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 4)

Study Period: October 2011 to May 2012

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Oct 20, 2012

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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 fourth year of a five-year study commissioned by BC Hydro to develop an improved understanding of the effects of hydro operations on Burbot life history.

Year 4 consisted of: 1) Trapping in the upper reach of the Arrow Lakes Reservoir in late October 2011 to catch Burbot for acoustic transmitter implantation; and 2) Fixed-station and mobile tracking of tagged Burbot, coupled with maturity sampling to determine their movements and gather information on timing and location of spawning in the Arrow Lakes Reservoir system.

The area for trapping was divided into five zones of approximately equal length in the upper reach (Revelstoke to Arrowhead) of the Upper Arrow Lake (trapping that occurred in The Narrows in Year 3 was not continued in Year 4). In each zone, 21-29 traps were set, and 23-47 Burbot were caught. Median catch rates for each zone ranged from 0.48 - 0.53 Burbot per trap day. A total of 167 Burbot was biosampled, of which 140 (84%) were sexually mature. Median Burbot total lengths for each zone ranged from 56.5 to 65.1 cm. Distance from Revelstoke Dam showed weak (but statistically significant) negative relationships with CPUE and Burbot size.

In 2011, 50 mature Burbot were implanted with Vemco acoustic transmitters: 10 in each of the five zones in the Revelstoke-Arrowhead reach. Also available for tracking in Year 4 were 50 fish released in 2010 (Vemco tags), 50 fish released in 2009 (Vemco tags), and 20 (tags still weakly functional) fish released in 2009 (Lotek MAP tags). The Vemco tags were tracked by fixed-station receivers and mobile surveys (by boat), whereas the MAP tags were tracked by mobile surveys only.

Continuous tracking was possible using an array of fixed-station Vemco VR2W receivers, including 10 in the Revelstoke-Beaton Arm reach and one in The Narrows. During the period February 17 to March 8, 2012, two mobile tracking surveys were conducted covering various areas in the Arrow Lakes Reservoir.

From May 2011 to May 2012, 123 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). In late fall 2010, a large proportion of the tagged Burbot moved out of the Revelstoke to Arrowhead area (between rkm 184 and 212), and the proportion did not start to increase until the following spring/summer (June 2011). The same pattern of movement was evident for 2011, with fish departing the more northerly areas in late fall (Sept to Oct 2011). The proportion of fish found in the vicinity of the Beaton receivers did not drop below 59% at any point in the year, but was substantially higher than other areas in all three winters of study.

In 2012, spawning timing was protracted (late February to mid-March, or even later) and occurred mainly in deep water (>20 m) near the substrate in the Beaton area, and to a minor extent in McDonald Creek vicinity. These observations were based on biosampling, egg staging, underwater and video observations in areas where Burbot were concentrated. Further spawning-related investigations will be conducted in 2013 to confirm these observations.

The Status of CLBMON 31 Objectives, Management Questions and Hypotheses after Year 4.

Objectives	Management Questions	Management Hypotheses	Year 4 (2011-2012) Status
1: Identify spawning habitat of Burbot in the reservoir.	1: Where are Arrow Lakes Reservoir Burbot spawning?		In Years 2-4, we tracked the Arrow Lakes from south of Needles (Year 2 and 3) or south of Burton (Year 4) to Revelstoke at least once and then focused the remaining tacking effort on the areas of highest detected tag presence. These focus areas were the Upper Arrow Lake and The Narrows. These two areas correspond with our study objective to concentrate on the areas most likely to be affected by winter drawdown and Unit 5 operation. In summary, tracking during the assumed spawning period over three consecutive winters (February-March) has shown that there are consistent locations of elevated Burbot concentration. Sampling in Year 4 confirmed that the Burbot in the aggregation areas are in spawning condition, and some were spawned out. Sampling in Year 5 should further clarify whether or not the Burbot in these aggregations are spawning.
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 are 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 thus far 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. Further tracking in Year 5 will help confirm whether this is the case. Due to the number of factors at play, it cannot be determined if the burbot leave the drawdown area as a result of changes in water elevation.
	4: Can modifications be made to the operation of Arrow Lakes Reservoir to protect or enhance spawning success of the Burbot population(s)?		The main objectives, management questions and management hypotheses will be more fully addressed in Year 5. At that stage, it may be possible to recommend modifications to the operation of Arrow Lakes Reservoir.

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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 wintertime dewatering of nearshore areas and the lower reaches of tributaries (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 in the reservoir. The results of the work completed during the first (2008-2009), second (2009-2010) and third (2010-2011) years of study are in Glova et al. (2009), Glova et al (2010), and Robichaud et al. (2011), respectively. This report is for the findings of the fourth study year (2011-2012).

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.

This report includes a description of the field and analytical methods, data summaries and analyses, GIS mapping of Burbot movements, a brief summary of spawning-related investigations, some preliminary interpretations of findings in relation to BC Hydro’s key management questions and hypotheses, and recommendations for Year 5 (2012-2013).

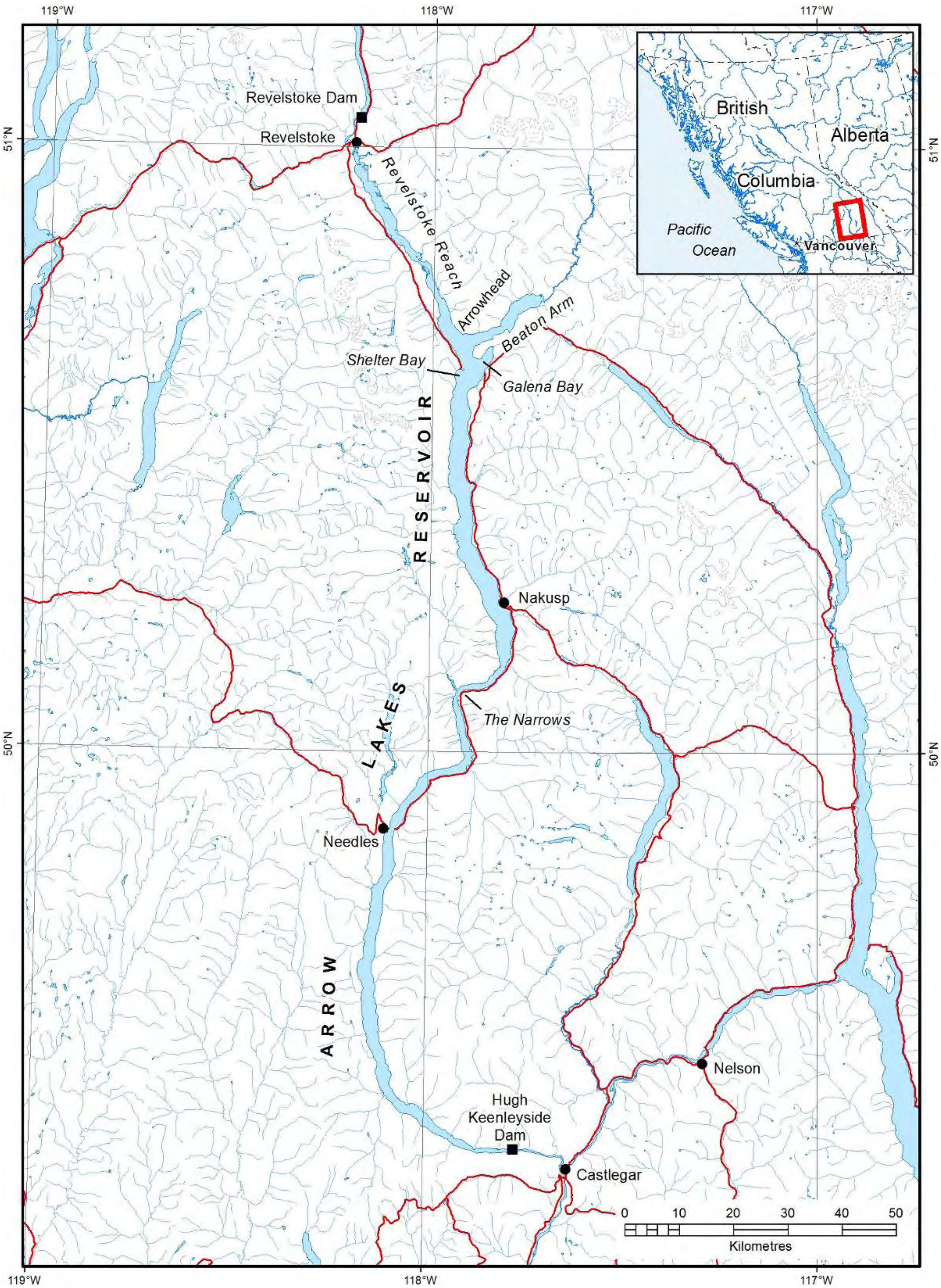

Figure 1. **Map of the mid-Columbia River watershed between Revelstoke and Hugh Keenleyside dams. Red lines show the positions of major roads.**

1.1 MANAGEMENT QUESTIONS AND HYPOTHESES

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 fourth year of the monitoring program consisted of three main tasks: 1) Trapping in priority areas of the Arrow Lakes Reservoir in October 2011 to catch Burbot for transmitter implantation; 2) Tracking (with the use of mobile and fixed-station receivers) the tagged Burbot to determine their post-release movements; and 3) Assessments of egg maturity stages (via biosampling) to gather information on timing and location of spawning in the Arrow Lakes Reservoir system.

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 (from Revelstoke 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 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 TRAP SITE SELECTION

The target area for trapping was restricted to the five numbered zones of approximately equal size in the upper reach (Revelstoke-Arrowhead) of Upper Arrow Lake (from north to south: zones 100, 200, 300, 400 and 500; Figure 2). In each zone, 21-29 traps were set in 4-5 sites per zone, and 10 Burbot were tagged per zone (Table 1).

Table 1. Summary of Burbot trapping effort and catch, by numbered zone in Arrow Lakes Reservoir. See Figure 2 for boundaries of each zone.

Zone	Number of Sites	Number of Traps Set	Soak Duration (days)	Burbot Caught	Burbot Tagged
100	4	25	2-3	47	10
200	4	25	2-3	34	10
300	4	25	2-3	37	10
400	4	21	2-3	23	10
500	5	29	2-3	28	10

Trap sites were selected to maximize catch and to minimize barotrauma to Burbot. Thus, sites were relatively shallow (<13 m), and were either near locations known (or presumed) to produce high catch rates (Arndt and Baxter 2006, Glova et al. 2009), or were in the proximity of possible Burbot spawning streams. Locations of trap sites in Upper Arrow Lake are shown in Figure 3.

2.3 TRAPPING AND PHYSICAL DATA COLLECTION

The Burbot traps (Photo 1) were baited with frozen adult kokanee collected from the Meadow Creek Hatchery in the late autumn of 2011. The kokanee were tied into a mesh bag in the center of the trap.

To avoid injuring the trapped Burbot through barotrauma, traps were hauled slowly to the surface over several days: traps were lifted each day to a depth at which gas volumes would expand by about 1.5 times and were left overnight at this depth. In general, total soak time was two days for traps that were set <13 m and three days for traps set in deeper water (occasionally traps drifted to depths >13 m during the first soak night); however, shallow-deployed traps were sometimes soaked for three days if daylight was limited and the fish were not required for tagging. After two to three nights of soaking, traps were hauled to the surface and the catch was biosampled.

