The positions of the receivers during Year 5 are shown in Figure 3. One receiver was located in The Narrows near McDonald Creek. Six receivers were deployed in the Beaton area, either in Beaton Flats or in Beaton Arm, but only four were ever recovered. Four receivers were deployed in Upper Arrow Lake in the reach between Beaton Arm and Revelstoke, all of which were operational until March 2013, but one was subsequently lost and another malfunctioned (i.e., no data from March to May 2013).

Fixed-station receivers were downloaded periodically throughout the year.

2.2.2 Mobile Tracking

Tags were tracked using a VR100 receiver with an omnidirectional hydrophone (model VH 165). All mobile tracking was conducted using a 6.7 m long and 2.4 m wide aluminum jet boat powered with a 350 hp inboard motor. As the boat had a draft of only 0.25 m, lowering the hydrophones to 0.5 m below the water surface was sufficient to achieve unobstructed reception of signals from all directions. The boat was equipped with a combination GPS and chart plotter (Lowrance LMS 520C) and custom-welded adjustable hydrophone holders on either side that could be lowered and raised out of the water as required (Photo 1).

Detection range tests were conducted in a sheltered bay in The Narrows in 2009 (Glova et al. 2010), at which time the audible and 'decodable' ranges for the tags were determined

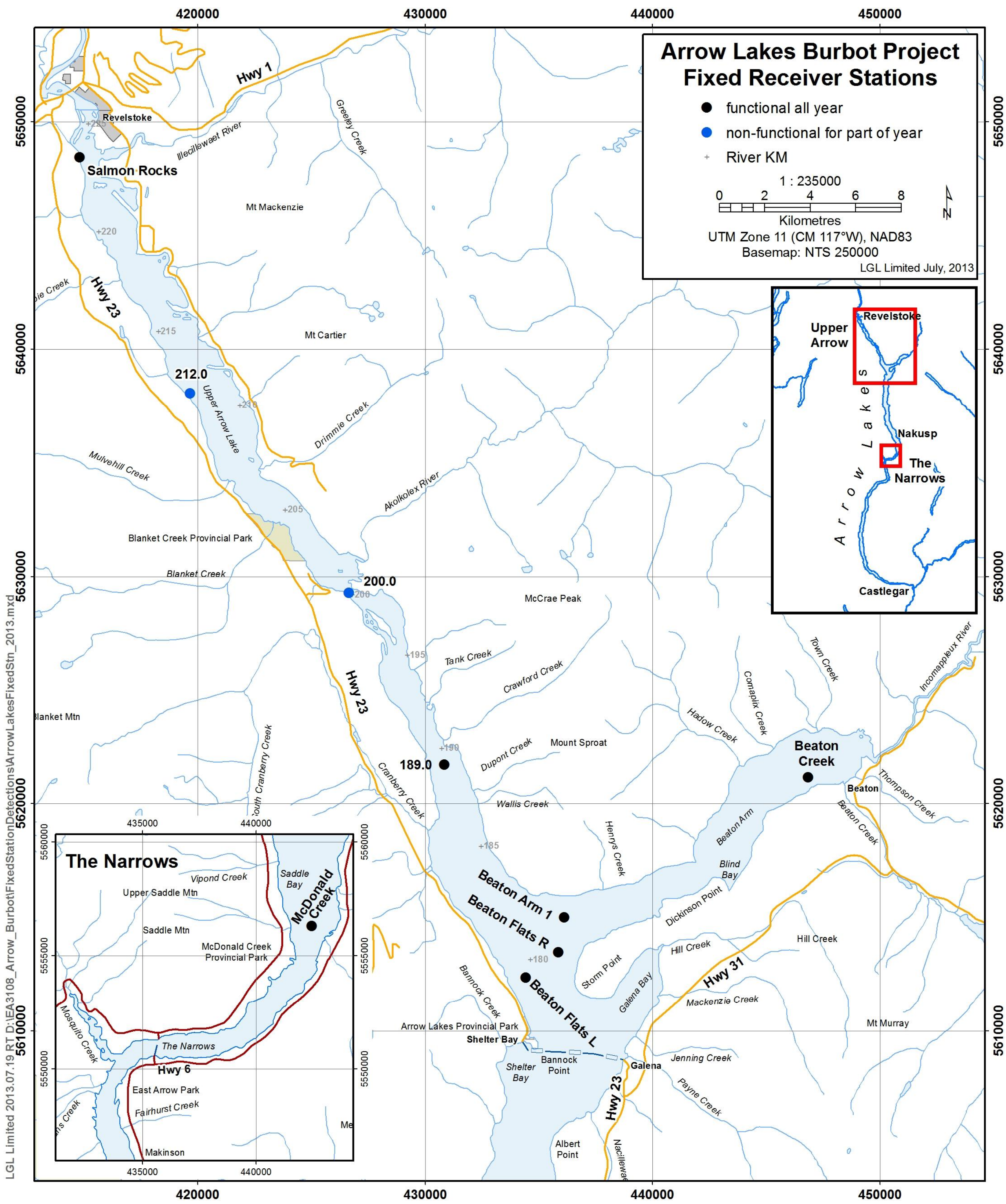

Figure 3. **Locations of fixed-station receivers in the Upper Arrow Lake and The Narrows, in place during Year 5. River km designations between Beaton and Revelstoke are marked (every 5 rkm) in gray text. Several of the fixed-station receivers were named for their position along the rivers length, in rkm.**

Photo 1. **Jet boat equipped for tracking with vertically adjustable hydrophone holders mounted on either side.**

to be 1200 m and 1000 m, respectively (the 'decodable' range was that at which detection probability was 100% if the line of sight was not obstructed). Based on the detection rates we chose our travel distance between tracking locations to be a maximum of 1.5 km in the lake. In the upper river section close to Revelstoke, where the line of sight to the tags was assumed to be shortened, we drifted with the current with the hydrophones constantly deployed. Once the current slowed down, we stopped the boat at regular intervals (maximum of 500 m) or wherever the line of sight between one and the next tracking location was visibly interrupted.

When the boat was stopped at a tracking location, the hydrophones were lowered into the water and we listened for signals for a minimum of 170 seconds while the receiver was recording all coded signals. We chose a duration of 170 seconds per stop since the maximum delay between pings from the acoustic tags was set to 160 seconds. Detections were saved on the receiver and also recorded manually. Following the 170 seconds listening period, the hydrophones were raised out of the water, the boat was advanced to the next tracking location and the listening procedure repeated. If very weak signals could be heard but the receivers could not code the tag, a search for a stronger signal was carried out at slow speed until the maximum signal strength was located and position recorded on GPS. On any given day, a tag might be detected at several of the listening stations. For each tag on each tracking day, the station at which signal strength was greatest was assumed to be its most likely position.

Throughout the tracking period in 2013, the detection ranges were continually reassessed to ensure that listening locations were spaced conservatively enough to detect all available tags. Reassessment was performed as follows. Once a tag was clearly audible and decoded with high signal strength from one tracking location, special attention was paid at the next tracking location to see whether the same tag could still be detected. For the majority of tags in the lake, where line of sight was generally assumed to be unobstructed, this was the case.

The main Year 5 mobile tracking survey, conducted from 2-7 March 2013, provided overall coverage of the locations of tagged-Burbot from the vicinity of Revelstoke to Burton in the Lower Arrow Lake. The primary goal of the tracking survey was to identify potential spawning areas (identified as areas of Burbot aggregation). In general, we followed the shoreline at a distance of approximately 500 m in the Arrow Lake area. During the survey, water temperature ranged between 3.1 and 3.9 °C.

Additional mobile-tracking data were collected in Beaton Flats on 16 March.