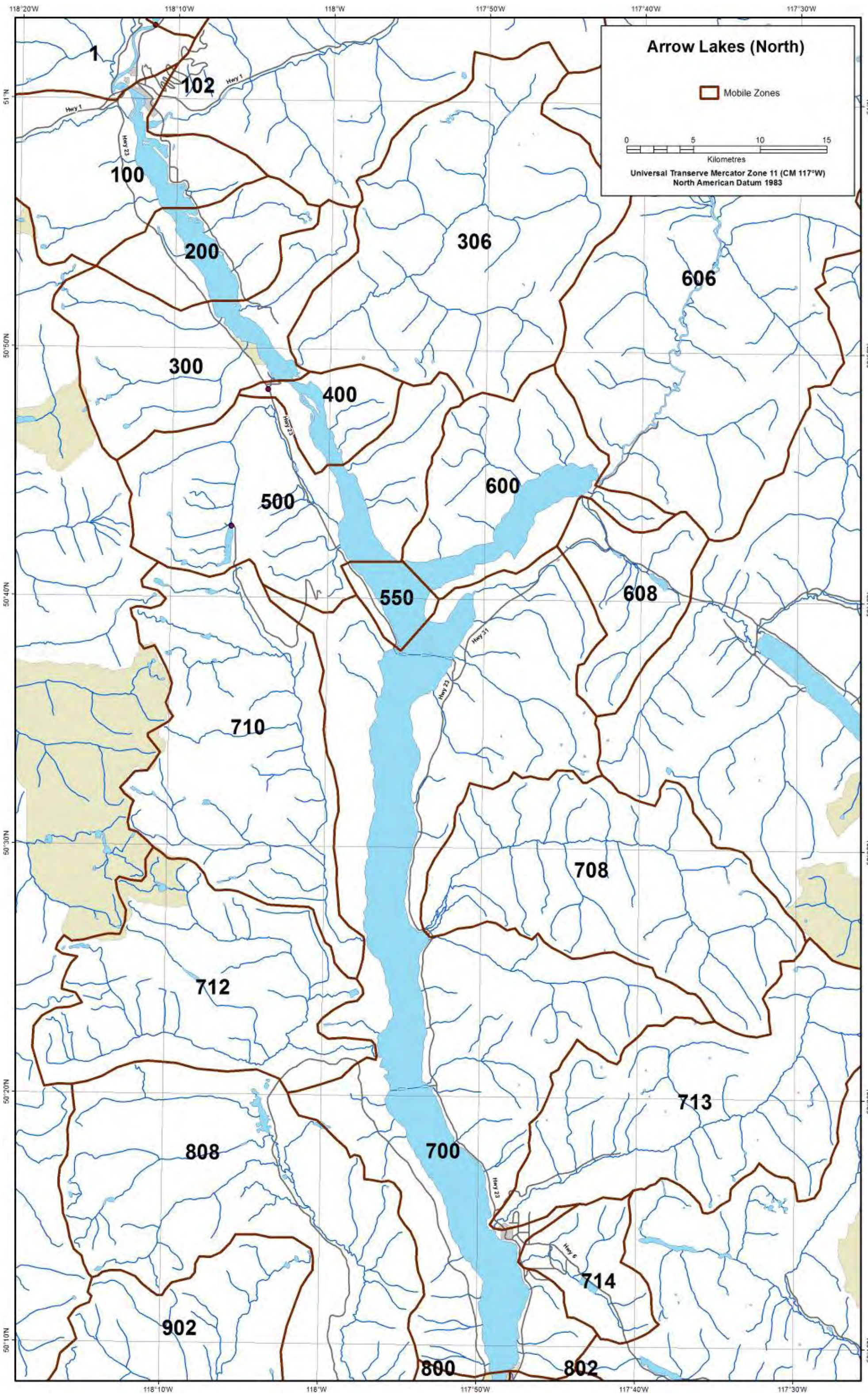

Figure 2. **Numbered zones of the Arrow Lakes Reservoir system.**

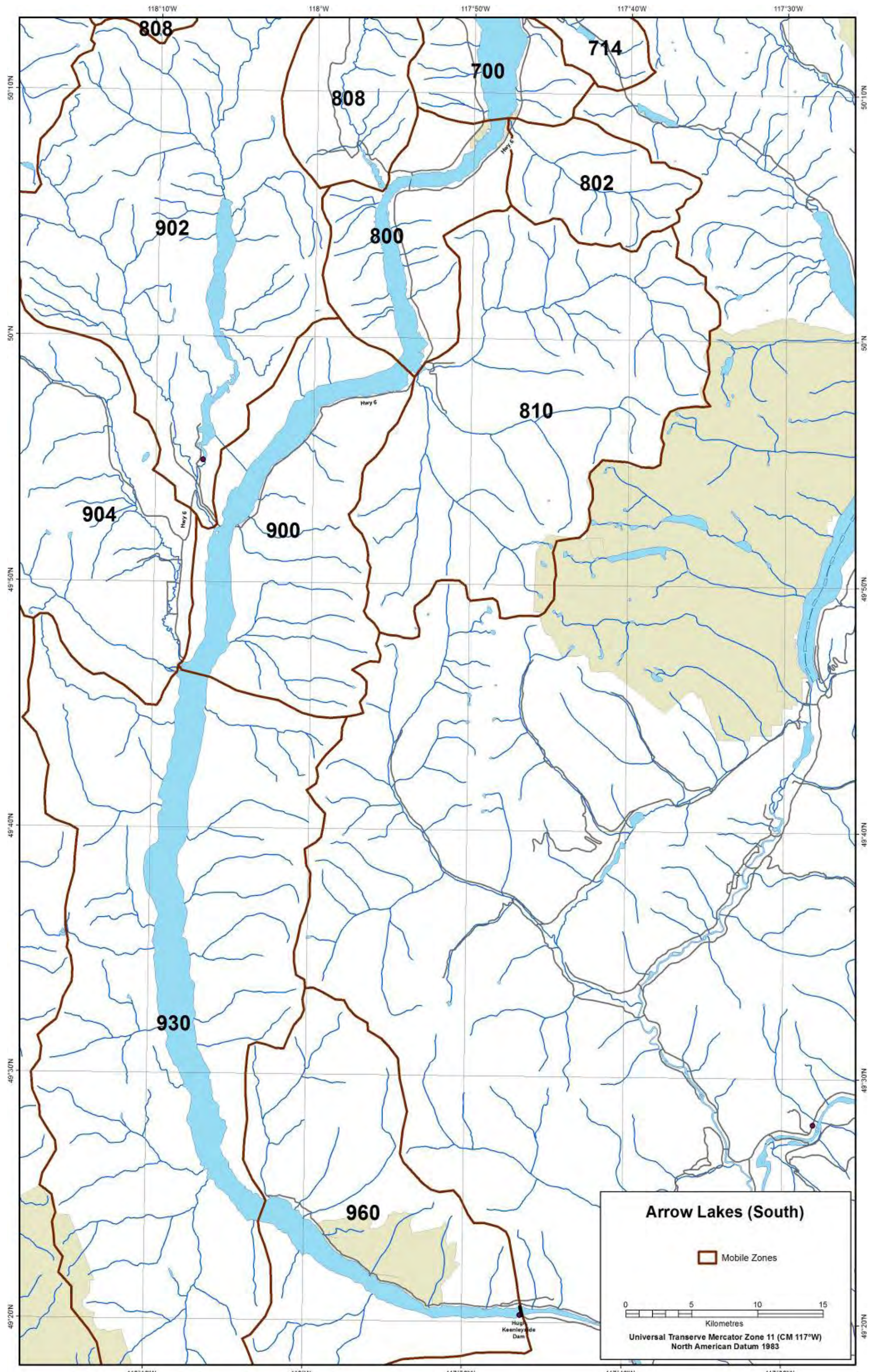

Figure 2 continued.

Figure 3. **Locations of trap sites in Upper Arrow Lake. Multiple (4-9) traps were deployed at each site. Numbers of tagged Burbot are shown for each release site in yellow boxes. Map constructed using base maps from Google.**

For each trap, the zone number, set depth, trap location (UTM coordinates), trap number (each trap had a unique identifier) and set date and set time were recorded. GIS was used to calculate the distance of the trap set from Revelstoke Dam. Traps were deployed in clusters called sites. At each site, a Cline Finder meter was used to measure water temperature at depth on both trap deployment and haul (tagging) days.

The effects of temperature, zone, trap set depth, and distance from Revelstoke Dam (potentially a proxy for flow and depth) on catch rates (Burbot per trap per day of soak) were examined using general linear models (GLM) with negative binomial error structures. Catch rates (CPUE) were modelled by assigning ‘catch’ (i.e., counts) as the response variable, and using ‘soak time’ as an offset. The effect of trap set depth was modelled both as a continuous variable (‘set depth’) and as a categorical variable (‘depth bin’); with depths categorized as either ‘<10 m’ or ‘≥10 m’. Analyses were conducted using the statistical software ‘R’ (R Development Core Team 2011) and the negative binomial GLM functions included in the ‘MASS’ package (Venables and Ripley 2002).

Photo 1. Preparing traps for deployment into the lake.

2.4 BIOSAMPLING

Biosampling of captured Burbot included the measurement of body girth, total length (tip of nose to end of tail), and weight. When possible, sexual maturation was determined by tactile examination of the ventral side of the fish. Those that were in an advanced state of sexual maturity had gonads that were large enough to be felt during this examination. All others were marked as unknown. Sex could be determined for only a small fraction of the fish, thus sex data were not treated in this report.

All fish were examined and rated for barotrauma effects using a Cavity Inflation Index (0 = none, 1 = low, 2 = medium, and 3 = high). All Burbot of a sufficient size for tagging were marked with a numbered, coloured plastic anchor tag attached near the dorsal fin. Biosampled fish were also rated in terms of their vigour upon release (vigorous, intermediate, or struggling).

The effects of zone, trap set depth, and distance from Revelstoke Dam (potentially a proxy for flow and depth) on size of fish caught (Burbot total length, weight, and girth) were examined using linear regression and ANOVA (Sokal and Rohlf 1995). The effect of trap set depth was modelled both as a continuous variable (‘set depth’) and as a categorical variable (‘depth bin’); with depths categorized as either ‘$<$10 m’ or ‘$\geq$10 m’.

Following Fisher et al. (1996), length-weight relationships were modelled as $\log_{10}Wt$ (in g) = $b + m \cdot \log_{10}TL$ (in mm); where the coefficients b and m represented the intercept and the slope of the line of best fit, respectively. The relative weight (W_r) was calculated for each of our measured individuals as 100 times the ratio of their measured weight (W) and their standard weight (W_s):

$$W_r = 100\frac{W}{W_s},$$

where the standard weight for each individual was calculated from the formula in Fisher et al. (1996). As per Murphy et al. (1990), the relative frequency of the W_r values was plotted to contrast the weight-at-length of the Arrow Lakes Burbot population versus that of other Burbot populations in North America. Also, the method of Murphy et al. (1990) was used to examine the relationship between length and relative weight.

2.5 FISH TAGGING

Biosampled fish that were deemed healthy, of sufficient size (tag was < 2% of the Burbot's body weight), and in an advanced state of sexual maturity were tagged by surgically implanting a Vemco acoustic transmitter into the peritoneal cavity (Photo 2). Transmitters and surgical instruments were soaked and disinfected with germicide solution prior to each surgery.

Surgical procedures were adapted from Adams et al. (1998). Individual Burbot were placed in an anaesthetic bath of clove oil for about 2.5 minutes or until they lost equilibrium. As was the case in the previous two years, a clove oil-water solution of 100 ppm was used as the baseline concentration of anaesthetic. This baseline dose was increased in steps of 20 ppm when needed. Each fish was then removed from the bath and placed ventral side up in a wet, shallow V-shaped trough (coated with Stress Coat to minimize scale loss and maintain the exterior mucous covering) to undergo the tagging procedure. A tube was placed in the fish's mouth throughout the duration of the surgery, and the gills were continuously flushed, initially with anaesthetic solution, and, for the final minute of the procedure, with fresh water. An incision approximately ≤17 mm in length was made about 10 mm away from and parallel to the mid-ventral line, starting 10 mm forward of the pelvic girdle. The incision was made just deep enough to penetrate the peritoneum. The transmitter was inserted into the cavity, positioned directly under the incision. The incision was then closed with two to three interrupted, absorbable sutures, evenly spaced along the length of the incision.

Upon completion of surgery, all tagged fish were returned to the trap which was hanging in the surface water off the side of the boat, for observation. Once the fish had fully regained equilibrium, the trap was re-deployed at about a 2 m depth for an overnight recovery period. The following day, the traps were brought to near the surface and the tagged Burbot were visually examined.

Two tagged fish in Zone 100 were killed by an otter during the overnight between the tagging and release days. As a result, new traps were set in this zone and different fish were tagged and released following the procedure described above. Other than the two otter-kills, all of the other 50 Burbot that were tagged and released in 2011 appeared to be in good health and were released the day after tagging. Fish were released by opening the trap while it remained subsurface (to avoid taking the tagged fish out of the water unnecessarily).

Photo 2. Suturing the incision following insertion of a Vemco transmitter into a Burbot.

2.6 TAG TYPES

In October 2011, Vemco acoustic transmitters (Model V13-1x-A69-1303; 69 KHz) were implanted in the fish. The tags measured 13 mm in diameter, were 36 mm long, and weighed 6 g in water. A key feature of the Vemco tags is that they could be detected by the array of ‘fixed-station’ VR2W receivers in the Revelstoke to Beaton Arm area which provided additional monitoring of the movements of fish. The transmitters were coded such that all tags were unique and receivers could distinguish individual fish. In addition, Vemco tags deployed in late 2010 and Vemco and Lotek MAP tags deployed in late 2009 were available for tracking in early 2012. Details of these tags and their deployment are available in Robichaud et al. (2011) and Glova et al. (2010), respectively.

2.7 FIXED-STATION TRACKING

The Vemco-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 4). 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 Lotek CART and Lotek MAP tags could not be tracked with these fixed-station receivers.

The positions of the receivers during Year 4 are shown in Figure 4. One receiver was located in The Narrows near Mosquito Creek. Six receivers were deployed in the Beaton area, either in Beaton Flats or in Beaton Arm. Four receivers were deployed in Upper Arrow Lake in the reach between Beaton Arm and Revelstoke.

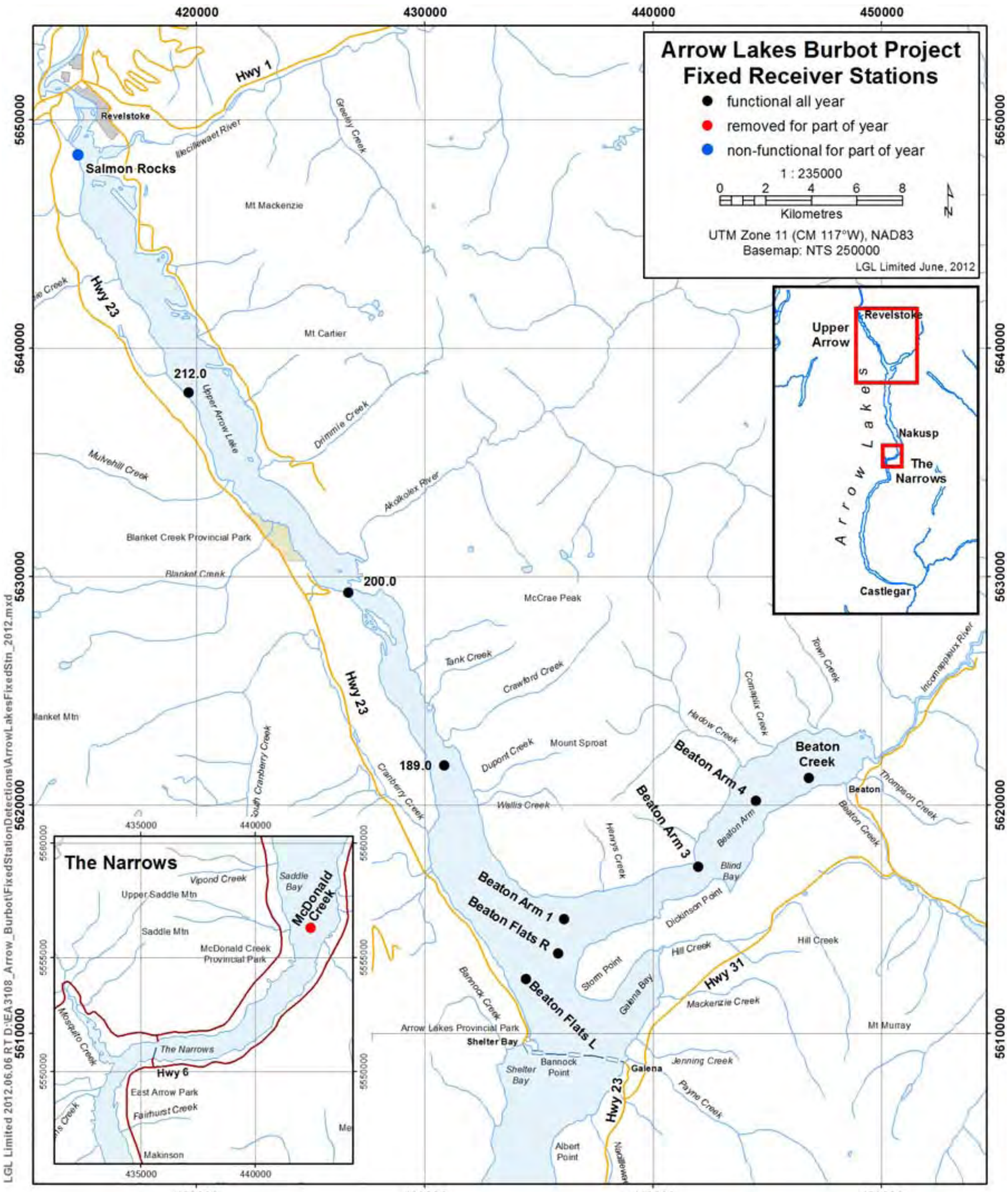

Figure 4. **Locations of fixed-station receivers in the Upper Arrow Lake and The Narrows, in place during Year 4. Many of the fixed-station receivers were named for their position along the rivers length, in rkm.**

Fixed-station receivers were downloaded periodically throughout the year. In March 2012, when the Salmon Rocks receiver was retrieved for downloading, its anchor points were found to be frayed. To avoid loss, the receiver was removed. It was replaced in May 2012, during a subsequent downloading trip, with more robust anchor materials. A data gap therefore exists for the Salmon Rocks receiver between March 12 and May 9 (58 days).

For logistic reasons, the receiver in The Narrows could not be accessed during the October 2011 download trip. When it was accessed in February 2012, the battery was dead and no replacements were on hand. The battery was replaced during the March 2012 download trip. Therefore, the receiver was offline between December 14, 2011 and March 6, 2012 (83 days).

2.8 MOBILE TRACKING

In February and March 2012, mobile tracking of tagged fish was done using two types of mobile tracking gear. The Vemco tags were tracked using a VR100 receiver with an omni-directional hydrophone (model VH 165). The Lotek MAP tags were tracked using a MAP 600 RT receiver hooked up to two hydrophones (model LHP_1). The Lotek CART tags deployed in late 2008 had stopped transmitting (they were beyond their battery life) and were therefore not a target of mobile tracking in Year 4.

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. 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 3).

Photo 3. Jet boat equipped for tracking with vertically adjustable hydrophone holders mounted on either side.

Three hydrophones were used during the tracking surveys: two (one on either side of the boat) for tracking MAP tags; and one for Vemco-tag tracking. The use of two hydrophones for tracking MAP tags facilitated triangulating the position of a detected tag. 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.

Detection range and receiver output tests for all three tag types were conducted in a sheltered bay in The Narrows on November 11, 2009. Details of the methodology can be found in Glova et al. (2010). The detection probability of tags within the decodable range was determined to be 100% if the line of sight was not obstructed. The observed detection ranges are shown in Table 2.

Table 2. Range of acoustic and radio signals for the three tag types used in this study.

Tag Type	Signal Type	Decodable Range	Audible Range
Lotek MAP	Radio	400 m	500 m
Lotek MAP	Acoustic	900 m	1000 m
Lotek CART16_1	Radio	400 m	500 m
Lotek CART16_1	Acoustic	900 m	1000 m
Vemco V13	Acoustic	1000 m	1200 m

Throughout the tracking period in 2012, the detection ranges were continually reassessed to ensure that our 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.

Based on the detection rates of the Lotek MAP tags and the Vemco V13 tags 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 a maximum of 500 m intervals, 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 receivers were recording all coded signals. We chose a duration of 170 seconds per stop since the maximum delay between pings from the Vemco acoustic tags was set to 160 seconds. Detections were saved on the receivers and also recorded manually. Following the 170 seconds listening period, the hydrophones were raised out of the water, the boat was advanced 1.5 km (or appropriate distance to maintain line of sight between stops) 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. In general, we followed the shoreline at a distance of approximately 500 m in the Arrow Lake area.

During the period February 17 to March 8, 2012, two tracking surveys were conducted covering various areas in the Arrow Lakes Reservoir. The primary goal of the tracking surveys was to identify spawning areas. During the surveys, low temperatures prevailed (water temperature range 2.0 to 3.3 °C) and extensive, thick ice-cover existed in the northeast end of Beaton Arm making it impossible to track in this area. The first survey (February 17-20) provided overall coverage of the locations of tagged-Burbot from the vicinity of Revelstoke to Burton (in Lower Arrow Lake). For the second survey (March 3-8), tracking efforts were concentrated in the Shelter Bay / Beaton Arm area, and near McDonald Creek (in the Shelter Bay / Narrows area).

2.9 SPAWNING-RELATED INVESTIGATIONS

During both mobile tracking surveys a limited number of Burbot were captured from Burbot aggregations in the Beaton Arm and McDonald Creek vicinity, and sampled to assess gonad maturity. Baited traps (usually 1-3) were set overnight in each of the two areas at various depths (7-30 m) and emptied the following morning. In the Beaton area, traps were set on February 19 and March 5, 8 and 11-12. In the McDonald Creek area, traps were set on March 7 and 10.

Maturation of each fish was first examined externally. Of the fish that appeared to be in a more advanced state of maturation, a small subsample was selected and sacrificed (held in a lethal dose of anaesthetic) for detailed gonad assessment (eggs still in ovarian sheath, ripe, spawned-out, etc.) and egg-staging analysis; the remaining fish were released. For egg-staging, 3-5 ova were placed in a Petri dish and examined with the aid of a dissecting microscope onboard to determine development stage as per criteria developed by the Kootenai River Hatchery staff.

In addition to biosampling, underwater video cameras connected to monitors onboard were used to observe Burbot within the aggregation areas in Beaton Arm and McDonald Creek vicinity. We searched for Burbot at various depths and near the bottom along various transects during the day and after dusk. Two cameras were tested: the first was a Sony with 20 m cable, which proved unsuitable as the cable was too short for the depths commonly occupied by Burbot in these areas. The other, a more sophisticated model (Ocean Systems, Deep Blue Pro Package with 60 m cable and recording capability) was appropriate for deep water observations, although visibility at these depths was limited by the built-in camera lighting.

2.10 DATA PROCESSING

Data from fixed stations were downloaded throughout the year at regular intervals. 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.

2.11 Determining the Fate of Tagged Fish

One fish is known to have been taken by an angler who returned the transmitter to the LGL office in Sidney, along with the recapture date and location. There are three tagged fish that have never been detected during this study, either by mobile tracking or by the fixed-station receivers. 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 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 speed of the vessel used for tracking, the frequency of the tag's signal transmission, the position of the vessel relative to the riverbanks, etc.) and a tag can appear to "move" from survey to survey even if it is motionless on the riverbed. It is therefore necessary to determine the minimum movement threshold below which any observed "movements" might be spurious. We have not done an exhaustive assessment for this Year 4 Report, but a more thorough examination will be completed for the final Year 5 Report.

2.12 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 15th day of each month. If a fish was detected at a fixed station receiver on the 15th day, the fish was 'assigned' to the coordinate position of that fixed-station receiver. If a fish was not detected on the 15th 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).

2.13 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 for releases at Revelstoke Dam from January 1, 2008 to April 30, 2012. 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 October 29, 2011. These 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' or '2011-2012'. 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. Control data will be sought before temperature effects are further investigated.

3 RESULTS

3.1 TRAPPING EFFORT, CATCH AND PHYSICAL DATA

From October 12 to 26, 2011 a total of 125 traps were fished with 21-29 sets deployed in each of the five zones (see Table 1). Soak times ranged from 1.9 to 3.0 days (median = 2.0 days) and total catch was 169 Burbot. Catch rates varied among zones (Figure 5), but the differences were not statistically significant (Dev = 6.5, df = 4, P = 0.16). Median CPUE (Burbot per trap per day) for zones 100 through 500 were: 0.53, 0.53, 0.51, 0.48, and 0.48. Despite this, there was a weak but statistically significant negative relationship between distance from Revelstoke Dam and CPUE (Figure 5; Dev = 4.83, df = 1, P = 0.028).

CPUEs in the northernmost zone (zone 100) were 4 times higher than they were in Year 3 and twice as high as in Year 2. In contrast, CPUEs in the southernmost zone (Zone 500) were half those in Years 2 or 3.

CPUE did not vary significantly with depth category (Figure 6; median = 0.49 in sets < 10 m; 0.51 in sets ≥ 10 m deep; Dev = 0.43, df = 1, P = 0.51). Similarly, the relationship between set depth (as a continuous variable) and CPUE was not statistically significant (Figure 6; Dev = 0.012, df = 1, $P = 0.91$).

During the Burbot trapping period, water temperature ranged from 8.7 to 10.8 °C (Appendix Table A1). Temperature had a statistically significant negative relationship with CPUE (Dev = 7.4, df = 1, $P = 0.0066$). As temperature decreased, CPUE increased; although predictive power was weak ($r^2 = 0.049$).

3.2 BIOSAMPLING

A total of 167 Burbot were biosampled from October 14 to 27, 2011. Of these, 140 were sexually mature and 15 were of an unknown maturity state (and 2 escaped before maturity could be assessed). Mature Burbot ranged widely in length (425 to 1000 mm TL) and weight (590 to 6205 g).

The length-weight relationships did not differ statistically between tagged and untagged Burbot (ANCOVA interaction term: $F_{1,159} = 0.4$, $P = 0.51$). The overall Burbot length-weight relationship (n= 163, $R^2 = 0.93$, $F_{1,161} = 2060.1$, $P < 0.0001$; Figure 7) had a slope of 2.65 (95% CI: from 2.54 to 2.77) and an intercept of −4.24 (95% CI: from −4.56 to −3.29). These coefficients were significantly different from the regression built by Fisher et al. (1996) for 79 Burbot populations in North America.

The median of the distribution of relative weights was 87.8 (Figure 8). Had the weight-at-length values for Arrow Lakes Burbot matched those predicted from the 75th percentile standard weight equation (Fisher et al. 1996), the median value would have been 100. The observed departure from 100 indicates that, on average, relative other North American populations, the Arrow Lakes fish were ‘underweight’. This result is not surprising given that Fisher et al. (1996) demonstrated lower relative weights (80±5) for reservoir-dwelling Burbot populations.

The relationship between relative weight and total length (Figure 9) showed a relatively consistent pattern across lengths. Had departures from the ‘standard’ been associated with differences in gonad development, then the largest departures would have been expected in the largest length categories.

The size of Burbot did not vary significantly among zones (Figure 10; $F_{4,159} = 2.3$, $P = 0.06$). Median Burbot total lengths for zones 100 to 500 were 62.5, 61.5, 56.5, 65.1, and 63.2 cm. Nevertheless, there was a statistically significant positive relationship between Burbot total length and distance from Revelstoke Dam (Figure 10; $F_{1,162} = 4.7$, $P = 0.03$), but it had poor explanatory power ($r^2 = 0.03$). Results were similar regardless of whether length, weight or girth was analyzed.