2.3 SPAWNING-RELATED INVESTIGATIONS

In addition to fixed-station and mobile tracking, several spawning-related investigations were undertaken in presumed spawning areas in the Beaton Flats and Beaton Arm. These included: 1) Biosampling Burbot that were trapped at regular intervals for maturity assessment, 2) Collecting Burbot eggs by plankton net tows and egg mat sets for staging purposes, and 3) Underwater video recording along various transects and depths during both day and night intervals in an effort to observe Burbot spawning behaviours. Water temperature during these investigations (2 March to 7 April) ranged from 3.1 to 5.0 °C.

2.3.1 Biosampling

A limited number of Burbot were captured and sampled to assess gonad maturity. Baited traps (variable number, 1-5) were set on 7, 9, 12, 15, and 17 March, and on 5 April. The traps were set overnight at various depths (3-38 m) and emptied the following day. All fish captured were sacrificed by holding them in a lethal dose of anaesthetic. Gonadal development was scored into one of the following categories: “Not Ripe” (eggs/sperm not close to being released; ovaries firm and orange in color); “Ripe” (ovaries soft with interstitial space developing; eggs white in colour); “Expressing” (eggs/sperm expressing from cloacae; ovaries soft; eggs free flowing); “Half Spent” (half of eggs/milt have been released from the ovaries/gonads); “Spent” (all or the overwhelming majority of eggs/milt have been released from the ovaries/gonads); or “unhealthy” (i.e., ovaries/gonads appeared to be in a degenerate state).

A sample of eggs was taken for staging from 15 females collected between 8 March and 6 April. Eggs were stored in formalin in glass vials until staged. In the laboratory, a subsample of about 100 eggs was extracted from each vial with an eye dropper and placed in a petri dish (with 1 mm grid for measuring egg diameters) for examination under a compound microscope. Each of the egg subsamples was staged on two separate days according to oocyte development images for hatchery Burbot (see Foltz et al. 2012). The diameter was recorded for a random sample of 10 eggs in each subsample. In instances where there was disagreement between the two stage readings, the sample was re-examined to decide on the final stage. As it was difficult to identify all the stages of egg development reported by Foltz et al. (2012), several successive stages were lumped into a single category to facilitate the staging procedure: these included stages B-D inclusive (oil globules present; eggs were at approximately 11-4 days to spawning), and stages E-H inclusive (eggs clearing, no oil globules present; eggs were within a few days of spawning, or ready to spawn).

2.3.2 Egg Mat Sampling

Ten egg mats with filter-fibre mats secured in metal frames (0.9 m^2) were set at 2-4 day intervals during 4-18 March 2013. Each set was allowed to soak for at least 36 hours. The locations (Figure 4) and water depths at which the mats were set were recorded, and any eggs collected were extracted and preserved in glass vials with formalin for later examination.

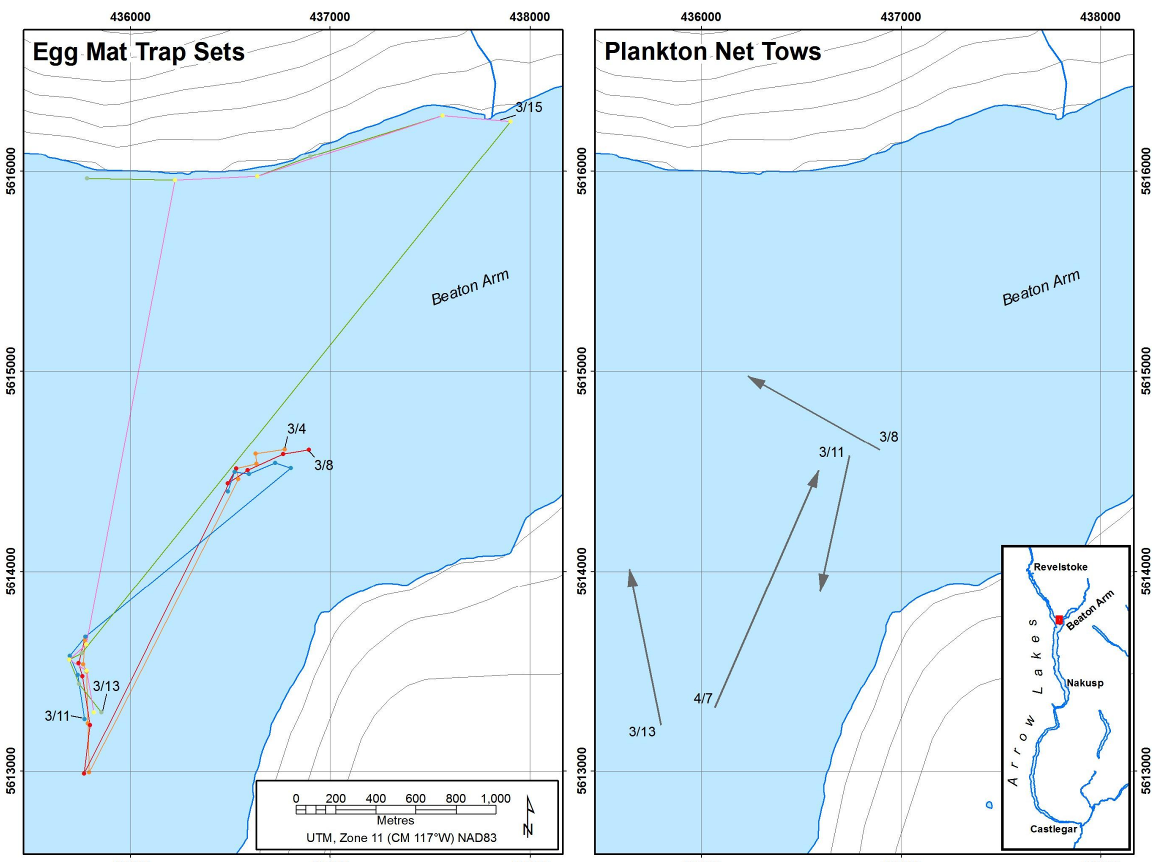

Figure 4. **Maps showing locations of the egg mat sampling and plankton net tows in Beaton Arm (see inset). Egg mats were set at locations marked by coloured dots, all sets deployed on a given date are connected with a line. Dot and line colours are date-specific. The path of each plankton net tow is shown as an arrow, indicating location and direction, and each is marked with the date.**

2.3.3 Plankton Net Tows

Plankton net tows were conducted during the day on 8, 11, 13 and 17 March, and on 7 April, 2013. The net, made of 350 micron mesh, was 2 m long, conical-shaped, and tapered from 0.5 m at the mouth to 0.1m at the cod-end. A downrigger, rigged with a 4.5 kg lead weight, helped stabilize the net at the desired depth. The net was towed at 1.5 - 2.0 km/h along transects that were perpendicular to shore, usually moving from the deep to the shallow end (depth range, 50-20 m), at approximately 1-2 m off the bottom. See Figure 4 for locations of plankton tow transects.

2.3.4 Underwater Video Recording

An underwater video camera (Ocean Systems, Deep Blue Pro Package with 60 m cable and recording capability) connected to monitors onboard was used to search for Burbot within the aggregation areas. In addition to the camera lighting provided by the manufacturer, a battery-powered underwater lighting unit was installed, suitable for deep water observations. A 4.5 kg lead weight was attached to the camera to help stabilize it at the desired depth when towed. On various days between 2 March and 5 April, at speeds of approximately 1.5-2 km/h, we searched for Burbot at various depths and near the bottom along several transects during the day and after dusk.