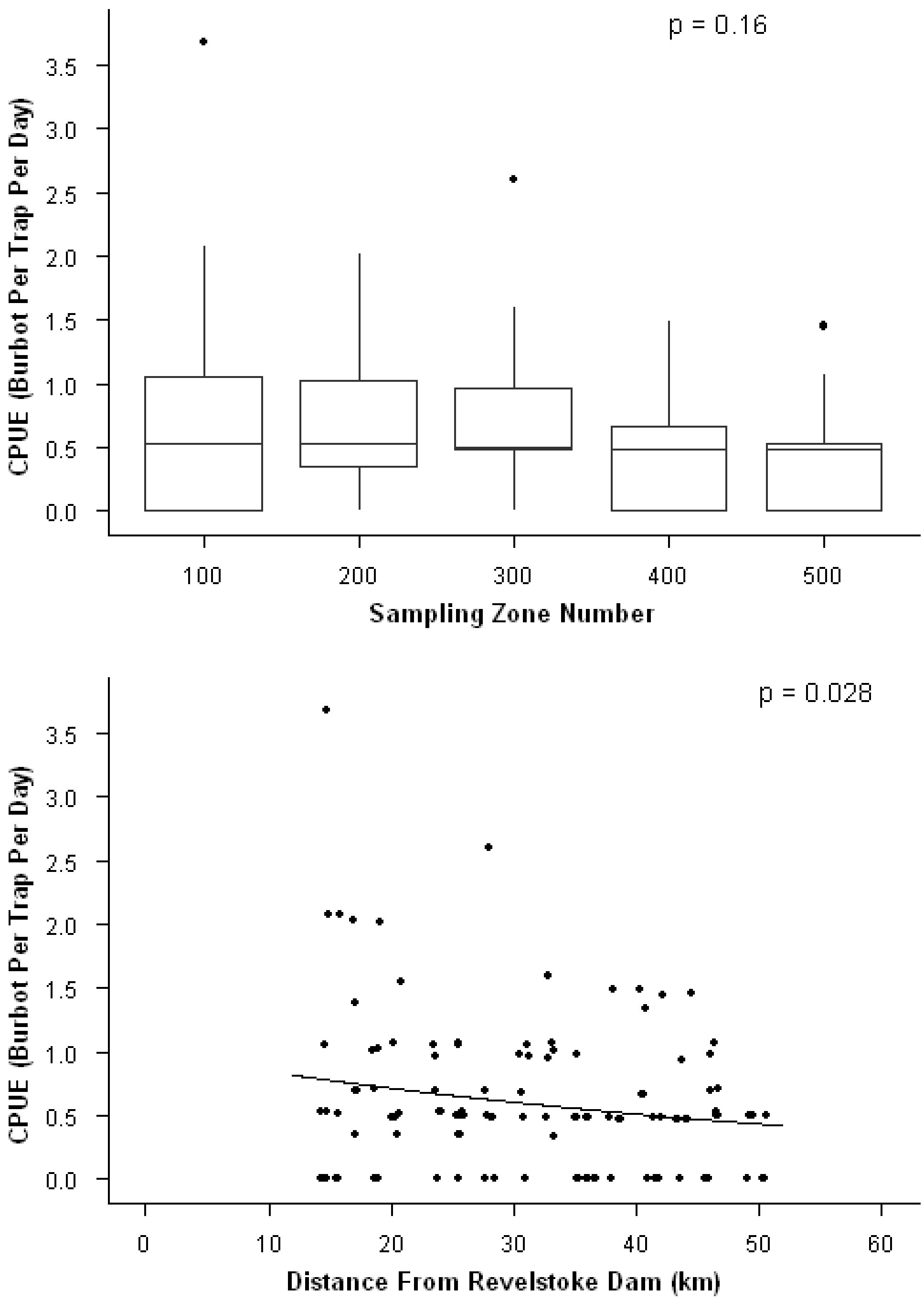

Figure 5. **Effect of sampling location (shown categorically as zone number in upper panel, and as a continuous variable, distance from Revelstoke Dam, in the lower panel) on Burbot catch per unit effort, October 12-26, 2011. Upper panel: boxes enclose the 25th and 75th percentiles, with horizontal lines drawn through the medians, bars extend to 1.5 × the interquartile range, and observations outside of this range are plotted with dots, n = 25 for all zones except n= 21 for Zone 400, and n = 29 for Zone 500.**

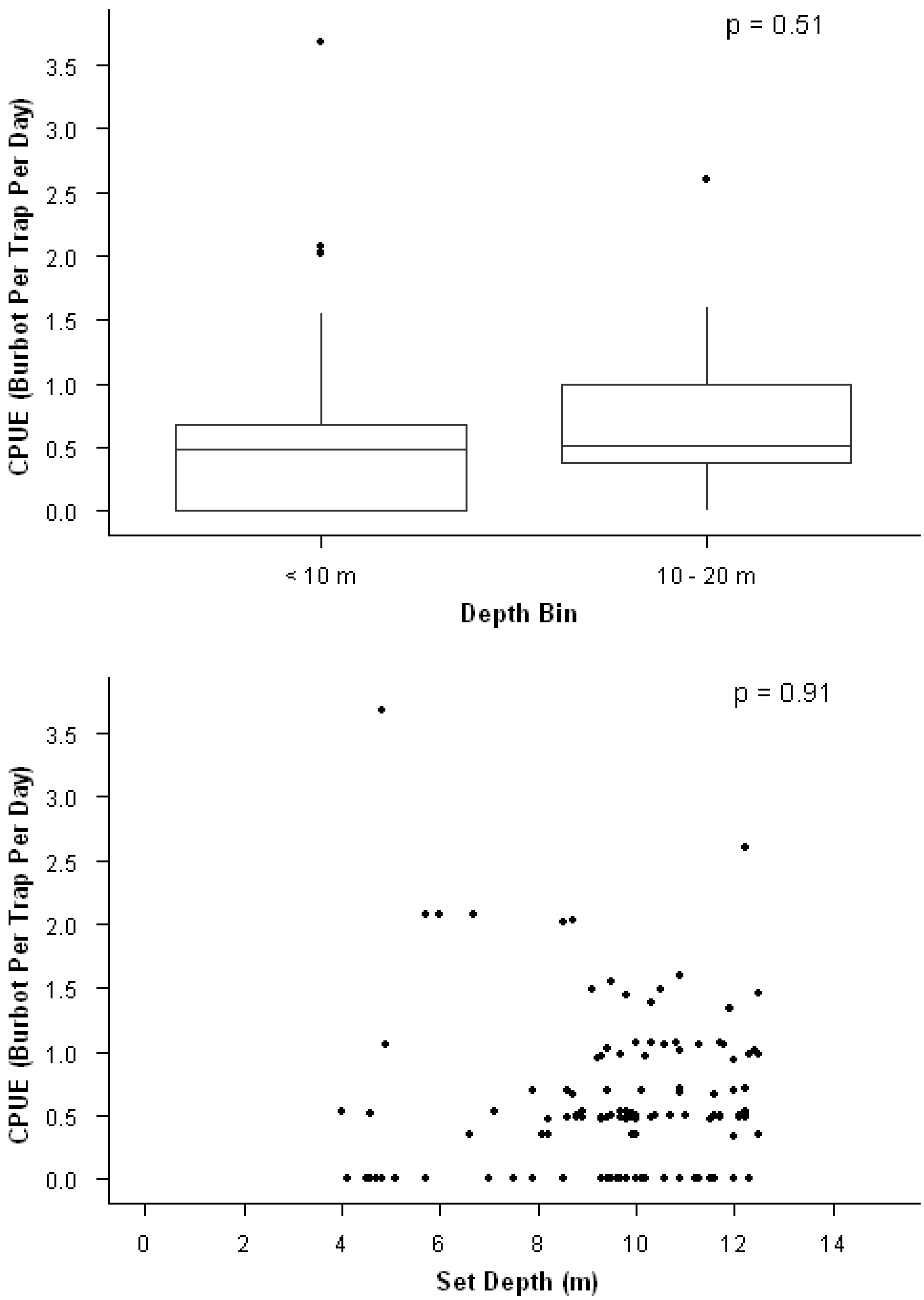

Figure 6. **Effect of set depth (shown categorically in upper panel, and as a continuous variable in the lower panel) on Burbot catch per unit effort, October 12-26, 2011. Upper panel: boxes enclose the 25th and 75th percentiles, with horizontal lines drawn through the medians, bars extend to 1.5 × the interquartile range, and observations outside of this range are plotted with dots, n = 67 for shallow bin, and 58 for deeper bin.**

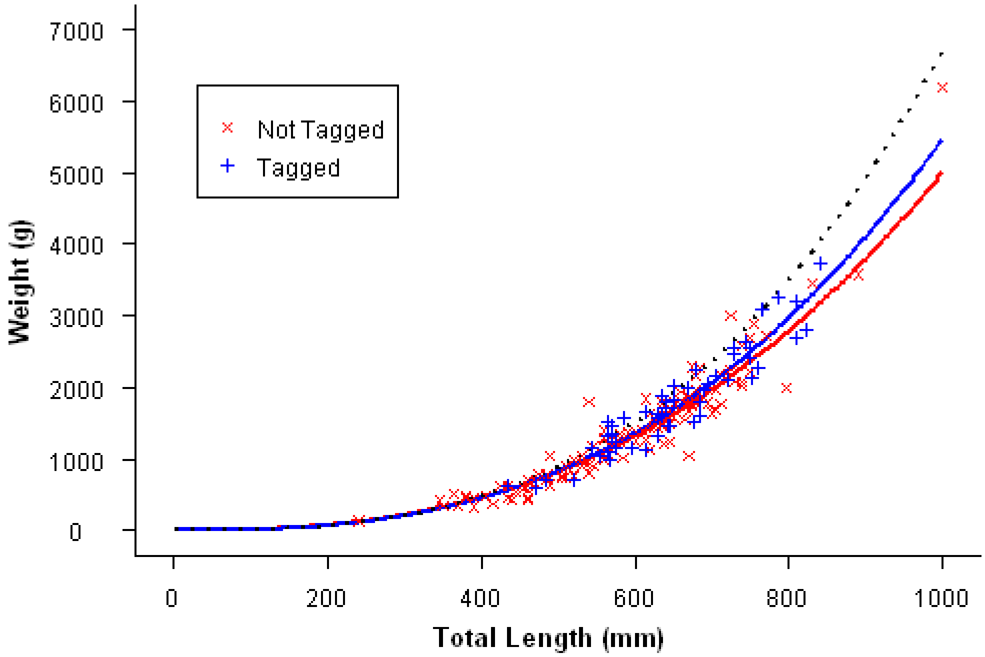

Figure 7. **Length-weight relationship for Burbot in Arrow Lakes Reservoir, October 12-26, 2011. Regressions: tagged $\log_{10}Wt = -4.43 + 2.72 \log_{10}TL$; untagged $\log_{10}Wt = -4.13 + 2.61 \log_{10}TL$; all $\log_{10}Wt = -4.23 + 2.65 \log_{10}TL$. The relationship reported in Fisher et al. (1996) is shown as a black dotted line.**

The size of Burbot did not vary significantly with the depth of the trap set (Figure 11). The regression ($F_{1,162} = 1.2$, $P = 0.28$) had negligible explanatory power ($r^2 = 0.007$). The lack of apparent effect was also observed in the analysis using categorical depth bins ($F_{1,162} = 1.0$, $P = 0.31$). Again, results were similar regardless of whether length, weight or girth was analyzed.

3.3 Fish Tagging

Fifty Burbot were tagged with Vemco acoustic transmitters in 2011 (Table 3, Figure 3). Tagged fish ranged in length from 43.5 to 84 cm (total length), and weighed from 600 to 3720 g. In each of the five zones fished, 10 Burbot were captured, tagged and released. The release locations of the 2010 Vemco-tagged Burbot, and the 2009 Vemco-tagged and Lotek MAP-tagged fish are provided in Robichaud et al. (2011), and Glova et al. (2010), respectively.

Average durations of the surgical procedures were as follows. Burbot were placed in an anaesthetic solution of clove oil for between 1.9 and 4.9 min (average 3.2 min). The total time that Burbot were exposed to anaesthetic (including both the pre-surgery and surgery times) ranged from 3.8 to 7.5 min (average 5.0 min). After surgery was complete, the tagged Burbot were returned to the trap in the lake, and the total time that they were out of the lake ranged from 4.3 to 7.7 min (average 5.6 min).