2.4 TELEMETRY DATA PROCESSING

Data from fixed stations were downloaded in September 2012 and March and May 2013. The downloaded data, along with mobile-tracking records and fishery-related recaptures were processed and analyzed using LGL's custom database software, "*Telemetry Manager*." *Telemetry Manager* facilitates data organization, record validation and analysis through the systematic application of user-defined criteria. Raw data were archived so that the temporal or spatial resolution, and noise filtering criteria could be changed by the user at any time without altering the raw data. An important aspect of telemetry is the removal of false records in receiver files; for example, those that arise from electronic noise. In this study, detections were only considered valid if a tag was decoded at least twice within a single zone, with the detections occurring within 60 minutes of each other (single records, or records separated by more than 60 minutes were rejected). Other 'false' records included detections prior to release or after recapture. Once false records were removed, *Telemetry Manager* created a compressed database of sequential detections for each fish. Each record included the tag number, location, and the first and last time stamp for sequential detections in that location in that interval. The compressed database was used to examine movements between detection sites, and sites of last detection.

2.5 EVALUATING THE FATE OF TAGGED FISH

Two fish are known to have been taken by anglers who returned the transmitters to the LGL office in Sidney, along with the recapture date and location. There were nine tags (four CART tags, a MAP tag and four Vemco-tags) that were never detected during this study (see Glova et al. 2009, 2010, and Robichaud et al. 2011, 2012 for descriptions of each of these three tag types, along with their deployment dates and locations), either by mobile tracking or by the fixed-station receivers. In addition, there were 11 tags (9

CART and 2 MAP tags) that were only detected on a single occasion. The fate of these missing fish cannot be determined. Their transmitters may have failed, they may have left the study area, or they may have been removed by anglers.

Several of the detected fish did not move much from survey to survey, and may have died. Assessing which of these tags are likely mortalities is complicated, as a live, sedentary fish would 'track' the same as a dead fish. From position-based telemetry data, it is not possible to determine if a fish is living or dead. It is generally acceptable to assume, when movements are observed, that an individual is alive. It should be noted, however, that there is error associated with our position estimates (based on the actual location of the survey track, and the distance between listening stations) and a tag can appear to "move" from survey to survey even if it is motionless on the riverbed. For this study, we defined the minimum movement threshold below which any observed "movements" might be spurious as 750 m (i.e., half the distance between the listening station). Only one fish (with more than one detection) was never recorded as having moved more than 750 m among surveys, indicating that it may have died on site or expelled its tag. This fish was removed from further analysis.

Despite the above, this study was not designed to precisely determine the fate of tagged fish. No effort was made to accurately pinpoint the position of a fish in the field (tags were assigned to the location of the listening station where its power reading was strongest). Thus, among-year variance in the survey route likely had a large effect on tag position estimates. The analyses in this report utilize the proportions of detected fish to determine distribution, thus the fate of the fish that were not detected did not factor strongly. No assertions were made at a level of accuracy that required better than 750 m accuracy.

2.6 SEASONAL MOVEMENT PATTERNS

Only fixed-station data were used for analyses of seasonal Burbot movements, since mobile-tracking did not occur year-round. Analyses were also restricted to Upper Arrow Lake north of Galena Bay, since the majority of fixed-station receivers were located in that area. Analyses were also restricted to the fish that were implanted with Vemco transmitters, since only these were detectable by the array of fixed-station receivers. Analyses were also restricted to fish released into Upper Arrow Lake.

In order to assess seasonal movements in an unbiased manner (i.e., counting each fish only once), we calculated a single position for each fish for each month. The single monthly position for each fish was assigned to the 15^{th} day of each month. If a fish was detected at a fixed station receiver on the 15^{th} day, the fish was 'assigned' to the coordinate position of that fixed-station receiver. If a fish was not detected on the 15^{th} day, its position was interpolated from the coordinate positions of the receivers associated with its previous and subsequent detections. To visualize patterns of upstream and downstream movements over time, a plot was generated showing the monthly proportion of tagged fish located in various parts of the Upper Arrow Lake (north of Galena Bay), delimited by river kilometre (rkm).

The proportion of fish that 'overwintered' (i.e., that spent the winter months) in the Beaton area was compared among years. The analysis included the proportions in

January, February, March and April in each of the years. The analysis was conducted using a general linear model with binomial error structure. As an omnibus test for annual effects, a model including 'year' as a factor was compared to one without it. If a significant result was found, the model including year was selected as the more parsimonious, and then post hoc (Tukey) tests were used to test for differences between each possible pair of years.

Data for 2013 were truncated after February, after which we only have data from two of the four receivers north of Galena Bay.

2.7 FLOW AND TEMPERATURE EFFECTS OF UNIT 5

On December 10, 2010, an additional turbine at Revelstoke Dam ("Unit 5") was made operational. BC Hydro is interested in the effect of the additional turbine on flows, temperatures, and fish behaviour downstream of the dam.

BC Hydro provided daily average flow data (in cms) for releases at Revelstoke Dam from January 1, 2008 to April 30, 2013. Hourly measurements of turbine and spillway flow were recorded, and summed for total hourly flow rates. The 24-h daily sums were averaged for further analysis. In addition, temperature data (multiple daily observations, which were averaged for subsequent processing) were provided for the periods August 25, 2007 to November 28, 2008, and April 16, 2009 to April 30, 2013. Temperature readings were measured at 'Station 2 level-logger,' located north of Revelstoke at river km 234 (at elevation 436.8 m), and collected as part of BC Hydro's mid-Columbia Physical Habitat Monitoring Project (Golder Associates 2012). Flow and temperature data were plotted to look for obvious effects of the new Unit becoming operational.

Flow data were analyzed using an ANOVA, with 'flow' as the dependent variable (daily values were used as replicates, with daily averages calculated from hourly readings), and 'winter' and 'time period' as categorical explanatory variables. Analysis was restricted to the winter data (October 1 to February 28) for each year, thus the variable 'winter' took the values '2008-2009', '2009-2010', '2010-2011', '2011-2012' or '2012-2013'. All winter data were divided into two time periods ('before': October 1 to December 10; 'after': December 11 to February 28). For statistically significant results, Tukey's HSD test was used to identify which groups differed. If a statistically significant interaction term was observed, the main effects would not be further considered.

Temperature data were compared between all possible pairs of years. Since the temperature varied widely and predictably over each year, we controlled for seasonal effects by using paired t-tests. For a pair of years, the difference in temperature was calculated between them for each calendar date, and the distribution of differences was compared to a null value of zero. Thus, statistically significant differences would be found when differences were consistently positive or consistently negative. No control data were available at the time of writing. Without a control, no temperature effects can be reliably attributed to the operational change.

3 RESULTS

3.1 TRACKING RESULTS

From May 2012 to May 2013, 93 tagged Burbot were detected. Including all the detections (mobile and fixed-station) during this period, 22 of the 50 (44%) Vemco tags deployed in 2009, 27 of the 50 (54%) Vemco tags deployed in 2010, and 44 of the 50 (88%) Vemco tags deployed in 2011 were detected.

3.1.1 Details of Mobile Tracks

A total of 47 Burbot were detected during the mobile survey in March 2013 (Table 1). The survey track (shown in a different colour for each day) and tag detections locations are shown in Figure 5. Tag identification numbers for the Vemco tags deployed in 2010 ranged from 597 to 646, and those deployed in 2011 ranged from 311 to 360. Of the 50 Vemco tags deployed in 2010 and 2011, 32% and 62% were detected, respectively.

The main, six day survey (2 to 7 March) was extensive (Revelstoke to Burton in Lower Arrow Lake) to establish the overall distribution of tagged Burbot in the study area at the beginning of the 2013 tracking season. Note that the use of Burton as the southern tracking limit was established in Year 4 because no fish were detected between Burton

Table 1. Number of tags detected (and percent of total) by location for the mobile tracking survey in 2013. Percentages are not weighted by effort. The delimitations of the detection zones can be seen in Figure 2. Each fish was counted only once per survey, regardless of the number of times it was detected over the several-day survey*.