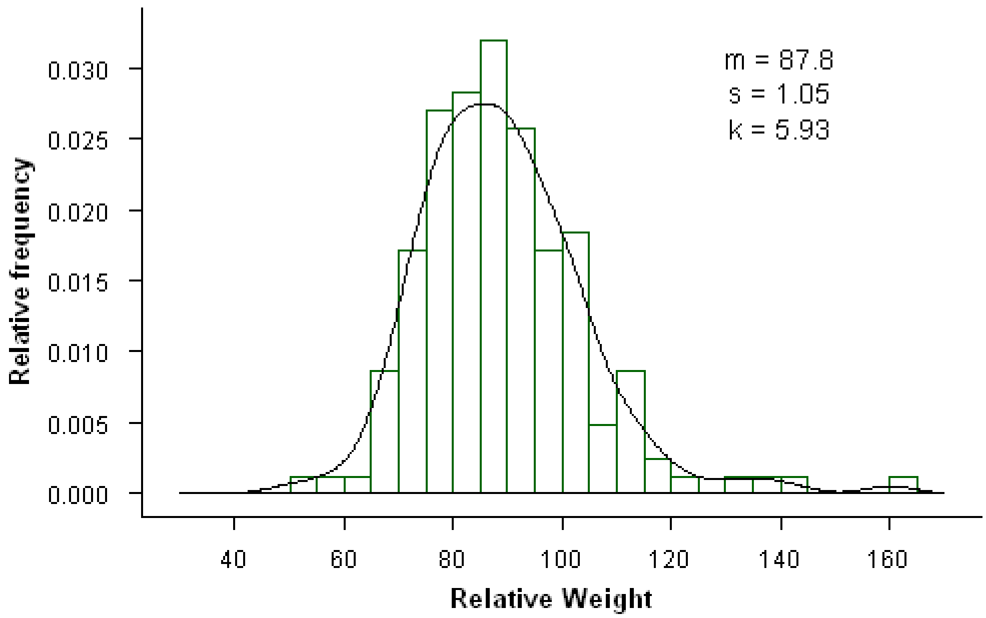

Figure 8. **Frequency histogram of relative weight values for Burbot in Arrow Lakes Reservoir, October 12-26, 2011. Median (m), skewness (s) and kurtosis (k) as shown. Expected values should cluster around 100.**

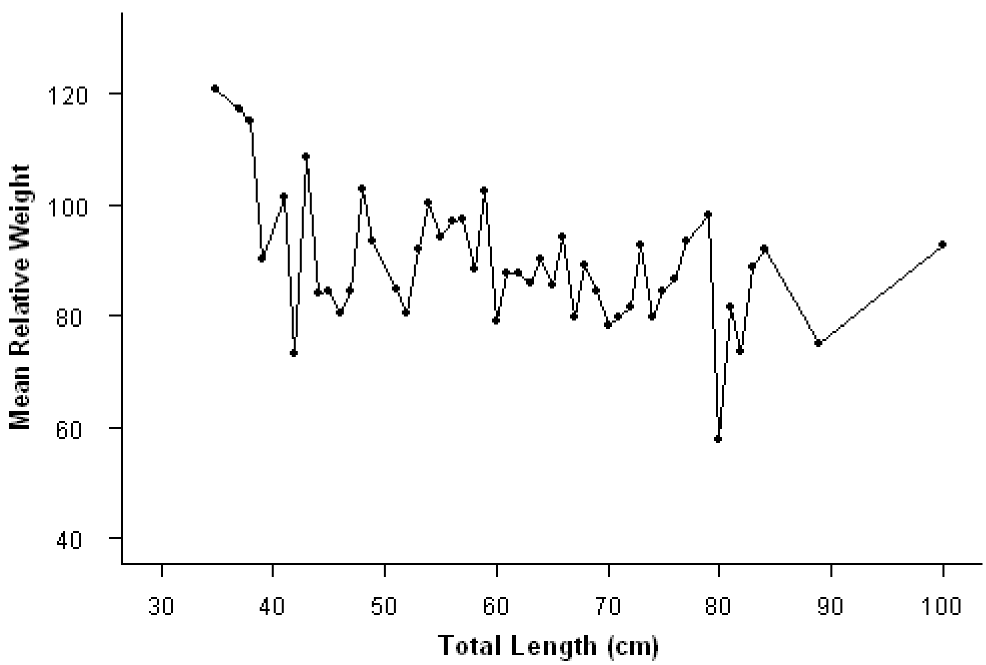

Figure 9. **Relationship of mean relative weight to total length in 1 cm length classes for Burbot in Arrow Lakes Reservoir, October 12-26, 2011.**

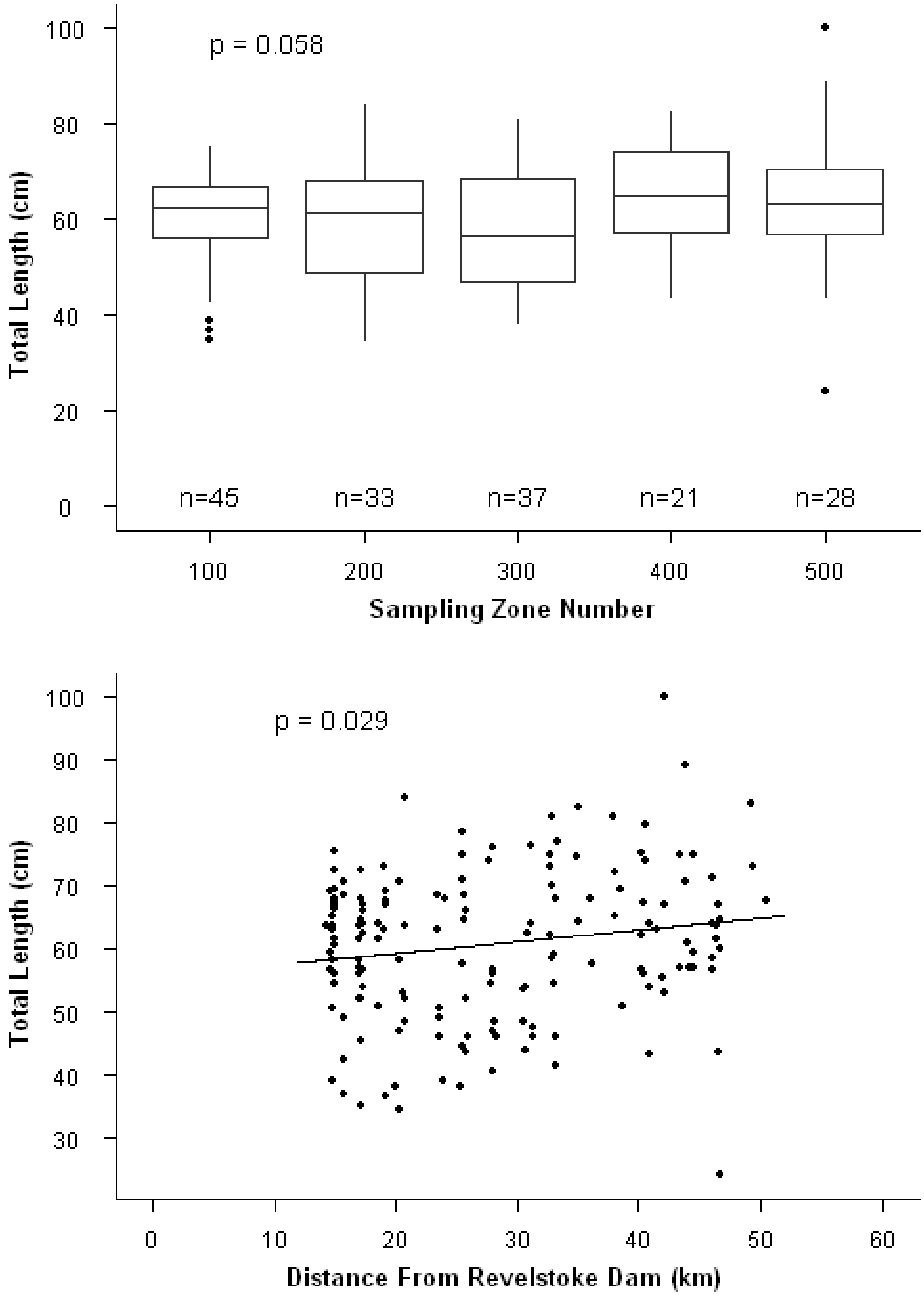

Figure 10. **Effect of sampling location (shown categorically as zone number in upper panel, and as a continuous variable, distance from Revelstoke Dam, in the lower panel) on Burbot total length, October 12-26, 2011. Upper panel: boxes enclose the 25th and 75th percentiles, with horizontal lines drawn through the medians, bars extend to 1.5 × the interquartile range, and observations outside of this range are plotted with dots.**

3.4 TRACKING RESULTS

From May 2011 to May 2012, 123 tagged Burbot were detected. Including all the detections (mobile and fixed-station) in 2012, 4 of the 20 (20%) Lotek MAP tags deployed in 2009 were detected, along with 31 of the 50 (62%) Vemco tags deployed in 2009, 39 of the 50 (78%) Vemco tags deployed in 2010, and 49 of the 50 (98%) Vemco tags deployed in 2011.

3.4.1 Details of Mobile Tracks

The detections of Burbot for each of the two mobile surveys are shown on the two maps in Figure 12, Figure 13, and in Appendix B. Each map includes the survey tracks by date, the total number of fish detected for each tag type, and tag identification numbers for each of the detections. The tag identification numbers for the Lotek MAP tags deployed in 2009 ranged from 111 to 130. The tag identification numbers for the Vemco tags deployed in 2009 ranged from 721 to 770, those deployed in 2010 ranged from 597 to 646, and those deployed in 2011 ranged from 311 to 360.

Overview – Maps 1-2

During the mobile tracks conducted in February and March 2012, 86 tagged Burbot were detected. Four of the 20 (20%) Lotek MAP tags deployed in 2009 were detected. Of the 50 Vemco tags deployed in each of 2009, 2010, and 2011, 34%, 52% and 78% were detected, respectively.

Map 1 (February 17-20, 2012; water temperature 2.0 to 3.3°C)

This four-day survey 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 2012 tracking season. Note that the southern tracking limit in Year 4 was chosen to be at Burton because no fish were detected between Burton and Needles in the previous two years of tracking. In total, 46 tagged Burbot were detected (Table 4). Burbot were mainly distributed in the Beaton Arm / Shelter Bay area, which contained 74% (34 fish) of the total detections. Only a single fish was detected in the Drimmie-Arrowhead Reach. The remaining detections were widely scattered: five fish (11% of the total) in the extensive reach between Shelter Bay and Nakusp, four fish (9%) from Nakusp to The Narrows, and two fish (4%) in The Narrows (Table 4).

Map 2 (March 3-8, 2012; water temperature 2.2 to 3.1°C)

During this five-day survey, tracking was conducted in the Beaton Arm / Shelter Bay area and in the Saddle Bay / McDonald Creek area. In total, 75 tagged Burbot were detected (Table 4). The distribution of detections was similar to that of the February survey (see Map 1), with the bulk of the detections in the Beaton Arm / Shelter Bay area (66 fish, 88% of the total). The remaining detections (9 fish, 12%) were in the Saddle Bay /McDonald Creek area, with all but one fish aggregated in the McDonald Creek vicinity. No surveying effort was spent in the extensive reach between Shelter Bay and Nakusp.

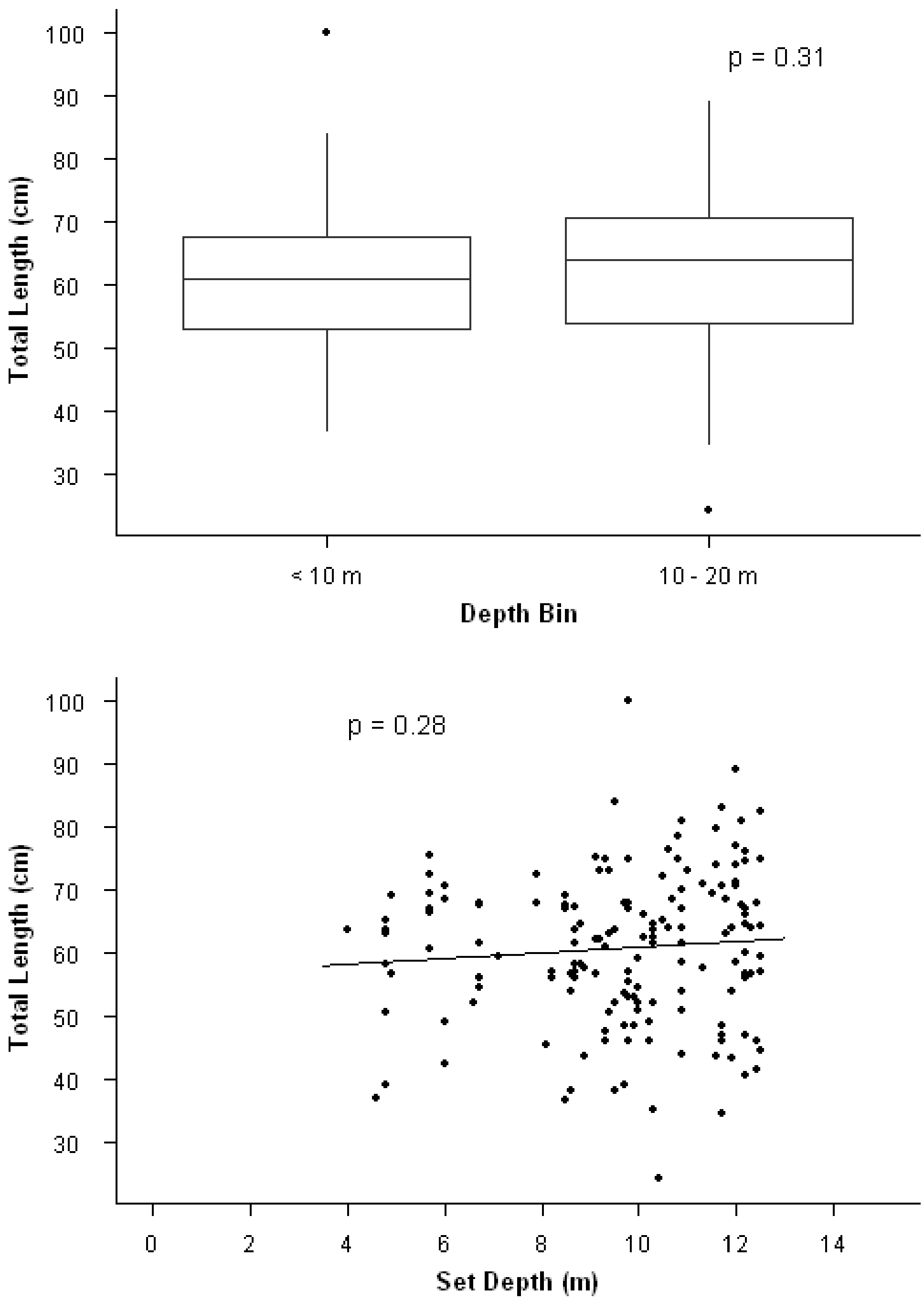

Figure 11. **Effect of set depth (shown categorically in upper panel, and as a continuous variable in the lower panel) on Burbot total length, October 12-26, 2011. Upper panel: boxes enclose the 25th and 75th percentiles, with horizontal lines drawn through the medians, bars extend to 1.5 × the interquartile range, and observations outside of this range are plotted with dots, n = 81 for shallow bin, and 83 for deeper bin.**

Table 3. Biometric and release data for 50 Burbot surgically implanted with Vemco acoustic transmitters in Arrow Lakes Reservoir, 2011. See Figure 2 for boundaries of each zone.