Detection Location	2-7 & 16 March
Revelstoke – Drimmie Creek (Zones 1-200)	0
Drimmie-Arrowhead Reach (Zones 300-500)	1 (2%)
Beaton Arm area (Zones 550 and 600)	29 (62%)
Shelter Bay area (upper part of Zone 700)	5 (11%)
Shelter Bay to Nakusp (middle part of Zone 700)	4.5 (10%)
Nakusp to The Narrows (lower part of Zone 700)	6.5 (14%)
The Narrows (Zones 800 and 808)	1 (2%)
Total detections	47

* Five tags were detected in two distinct zones within a survey period (e.g., Tag 311 was detected in zone 600 on Mar 3 and in zone 700 on Mar 4). For the above table, these fish are counted 0.5 times in each zone.

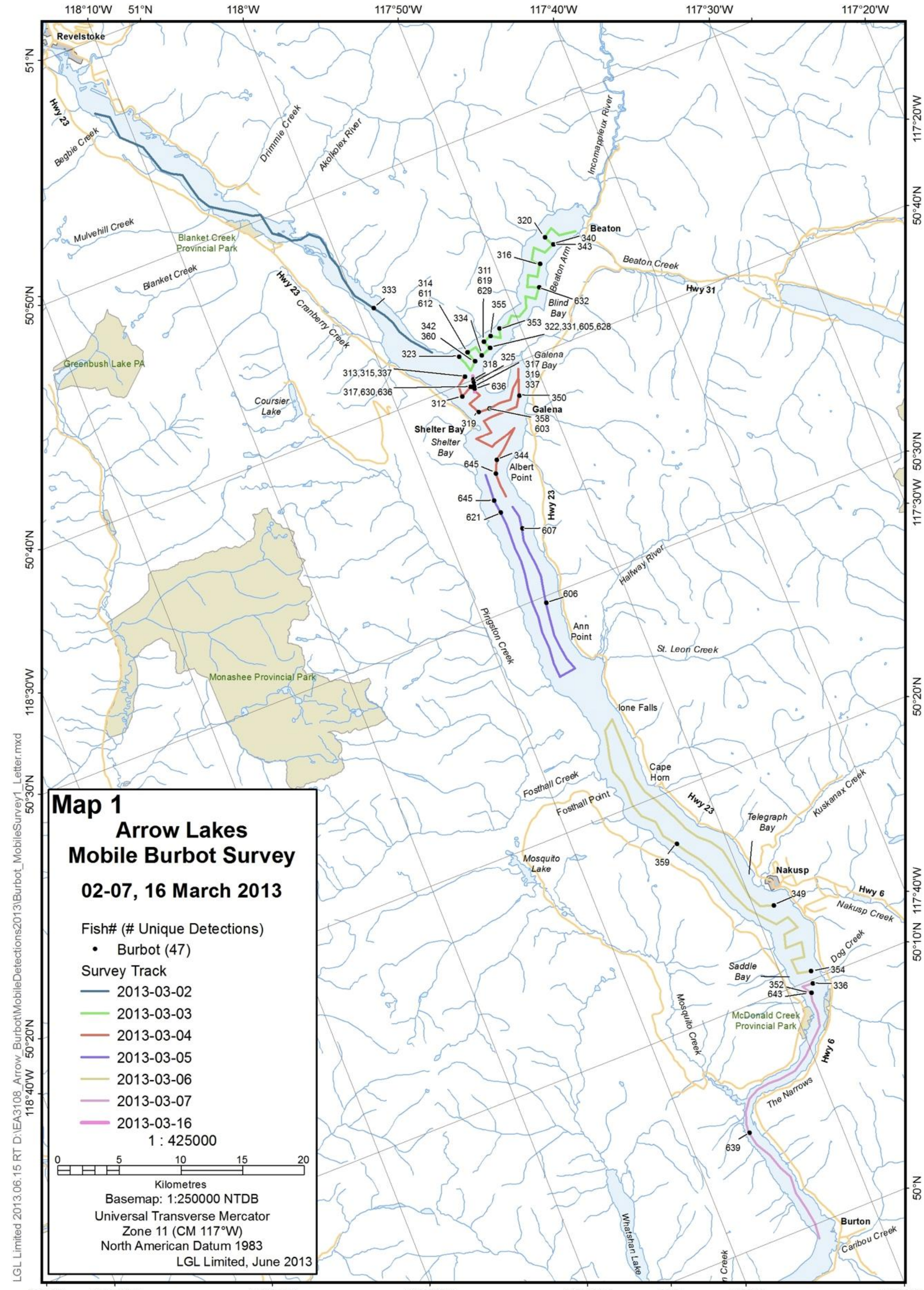

Figure 5. **Survey track and tags detected for surveys conducted in March, 2013.**

and Needles in the previous two years of tracking. Burbot were mainly distributed in the Beaton Arm / Shelter Bay area, which contained 73% (34 fish) of total detections. Only a single fish was detected in the Revelstoke-Arrowhead Reach. One fish was detected in the Narrows, and four were detected in Saddle Bay. The remaining detections were widely scattered in the extensive reach between Shelter Bay and Nakusp (Table 1).

3.1.2 Seasonal Movements

There was little seasonal pattern in Burbot movements in the northern parts of the tracking area (from rkm 212 to Revelstoke Dam). In previous years, no tagged fish were ever detected north of Salmon Rocks (rkm 224; since Year 4, Salmon Rocks was the northernmost receiver). In all years of tracking, the proportion of tagged Burbot that was located between rkm 212 and Salmon Rocks was relatively constant over time (Figure 6), typically ranging from 5-8% during each month, with a dip (< 5%) in November 2010, May 2011, November 2011, February to May 2012, and all months since September 2012.

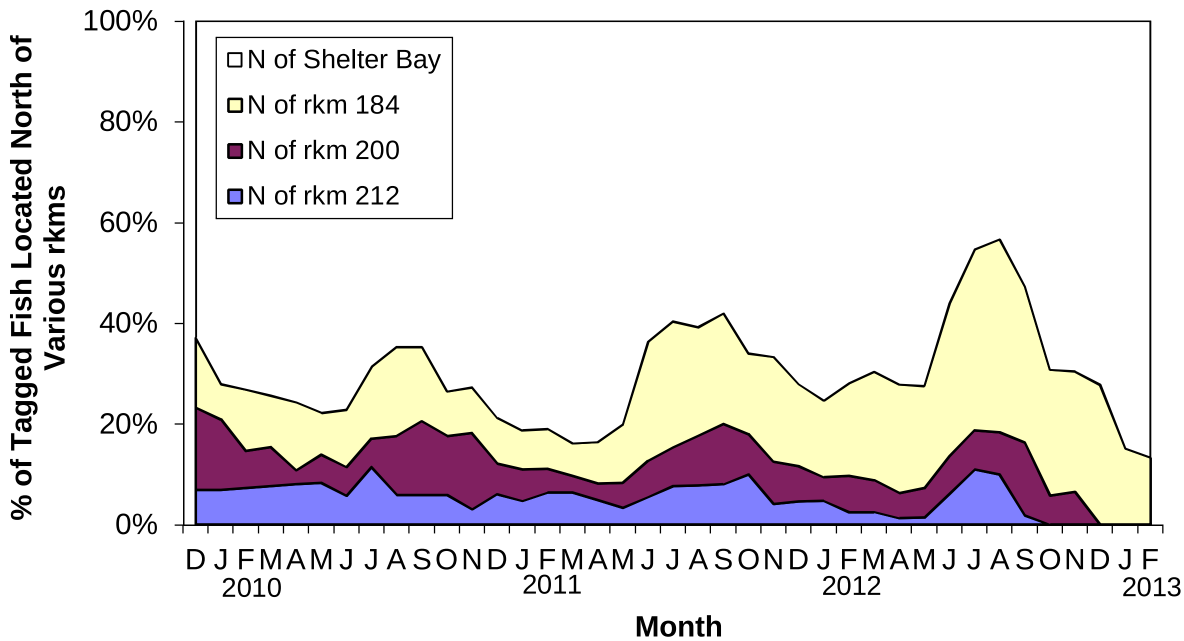

Figure 6. **Percent of Vemco-tagged Burbot that were located north of Shelter Bay and rkm 184, 200 and 212, by month (December 2009 to February 2013). The white area (above the yellow) represents Beaton Arm (up to rkm 184). The Revelstoke to Arrowhead reach is split into three areas, yellow representing the southernmost (rkm 184-200), purple representing the middle part (rkm 200-212), and blue representing the northernmost parts of the river (rkm 212 to Revelstoke Dam). Only fixed-station detections of fish with Vemco tags released in Upper Arrow Lake were included. Detections within the first month of release were ignored. See Figure 3 for locations of fixed-station receivers and rkms.**