Tag	Vemco		Weight		Release	
Number	Tag ID	TL (cm)	(kg)	Maturity	Date	Zone Number
313	58313	43.5	0.62	Mature	15 Oct	500
314	58314	56.5	1.52	Mature	15 Oct	500
315	58315	64.0	1.73	Mature	15 Oct	500
316	58316	75.0	2.42	Mature	15 Oct	500
317	58317	59.5	1.15	Mature	15 Oct	500
318	58318	57.0	1.37	Mature	15 Oct	500
319	58319	63.0	1.33	Mature	15 Oct	500
320	58320	55.5	1.06	Mature	15 Oct	500
311	58311	67.0	1.99	Mature	18 Oct	500
312	58312	61.5	1.14	Mature	18 Oct	500
321	58321	75.1	2.13	Mature	18 Oct	400
322	58322	56.7	1.01	Mature	18 Oct	400
323	58323	72.0	2.11	Mature	18 Oct	400
324	58324	65.0	2.02	Mature	18 Oct	400
325	58325	81.0	2.70	Mature	18 Oct	400
326	58326	57.5	1.23	Mature	18 Oct	400
328	58328	64.3	1.47	Mature	18 Oct	400
330	58330	69.5	2.07	Mature	18 Oct	400
327	58327	82.3	2.81	Mature	18 Oct	400
329	58329	74.5	2.64	Mature	18 Oct	400
331	58331	54.5	1.16	Mature	21 Oct	300
332	58332	81.0	3.22	Mature	21 Oct	300
333	58333	58.5	1.57	Mature	21 Oct	300
334	58334	76.5	3.09	Mature	21 Oct	300
335	58335	64.0	1.79	Mature	21 Oct	300
336	58336	76.0	2.28	Mature	21 Oct	300
337	58337	56.5	1.34	Mature	21 Oct	300
338	58338	47.0	0.60	Mature	21 Oct	300
339	58339	64.5	1.47	Mature	21 Oct	300
340	58340	68.5	1.61	Mature	21 Oct	300

…continued

Table 3 continued.

Tag Number	Vemco Tag ID	TL (cm)	Weight (kg)	Maturity	Release Date	Release Zone Number
341	58341	75.0	2.56	Mature	24 Oct	200
342	58342	78.5	3.26	Mature	24 Oct	200
343	58343	57.5	1.16	Mature	24 Oct	200
344	58344	68.0	2.24	Mature	24 Oct	200
345	58345	63.0	1.63	Mature	24 Oct	200
346	58346	84.0	3.72	Mature	24 Oct	200
347	58347	52.0	0.72	Mature	24 Oct	200
348	58348	48.5	0.72	Mature	24 Oct	200
349	58349	73.0	2.56	Mature	24 Oct	200
350	58350	63.0	1.58	Mature	24 Oct	200
351	58351	59.5	1.17	Mature	27 Oct	100
352	58352	63.5	1.88	Mature	27 Oct	100
353	58353	69.0	1.97	Mature	27 Oct	100
354	58354	56.5	1.11	Mature	27 Oct	100
355	58355	65.0	1.83	Mature	27 Oct	100
356	58356	63.5	1.60	Mature	27 Oct	100
357	58357	68.5	1.81	Mature	27 Oct	100
358	58358	70.5	2.16	Mature	27 Oct	100
359	58359	61.5	1.65	Mature	27 Oct	100
360	58360	57.0	1.48	Mature	27 Oct	100

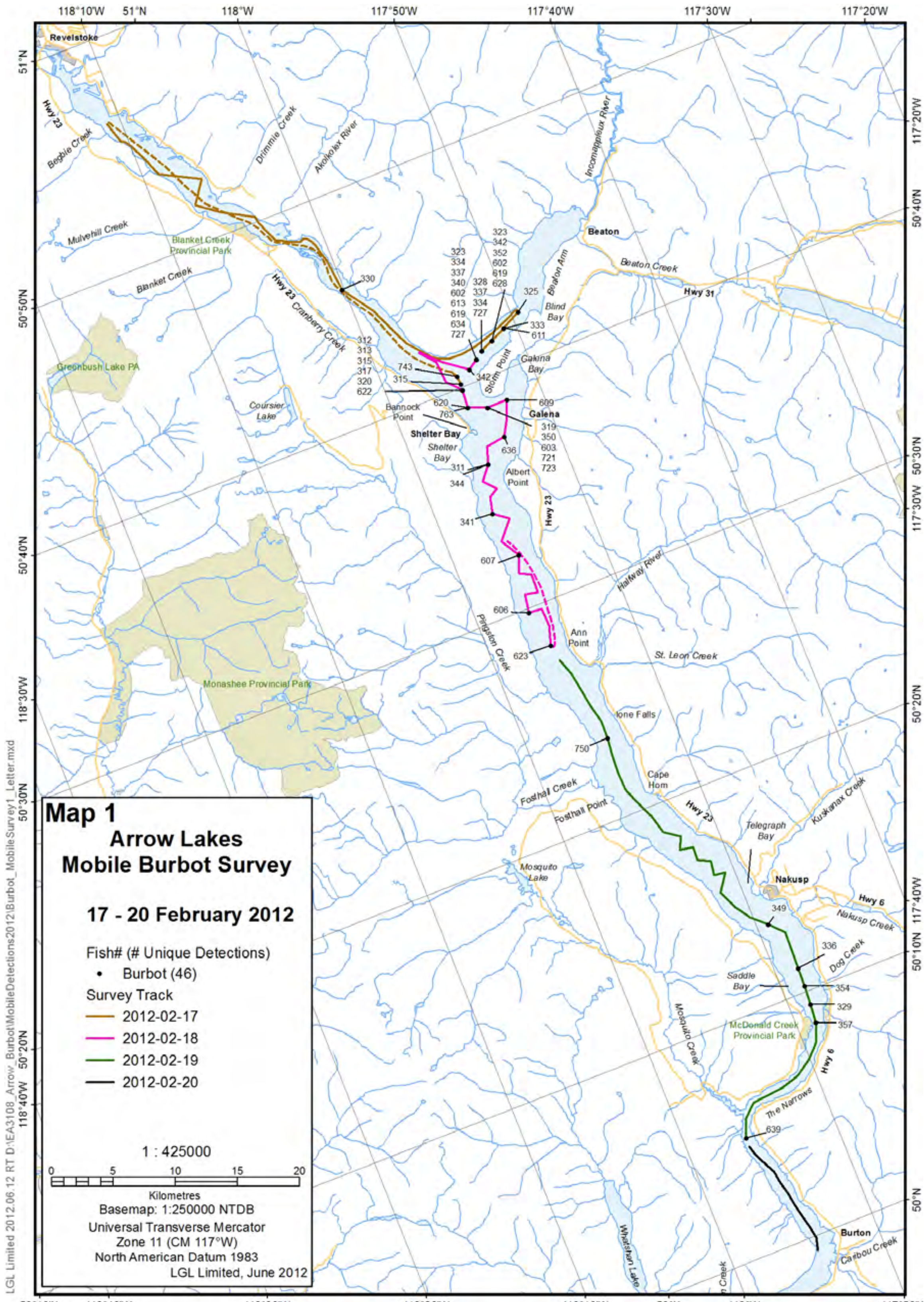

Figure 12. Survey track and tags detected for survey conducted 17-20 February 2012.

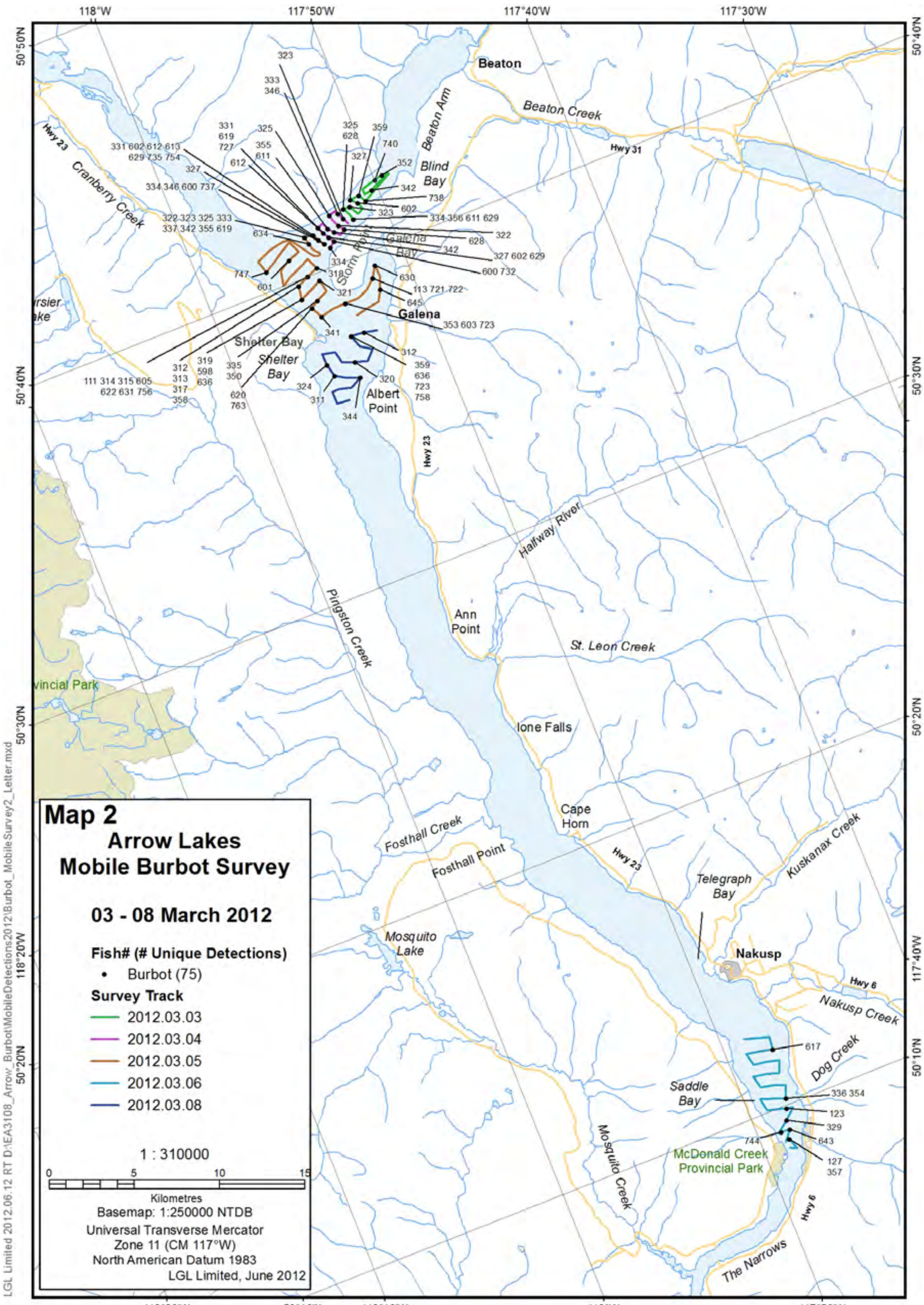

Figure 13. **Survey track and tags detected for survey conducted 3-8 March 2012.**

Table 4. **The number of tags detected (and percent of total) by location for the two mobile tracking surveys in 2012. 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	17-20 February	3-8 March
Revelstoke – Drimmie Creek (Zones 1-200)	0 (0%)	na
Drimmie-Arrowhead Reach (Zones 300-400)	1 (2%)	na
Beaton Arm area (Zones 500,550 and 600)	25 (54%)	51.5 (69%)
Shelter Bay area (upper part of Zone 700)	9 (20%)	14.5 (19%)
Shelter Bay to Nakusp (middle part of Zone 700)	5 (11%)	na
Nakusp to The Narrows (lower part of Zone 700)	4 (9%)	9 (12%)
The Narrows (Zones 800 and 808)	2 (4%)	na
Total detections	46	75

* Four tags were detected in two distinct zones within a survey period (e.g., Tag 359 was detected in zone 600 on Mar 3 and in zone 700 on Mar 8). For the above table, these fish are counted 0.5 times in each zone.