In contrast, there appeared to be distinct seasonal movements among the areas downstream of rkm 212. The proportion of tagged Burbot upstream of the Beaton Area (N of rkm 184) fluctuated annually, with the largest proportions in each year occurring in mid-late summer, and the smallest proportions recorded in winter or early spring (Figure 6).

The proportion of fish that 'overwintered' in the Beaton area was not consistent between years (general linear model with binomial error; Dev = 12.1; df = 3; $P = 0.007$). For example, in 2011, the proportion of relocated fish that were in the Beaton area in January, February, March and April was 81%, 81%, 84% and 84%, respectively; whereas the proportions for the same periods in 2012 were 75%, 72%, 70% and 72% (Figure 6). The difference between this pair of years was statistically significant (post-hoc Tukey test, $P = 0.023$), and drove the omnibus model results described above. No other pairwise test was statistically significant ($P > 0.05$). It is unknown whether the statistical difference among years has any biological consequence.

3.2 SPAWNING-RELATED INVESTIGATIONS

During the March/April survey, Burbot were sampled on 8, 10, 13, 16 and 18 March, and on 6 April in the Beaton area. The state of their gonads is briefly summarized in Table 2. Of the 82 Burbot sampled, 84.2% were categorized as "ripe", "expressing", or had fully or partially spent gonads. Only 13.4% had gonads that were not developed (immature) or were not ripe. Also, 2.4% had gonads that appeared unhealthy.

Of the 15 Burbot that were sampled between 8 March and 6 April, 80% were categorized as being 'within a few days of spawning, or ready to spawn', and the remaining 20% were within 'a couple of weeks to spawning' (Table 3). All of the latter eggs were collected between 8 and 16 March. From 18 March onward, all of the egg samples examined (for 7 fish) were within a few days of spawning, or ready to spawn. Overall, for the period 8 March to 6 April, egg diameters ranged from 0.5 to 1.0 mm, but generally were slightly larger (range 0.8 to 1.0 mm) for the fish sampled towards the end of the sampling period (after March 16); these diameters are within the range reported by others. For example, eggs from Burbot in spawning condition collected during late winter from beneath the ice (water temperature 3°C) in the Duncan Reservoir of the Kootenay River system ranged in diameter from 0.7 to 1.1 mm (Jensen et al. 2007).

No Burbot eggs or larvae were captured in egg mats. Similarly, no Burbot eggs or larvae were captured in plankton tows; mysids were abundant in the samples.

No spawning behaviours were observed during extensive underwater video observations conducted during the day or after dusk at various depths and transects in the Beaton area on 7, 9, 11, 14 and 17 March. Many Burbot were seen, either alone, or in groups of two or more fish; all were inactive, on or near the bottom. Also seen were several trout, baitfish and suckers (various sizes), and an abundance of mysids. It is possible that the lights affected fish behaviour.

The substrate in the Beaton area was mainly composed of silts and clay in the shallows (< 3.5 m deep), whereas coarser materials (sand, gravels, cobbles and bedrock) predominated in the deeper areas. Similar bottom characteristics of areas occupied by

Burbot in lakes have been reported by others (e.g., McCrimmon and Devitt 1954; Sorokin 1971). No evidence of Burbot diel movements in lakes was found in the literature, although spawning is reported to usually occur over nearshore shallows: 1.5 to 10 m deep

Table 2. Maturity states of sampled Burbot in Arrow Lakes, March and April 2013.

Sampling			Mature Gonad State						
Date	Sex	n	Immature	Not Ripe	Ripe	Expressing	Half Spent	Spent	Unhealthy
8 Mar	female	12			5	4	1	2	
	male	0							
10 Mar	female	16	2	2	7	1		4	
	male	3	1		2				
13 Mar	female	2		1	1				
	male	1				1			
16 Mar	female	12		2	2	5	1	2	
	male	1				1			
18 Mar	female	3	1			2			
	male	2			1	1			
6 Apr	female	23		2	2	3		14	2
	male	7			2	5			
Total		82	4	7	22	23	2	22	2

Table 3. Stages (see Foltz et al. 2012) of eggs sampled from female Burbot in Arrow Lakes Reservoir, 2013.

Sampling	Number of	Egg Stage		
Date	Females Sampled	A	B-D	E-H
8 Mar	2		1	1
10 Mar	1			1
13 Mar	2		1	1
16 Mar	3		1	2
18 Mar	2			2
6 Apr	5			5
TOTAL	15	0%	20%	80%

(Clemens 1951; Boag 1989), or over shallow offshore reefs and shoals (McCrimmon 1959). In the Arrow Lakes, nearshore areas may be unsuitable for spawning because of extreme dewatering during winter. Burbot make no site preparation for spawning, they are broadcast spawners, releasing eggs and sperm into the water column, usually not far off the bottom (Fabricius 1954), with the semi-buoyant eggs gradually settling into interstices in the substrate. Burbot are reported to spawn at night (Scott and Crossman 1973; Simpson and Wallace 1978), as well as at twilight (Fabricius 1954). The incubation period is temperature dependent, with, for example, hatching occurring within 30-40 days at 3°C (N.R. Jensen, University of Idaho, pers. comm.).

3.3 FLOW EFFECTS OF UNIT 5

Flows varied weekly, seasonally and annually, making it difficult to draw any conclusions about the effect of Unit 5 (Figure 7). In 2010, flows increased substantially from November 2 to 23, and were actually decreasing steadily over the period from December 2 to 26, 2010 when the new Unit came online (Figure 8). Flows appeared to be more variable after Unit 5 came online.

For statistical analyses, the flow data for each winter were divided into two time periods (‘before’: October 1 to December 10; ‘after’: December 11 to February 28; Figure 9). A two-way ANOVA that examined the effect of ‘winter’ and ‘period’ on flow rates had a statistically significant interaction term (Figure 9; $F_{4,746} = 2.5$, $P = 0.041$). The ‘after 10 Dec’ flows recorded during winters 2010-2011, 2011-2012, and 2012-2013 (i.e., after Unit 5 came online) were significantly higher than those observed in the winter of 2008-2009, but were not significantly different from those in winter 2009-2010. The ‘before 10 Dec’ flows recorded during the winter of 2011-2012 and 2012-2013 (i.e., after Unit 5 came online) were significantly higher than those observed in the winters of 2008-2009 and 2009-2010, but were not significantly different from those in winter 2010-2011. Despite a general trend for increasing mean flows over much of the 5-year study period, the statistically significant differences did not align with the new Unit becoming operational: the ‘jump’ in flow rates occurred in late 2009.