3.4.2 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; in Year 4, Salmon Rocks was the northernmost receiver). In all years of tracking, the proportion of tagged Burbot that were located between rkm 212 and Salmon Rocks was relatively constant over time (Figure 14), mainly ranging from 6-9% during each month, with a few months of lower proportional abundance (November 2010 (3%), May 2011 (4%), and all months since November 2011 (0-4%)).

In contrast, there appeared to be distinct seasonal movements among the areas downstream of rkm 212. In late fall 2010, a large proportion of the tagged Burbot moved out of the area between rkm 184 and 212, and the proportion did not start to increase substantively until the following spring/summer (June 2011). The same pattern was evident for 2011, with fish departing the more northerly areas in late fall (Sept –Oct 2011). Data collected from the fixed receivers later in 2012 (September-October) will reveal the timing of return movements, if they occur.

The proportion of fish found in the vicinity of the Beaton receivers did not drop below 59% of total detections at any point in any year, but has increased substantially in all three winters of study. In the wintertime, relative abundances reached 78%, 85%, and 80% in the first, second and third winter, respectively (Figure 14).

The proportion of fish that ‘overwintered’ in the Beaton area was not consistent between years: a larger proportion of the tagged fish were south of rkm 184 in the winter of 2010/2011 than in 2009/2010. For example, in 2010, the proportion of relocated fish that were in the Beaton area in January, February, March and April was 72%, 73%, 74% and 76%, respectively; whereas the proportions for the same periods in 2011 were 83%, 82%, 85% and 85% (Figure 14). These differences (overall ~10%) were statistically significant (general linear model with binomial error, with post-hoc Tukey test, $P = 0.042$). Values from 2012 were not significantly different from those of the previous two years.

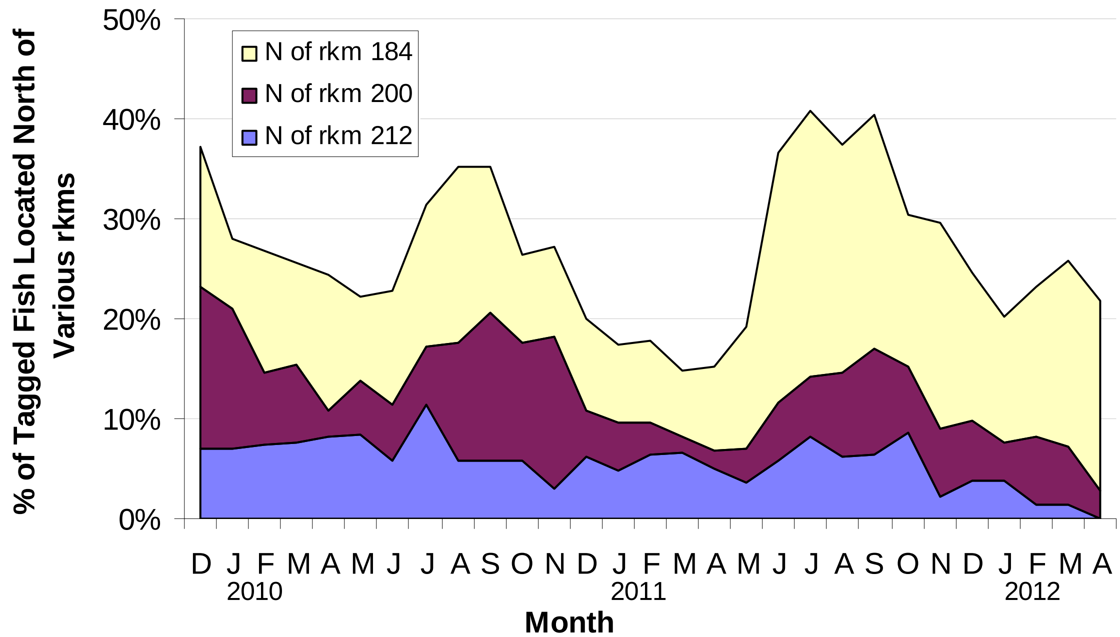

Figure 14. Percent of Vemco-tagged Burbot that were located north of rkm 184, 200 and 212, by month (December 2009 to April 2012). The white area represents Beaton Arm (up to rkm 184). The Revelstoke to Arrowhead reach is split into three areas, yellow representing the southernmost (rkm 184-200), purple 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 4 for locations of fixed-station receivers and rkms.

3.5 SPAWNING-RELATED INVESTIGATIONS

Each of the 10 females sampled in the Beaton Arm area during the February tracking survey had its eggs still firmly in the ovarian sheath (‘green’); no fish were sampled for spawning assessment in the Saddle Bay / McDonald Creek area during this survey.

During the March survey, Burbot were sampled on March 5 and 11-12 in the Beaton area and on March 7 in the Saddle Bay / McDonald Creek area. The state of their gonads (from biosampling and egg-staging) is briefly summarized in Table 5: 62% of the Burbot sampled were categorized as “ripe” or “spawned-out”, and 38% had gonads that were not developed (immature) or their gonadal state was unclear.

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 March 8 and 11, or in the McDonald Creek area on March 10. Of the few Burbot that were seen, each was alone and inactive, on or near the bottom.

Table 5. Maturity states of sampled Burbot in Arrow lakes, March 2012.

Sampling Date	Area	Sex	n	Spawned Out	Ripe	Green	Gonad State Unclear
5 Mar	Beaton	Female	8	1	2	5	-
5 Mar	Beaton	Male	8	-	-	-	8
11-12 Mar	Beaton	Female	11	2	9	-	-
11-12 Mar	Beaton	Male	1	-	1	-	-
7 Mar	McDonald	Female	2	1	1	-	-
7 Mar	McDonald	Male	4	-	4	-	-
Total			34	4	17	5	8

3.6 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 15). 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 16).

There was a general trend for increasing mean flows over time (Figure 17). 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). A two-way ANOVA that examined the effect of ‘winter’ and ‘period’ on flow rates had a statistically significant interaction term (Figure 17; $F_{3,597} = 3.1$, $P = 0.026$). The ‘after 10 Dec’ flows recorded during winters 2010-2011 and 2011-2012 (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 (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 time, the statistically significant differences did not align with the new Unit becoming operational: the ‘jump’ in flow rates occurred in late 2009.

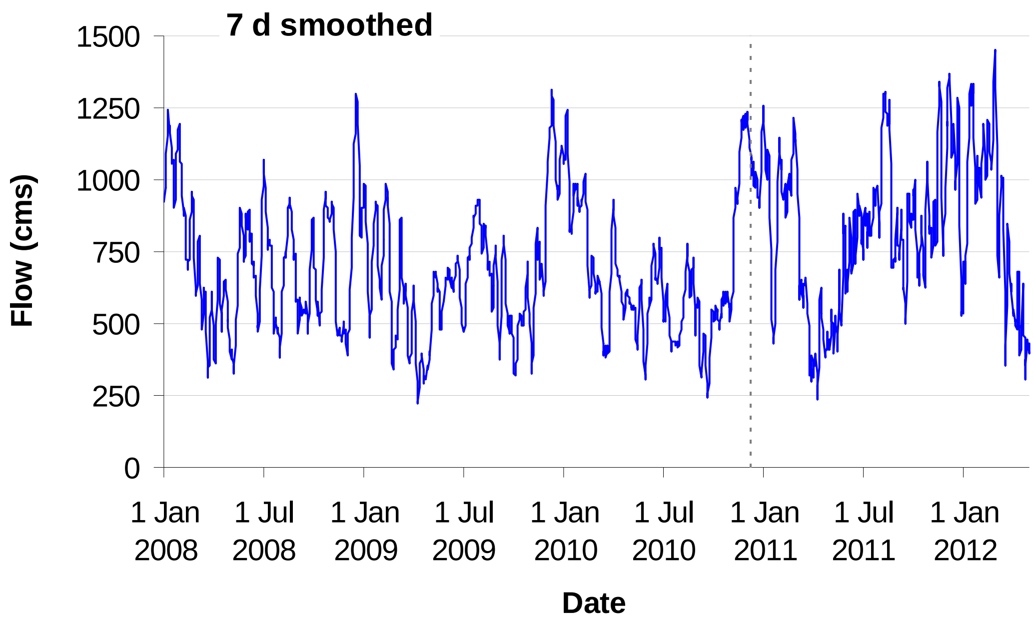

Figure 15. **7-day smoothed flow by date, January 2008 to April 2012. Dotted vertical line at Dec 10, 2010, shows the time at which Unit 5 became operational.**

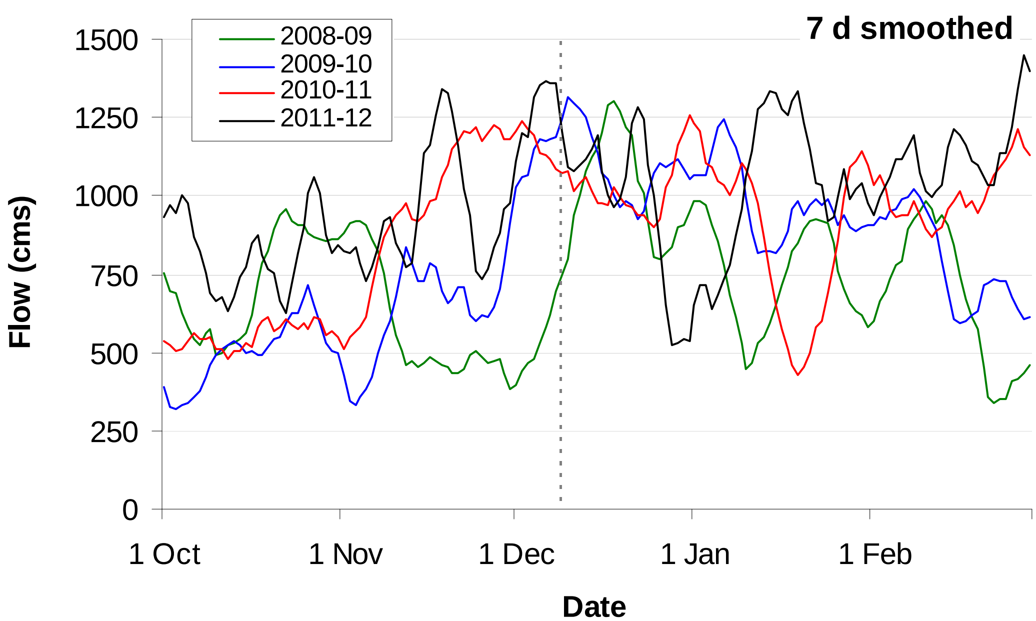

Figure 16. **7-day smoothed flows by date, October 1 to February 28 shown separately for each winter of data. Dotted vertical line at December 10 shows the time at which Unit 5 became operational in the 2010-2011 winter.**

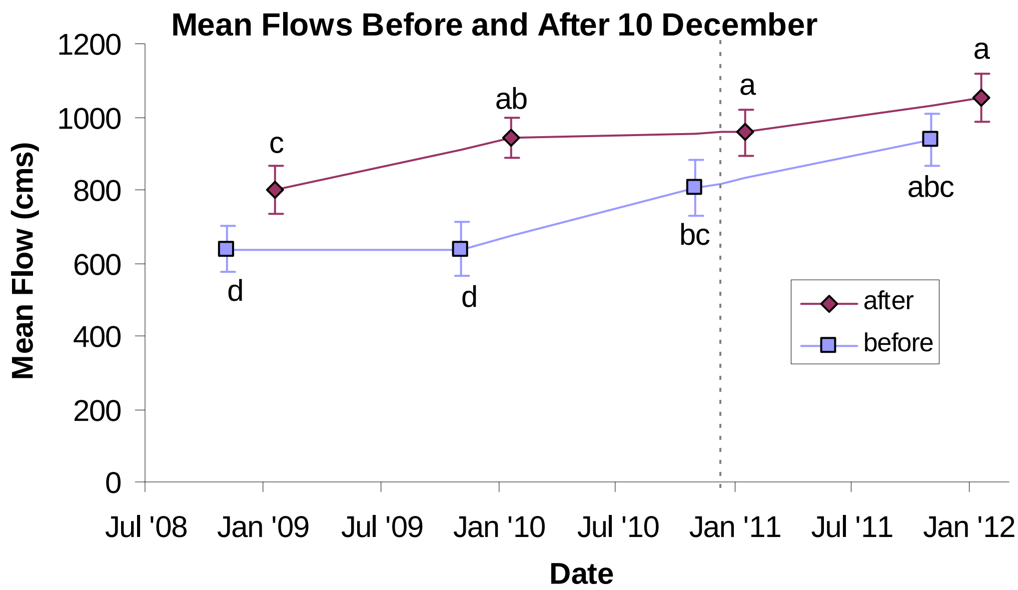

Figure 17. **Mean flow for four winters of data, each split into two time periods: 'before': Oct 1 to Dec 10; 'after': Dec 11 to Feb 28. Error bars show the 95% confidence intervals around the means. Levels not connected by the same letter are significantly different. Vertical dotted line at December 10, 2010 shows the time at which Unit 5 became operational in the 2010-2011 winter.**

3.7 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 18, Figure 19). In the year after Unit 5 came online, the lowest winter temperatures and the highest summer temperatures were both lower than those observed in any of the previous three years (Figure 18, Figure 19). Paired t-tests allowed comparisons between pairs of years, while controlling for seasonal variability. These showed that the 'before Unit 5' temperatures were significantly higher than those observed 'after Unit 5'. Specifically, the average temperatures in 2011 (7.6°C) were significantly colder than those in any of the other three years (2008: 7.8°C; 2009: 7.8°C; 2010: 8.4°C; *P*-values shown in Figure 20). 2010 was significantly warmer than any of the other three years, and there were no significant differences in temperatures between 2008 and 2009.