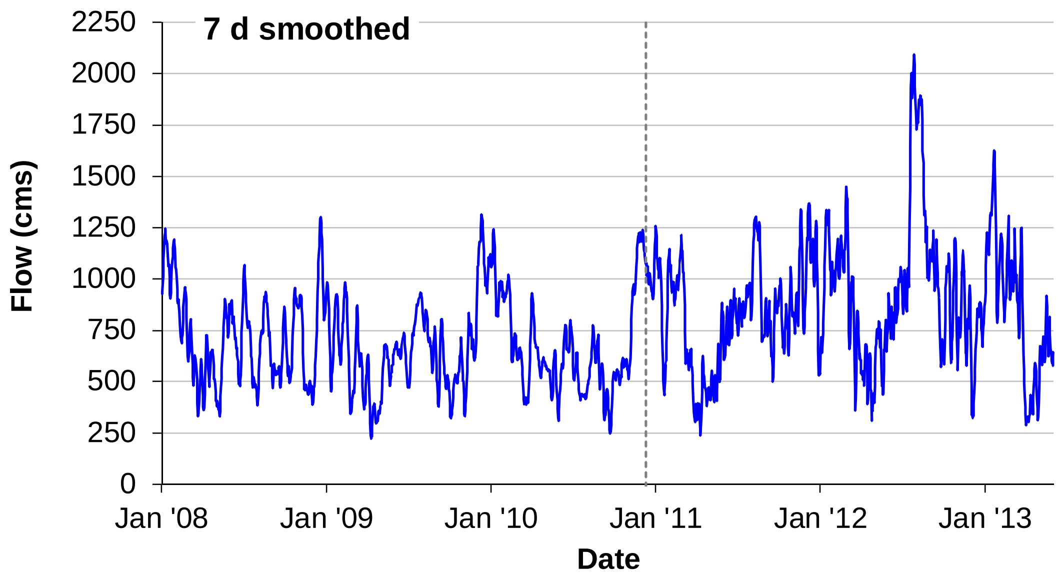

Figure 7. **7-day smoothed Revelstoke Dam turbine + spillway flow by date, January 2008 to April 2013. Dotted vertical line at Dec 10, 2010, shows the time at which Unit 5 became operational.**

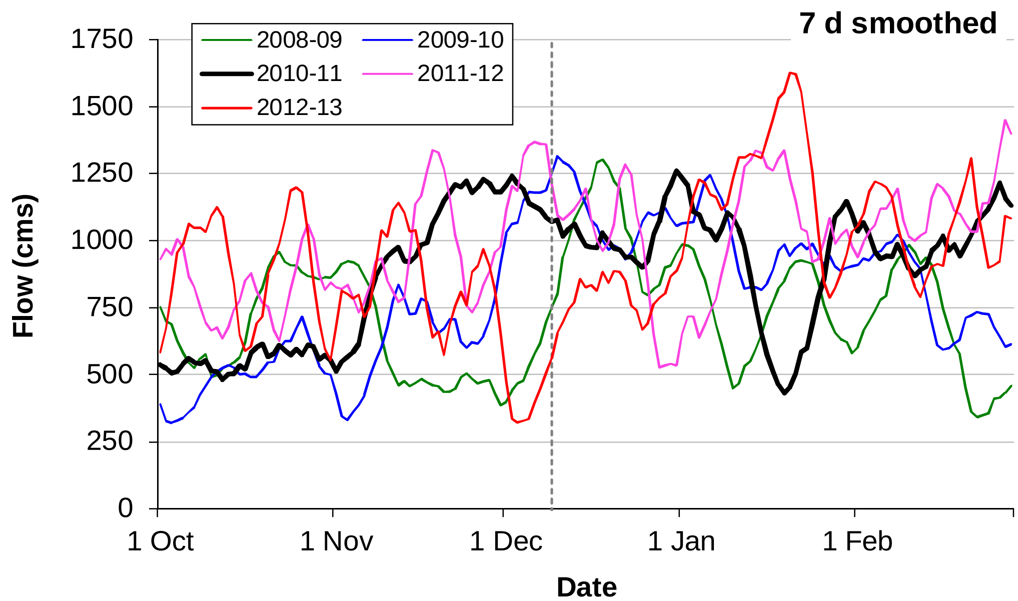

Figure 8. **7-day smoothed Revelstoke Dam turbine + spillway flow by date, October 1 to February 28 shown separately for each winter of data. Dotted vertical line at December 10 shows the time at which Unit 5 became operational in the 2010-2011 winter.**

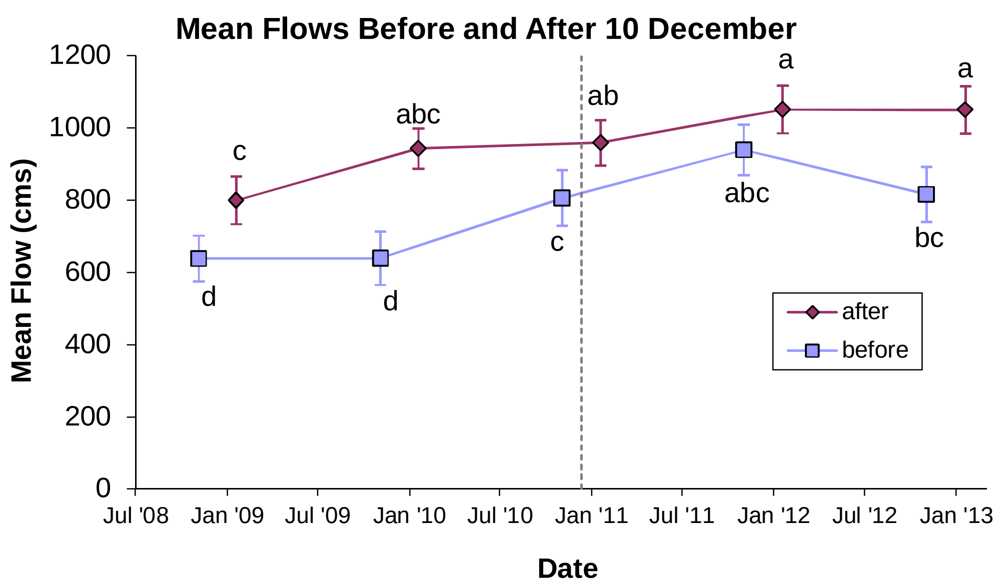

Figure 9. **Mean Revelstoke Dam turbine + spillway flow for five winters of data, each split into two time periods: 'before': 1 Oct to 10 Dec; 'after': 11 Dec to 28 Feb (Horizontal placement of points is at the time-period mid-point). The five winters were 2008-2009, 2009-2010, 2010-2011, 2011-2012, and 2012-2013. Error bars show the 95% confidence intervals around the means. Within each line, points not connected by the same letter are significantly different. Vertical dotted line is at 10 December 2010 and shows the date when Unit 5 became operational.**

3.4 TEMPERATURE EFFECTS OF UNIT 5

No control data were available at the time of writing. As such, it cannot be determined whether the temperature effects described below were climatic. Without a control, no temperature effects can be reliably attributed to the operational change.

Temperatures varied predictably over the course of each year, with largest day-to-day variability occurring in the warmer periods (Figure 10). The year after Unit 5 came online (2011) was the coldest in the five-year study period. Average 'April to November' temperature (7.58 °C) was lower than that in any of the four other study years (2008: 7.75 °C; 2009: 7.71 °C; 2010: 8.37 °C; 2012: 8.16 °C). Paired t-tests (which allowed comparisons between pairs of years, while controlling for seasonal variability) showed that the year after Unit 5 went online was significantly colder than any of the other four study years (*P*-values shown in Figure 11). The next coldest years were 2008 and 2009 (there were no significant differences in temperatures between these two years). The second warmest year was 2012, and the warmest year was 2010. 2013 was shaping to be the warmest year in the time series, but our dataset spanned only to the end of April.

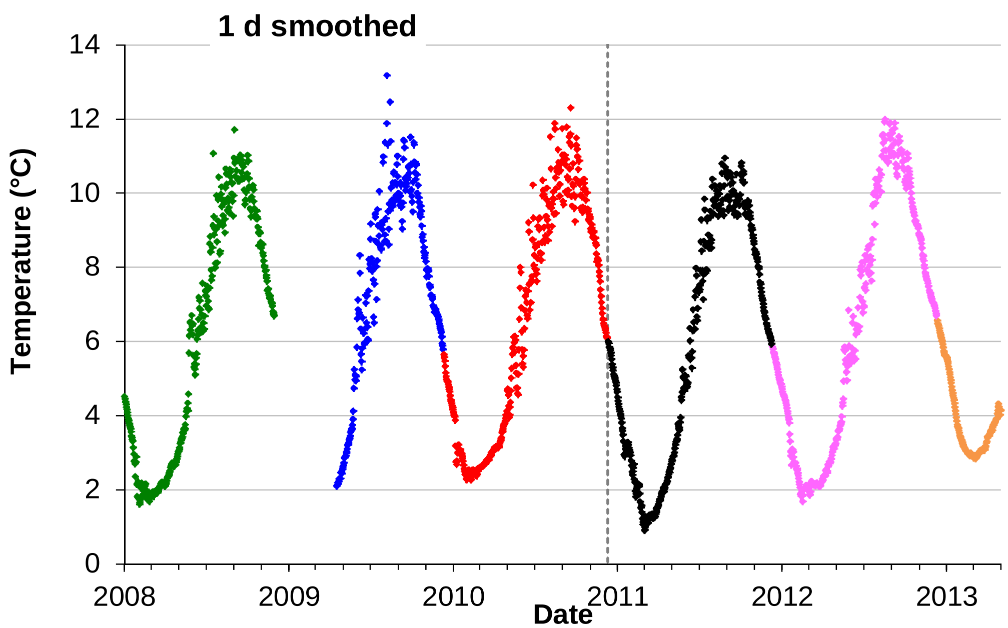

Figure 10. **Daily average water temperatures at 'Station 2' (below Revelstoke Dam) by date, January 2008 to April 2013. Dotted vertical line at 10 Dec 2010 shows the date when Unit 5 became operational. Colours correspond to consecutive years, changing on 10 Dec of each year.**

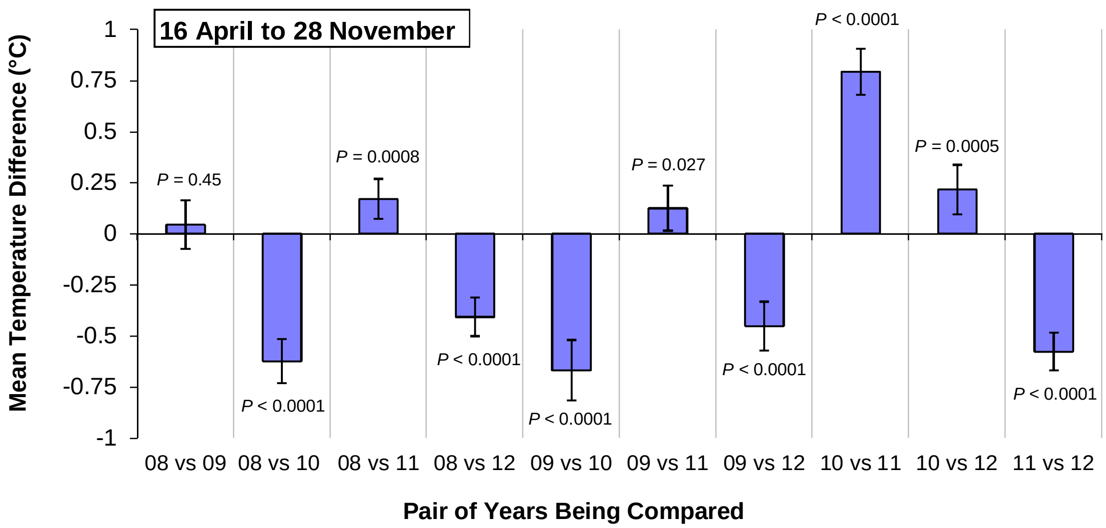

Figure 11. **Mean differences between paired daily temperature values, for comparisons of between all pairs of years. A positive difference in the 'Year1 vs Year2' comparison indicates that Year1 > Year2. The period 16 April to 28 November was selected as this is when data were available for all five years. Probability values for paired t-tests are shown by each bar.**

4 DISCUSSION

4.1 Management Objectives

Do flow fluctuations and dewatering and/or the addition of a fifth turbine unit at Revelstoke Dam affect Burbot spawning migrations or habitat? Before attempting to provide answers, the spawning locations and spawning time of Burbot in the study area had to first be determined.

In order to narrow down the possible spawning locations, we acoustically tagged Burbot, performed spawning-season mobile tracking surveys, and collected year-round fixed-station tracking data. The highest concentrations of fish were consistently found in the Beaton Arm/Shelter Bay area during the presumed spawning period (March) and, to a lesser extent, in the McDonald Creek area in The Narrows. Although spawning is a plausible reason for these fish to be aggregated, it has not been possible to conclusively demonstrate that it is occurring (despite egg mat and plankton sampling). Nevertheless, several lines of indirect evidence exist. Burbot were sampled in Year 4 and Year 5 from within and around these aggregations to assess gonad maturity and conduct egg-staging analysis. Of the fish that were assessed in these years, 62% and 84%, respectively, were in advanced stages of ripeness (or recently spawned). Since the telemetry data do not indicate much movement at this time of year, it suggests that spawning occurs in these areas, with the Beaton being the primary area. While a submersible video camera was not able to capture video of Burbot spawning behaviour, it did provide indirect evidence, as an egg plume (not formally identified) was seen near bottom (Robichaud et al. 2012), suggesting that spawning in the Beaton area occurs near the bottom in relatively deep water (>20 m).

In this report we further assessed potential effects on flows and water temperatures of the addition of Unit 5 at Revelstoke Dam. We examined the flow rates before and after the addition of the new Unit that came into operation on December 10, 2010 (to end of April, 2013). Also, we examined the effects on water temperature before and after the addition of the new Unit. Both of these topics are discussed in subsequent sections.

4.2 BURBOT MIGRATION AND AGGREGATION

The proportion of fish that congregated during winter in the Beaton area was not consistent among the four winters that were studied for this report. Specifically, a larger proportion of the tagged fish were in the Beaton / Shelter Bay area in the winter of 2010/2011 than in the other three winters observed (though not all differences were statistically significant, and it is unknown whether the statistical difference among winters has any biological consequence). Potential reasons for the relatively large proportions observed in 2010/2011 have not been formally investigated, but several are possible. If the area is a spawning ground, it may be that a larger portion of the tagged population spawned in 2010/11 than in other years. It is also possible that more severe winter conditions in 2010/2011 contributed to the observed distribution difference among years (spawning behaviour is known to be affected by temperature, McPhail and Paragamian 2000). Revelstoke data suggest that water temperatures were significantly colder in the 2010/2011 winter than in any other year in the five-year study period (Figure 11). However, we do not know if such among-year differences in temperature were experienced at the depths where burbot commonly occur in the Beaton area.

The Burbot that congregate during winter in the Beaton / Shelter Bay area may be there to take advantage of feeding opportunities. Over the 5-year study period, there were several occasions in which the submersible video camera showed baitfish and *Mysis* shrimp present in high densities on the bottom in the area - likely important food for Burbot. It is possible that differences in food availability among years may have driven the observed difference in relative abundances in the Beaton area among winters. It should also be noted that Burbot may be feeding *and* spawning in these areas. To address this uncertainty, it may be helpful to analyze stomach contents of fish captured in spawning condition during the late winter / early spring period.

4.3 EFFECTS OF WINTER DRAWDOWN ON BURBOT

From multiple years of mobile tracking surveys and year-round fixed-station tracking of acoustically-tagged Burbot, the highest concentrations of fish during the presumed spawning period (mainly March) were consistently found in the Beaton area. Despite considerable sampling effort, we have not observed Burbot spawning activity, nor collected free-floating eggs in the water column, which would serve as indirect evidence of Burbot spawning. Video observations and Burbot biosampling suggest that spawning probably occurs in the Beaton in relatively deep water (>20 m) near the bottom, covered with fine-grain substrate.

Within our focused study area, the areas that are most likely to be affected by winter drawdown include the mid-Columbia River between Revelstoke and Arrowhead, and the extensive littoral habitat of the Upper Arrow Lake and in the lower reaches of its tributaries. Although Burbot have been detected in these areas during high water levels (mainly early summer-late fall), relatively few fish have occupied them during the winter drawdown period. For example, a high proportion of the radio-tagged Burbot that were observed (in warmer months) in the river reach between Revelstoke and Arrowhead, were found to have moved into the Beaton, or further downstream, during the winter period. While there is considerable reduction in habitat for burbot and other fish species during the winter-drawdown, the potential effects on Burbot primary spawning habitat is in all likelihood low. From a substantial body of evidence gathered during this 5-year study, the primary spawning in this reservoir probably occurs in relatively deep (>20 m), near-bottom areas in the Beaton complex (Beaton Arm and Beaton Flats).Reservoir elevations at Nakusp (expected to be similar to those near Beaton Arm) showed annual ~ 10 m fluctuations from 430 to 440 m (Figure 12). Lowest elevations are observed in winter, when Burbot spawning is presumed to occur. If spawning occurs 20 m below the lowest pool elevations, drawdown appears unlikely to interfere with spawning activity. Although Burbot spawning is reported to occur over nearshore shallows 1.5 to 10 m deep (e.g., Clemens 1951; Boag 1989), in the Arrow Lakes the nearshore areas and lower reaches of tributaries may be unsuitable for spawning because of the winter drawdown effects.

4.4 EFFECTS OF UNIT 5 ON BURBOT

Despite a general trend for increasing mean flows over time, the statistically significant flow differences did not align with the new Unit becoming operational: i.e., the ‘jump’ in flow rates occurred in late 2009, not in late 2010. In fact, the flows were steadily decreasing during the time window when the new Unit became operational (early December 2010). Flows varied weekly, seasonally and annually, and from these data, we cannot attribute the observed flow patterns in 2010 and 2011 to Unit 5 operation.

Water temperatures in the year after Unit 5 became operational (2011) were the lowest during the five-year study period. However, the following year (2012) was significantly warmer than 2 of three ‘pre-Unit 5’ years; and 2013 was shaping to be the warmest year in the time series (but our dataset spanned only to the end of April). Since the statistically significant temperature differences did not consistently align with the new Unit becoming operational, we cannot attribute the observed temperature patterns to Unit 5 operation.

Since the addition of Unit 5 at Revelstoke Dam does not yet appear to be influencing temperature or flows, it may be unlikely for it to have an appreciable impact on Burbot spawning migration and habitat, especially as far from the dam as Beaton (~ 35 km downstream). This may change as longer-term post-Unit 5 discharge data become available.

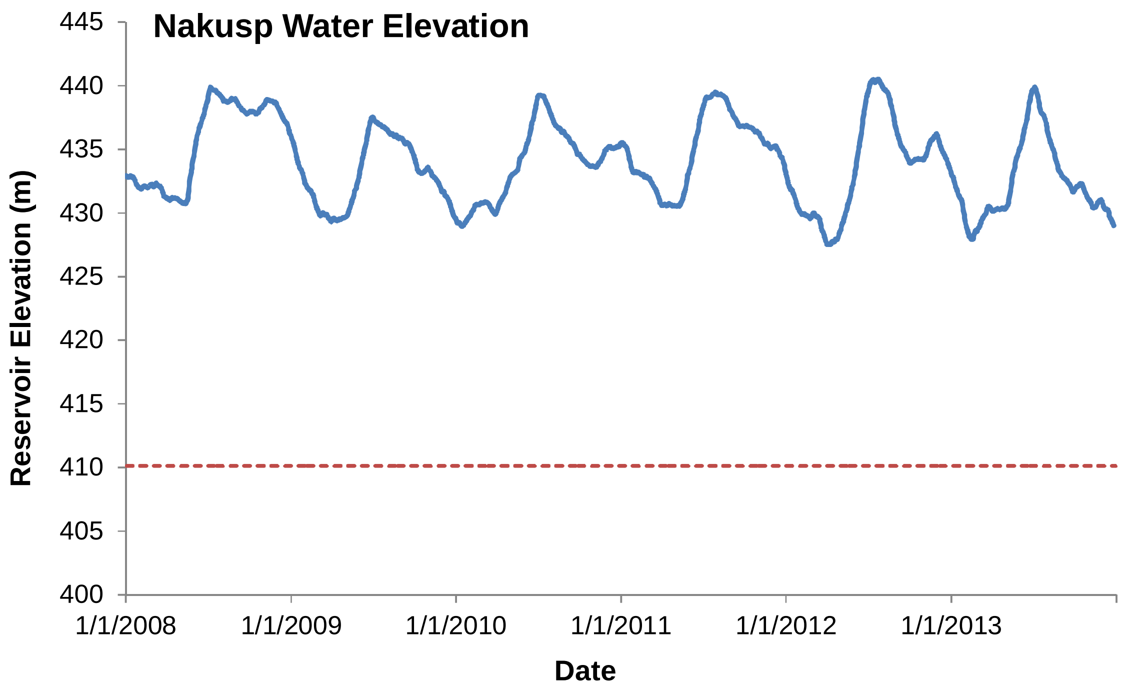

Figure 12. **Time Series data (Jan 2008 to Jan 2014) showing reservoir surface water elevations (solid blue line) at Nakusp. Also shown is the maximum elevation where Burbot were thought to be spawning (dotted red line) in February and March, 2011-2013 (i.e., about 20 m below the surface).**

5 SUMMARY OF FINDINGS

The main findings from the study in Year 5 are:

1. As was found in the previous year, a high proportion of the Burbot that were present in the Revelstoke-Arrowhead reach during tagging in October exited from the area during the winter. This movement was evident from fish detection data from the mobile tracking surveys and the fixed-station receiver array.
2. The proportion of tagged Burbot in the vicinity of the Beaton receivers increased substantially during the winter of 2012/2013, as it did in each previously observed winter period.
3. The relatively large numbers of Burbot detected in the Beaton area during the spawning period makes the Beaton Flats/Beaton Arm area the best candidate for potential spawning. Biosampling of Burbot from this area during the tracking period in 2013 indicated that 84% of all captured fish were ripe or spawned-out, suggesting spawning likely occurs in the Beaton Flats/Beaton Arm area. From the last two years of gonadal ripeness assessments (2012, 2013), it appears that the timing of spawning is protracted, beginning perhaps as early as late Feb, and continuing at least into April.
4. The discharge from Revelstoke Dam varied seasonally and annually, and has increased over time. Flows recorded after Unit 5 became operational during

winter 2010/2011 did not differ significantly from those recorded for similar dates in the previous years. Despite a general trend for increasing mean flows during the 5-year study period, the statistically significant differences did not align with the timing of the New Unit becoming operational; the increase in flows occurred one year earlier (late 2009). Thus changes in flows appeared to be seasonal and not attributable to Unit 5.

5. Among-year temperature differences did not consistently align with the new Unit becoming operational, hence we cannot attribute the observed temperature patterns to Unit 5 operation.
6. Longer-term post-operational data may reveal other trends related to the possible effects of Unit 5 on temperatures and the magnitude of flows from Revelstoke Dam.

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