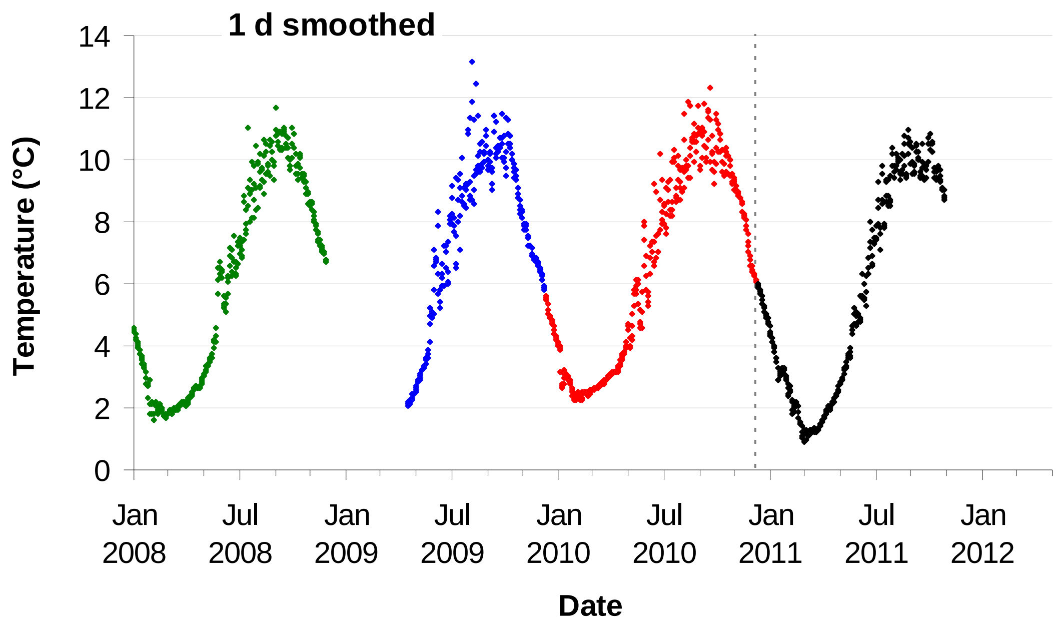

Figure 18. **Average water temperatures at 'Station 2' (below Revelstoke Dam) by date, January 2008 to October 2011. Dotted vertical line at 10 Dec 2010 shows the time at which Unit 5 became operational. Colours correspond to consecutive years, changing on 10 Dec of each year.**

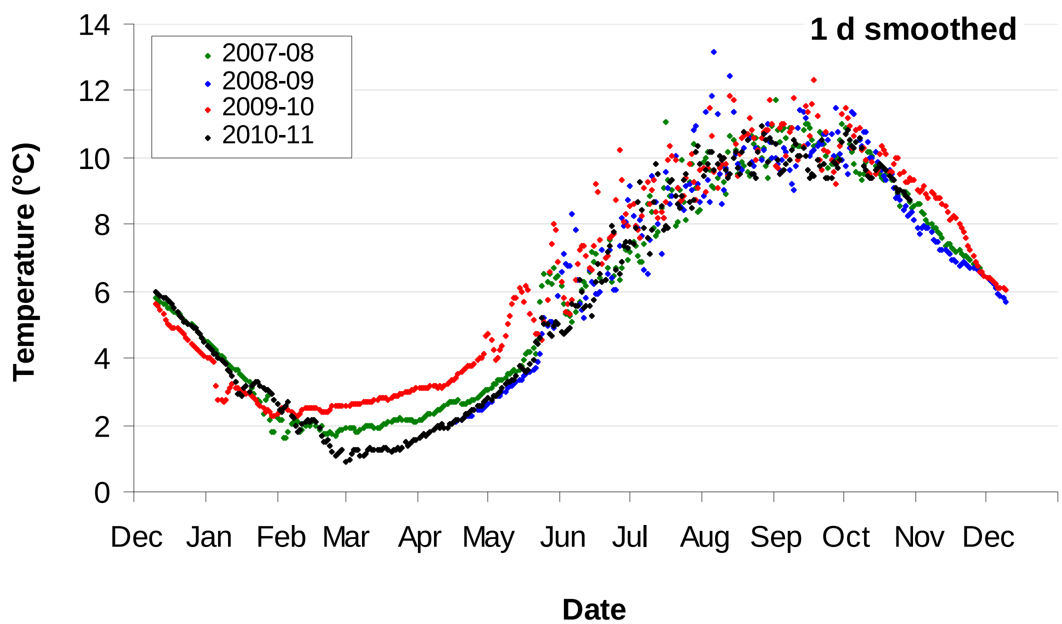

Figure 19. **Average water temperatures at 'Station 2' (below Revelstoke Dam) by date, shown in a different colour for each 365 day period (10 Dec through 9 Dec). Unit 5 became operational on 10 Dec, 2010. The green, blue and red dots predate Unit 5 activity, (2007-2008, 2008-2009, and 2009-2010, respectively) whereas Unit 5 was operational in 2010-2011 (black dots).**

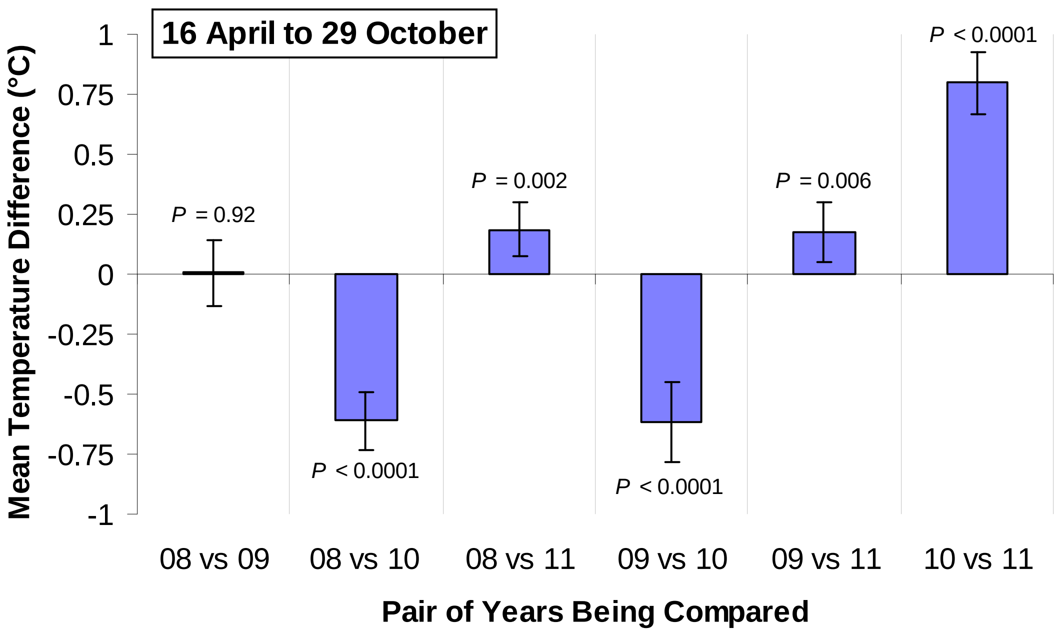

Figure 20. **Mean differences between paired daily temperature values, for comparisons of between all pairs of years. The period 16 April to 29 October was selected as data were available for all four years. Probability values for paired t-tests are shown by each bar.**

4 DISCUSSION

4.1 MANAGEMENT OBJECTIVES

BC Hydro wants to know whether flow fluctuations and dewatering and/or the addition of a fifth turbine unit at Revelstoke Dam affect Burbot spawning migrations or habitat. In order to begin providing answers, the spawning locations and spawning time of Burbot in the study area must 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 possible reason for these fish to be aggregated, it has not been possible to conclusively demonstrate that it is occurring. We have attempted in previous years (Glova et al. 2010) to use a submersible video camera to observe spawning behaviours and did observe several Burbot in daylight, with a few fish coming in close to investigate areas of disturbed sediment. Burbot appeared to be avoiding the camera lighting at night. During tracking in Year 4 (2012), to determine where and when Burbot spawn, Burbot were sampled from within and around these aggregations to assess gonad maturity and conduct egg-staging analysis. Of the fish that were assessed, 62% were in advanced stages of ripeness (or recently spawned), suggesting spawning likely occurs in these areas, with Beaton Arm being the primary area. Although spawning activity was not directly observed from underwater video observations in March, we have some indirect evidence (egg plume seen near bottom) to suggest that spawning in the Beaton area occurs near the bottom in relatively deep water (>20 m). Further underwater video investigations and maturity sampling will be pursued in Year 5 to confirm spawning activity. If it can be identified conclusively where and when spawning occurs, we will be in a position to assess whether they are in areas that could potentially be affected by winter drawdown and / or the addition of the fifth generating unit at Revelstoke Dam.

In this report we further assessed potential effects 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, 2012). 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. Since the addition of Unit 5 at Revelstoke Dam does not yet appear to be influencing flows, it may be unlikely for it to have an appreciable impact on Burbot spawning migration and habitat. This may change once precise spawning localities are confirmed, and longer-term post-Unit 5 discharge data are available.

4.2 Aggregation in the Beaton Area

The proportion of fish that congregated during winter in the Beaton area was not consistent between years: a larger proportion of the tagged fish were in the Beaton / Shelter Bay area in the winter of 2010/2011 than in 2009/2010 or 2011/2012 (though the latter difference was not statistically significant). Potential causes of this difference have not been 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 between years (spawning behaviour is known to be affected by temperature, McPhail and Paragamian 2000). However, we do not have the appropriate temperature data to address this hypothesis. We do not know whether a temperature differential existed between the Beaton area and the Arrowhead to Revelstoke Reach. We also do not know whether this differential was greater in 2010/11 than in the other winters.

The Burbot that congregate during winter in the Beaton / Shelter Bay area may be there to take advantage of feeding opportunities. The submersible video camera used in 2010 (Glova et al. 2010) showed that *Mysis* shrimp were present in high densities on the bottom in the area and likely are an 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 between winters. It should also be noted that it is unknown whether Burbot feeding and spawning areas in Arrow Lakes are mutually exclusive. To answer this question, we are recommending to carry out a stomach contents analysis of fish captured in spawning condition in the spring of 2013.

4.3 EFFECTS OF WATER DEPTH

CPUE, Burbot weight, length and girth did not vary significantly with depth. Although the effect of depth appeared minimal, it is important to note that the range of depths examined was limited. Traps were purposefully set in shallow water (4-12.5 m) to reduce the effects of barotrauma on the potential candidates for surgical tag-insertion. The true range of depths occupied by Burbot in Arrow Lakes is unknown, but since they are bottom feeders (Scott and Crossman 1973, McPhail 1997), they presumably occur at most depths.

4.4 EFFECTS OF DISTANCE FROM DAM

In this study, the distance from Revelstoke Dam, at least in the Revelstoke to Arrowhead reach, may act as a proxy for flow, depth, dewatering and temperature. Flows are strongest nearest to the dam, and depths there are shallowest. In shallow water, winter temperatures are likely to be lower and dewatering more likely.

For each of the previous three study years, there was a weak, but statistically significant positive correlation between distance from Revelstoke Dam and Burbot length, weight and girth: smaller, likely younger, fish were more often caught in the shallow areas closest to the dam. It is not uncommon for juveniles of deep-water gadid species to inhabit shallow waters, including Atlantic cod (*Gadus morhua*), Greenland cod (*G. ogac*), and pollock (*Pollachius virens*) to name a few (Rangeley and Kramer 1995, Methven and McGowan 1998). Juvenile cod may avoid larger, piscivorous adults by inhabiting the shallows (Linehan et al. 2001), and there is a distinct pattern of increasing depth with age of fish (Dalley and Anderson 1997). It is possible that similar ecological trends occur in Burbot. If so, then dam-related variation of flows and water-levels, which would be more pronounced near the dam, could have more influence on younger Burbot survival rates than on adult spawning behaviours.

The relationship between distance from Revelstoke Dam and CPUE varied among study years. In Year 4, there was a weakly negative, but statistically significant correlation. In Years 2 and 3, there was no significant correlation (Glova et al. 2010, Robichaud et al. 2011).

5 SUMMARY OF FINDINGS

The main findings from the study in Year 4 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. A large proportion of the tagged Burbot moved out of the river in late fall, and did not return until the following spring/summer.
2. The proportion of tagged Burbot in the vicinity of the Beaton receivers did not drop below 59% during any month of the study period, but increased substantially in each winter.

3. The relatively large numbers of Burbot detected in the Beaton Arm / Shelter Bay area (and to a lesser extent in McDonald Creek area) during the spawning period makes these areas the best candidates for potential spawning areas. Biosampling and egg-staging analysis of Burbot from these areas during the tracking period in 2012 indicated that 62% of all captured fish were ripe or spawned-out suggesting spawning likely occurs in these areas. Timing of spawning appears to be protracted, beginning in late Feb/early March, with fish actively spawning by the second week in March. We have no maturity data from late March, but, given the state of Burbot gonads in early March, it is likely that some spawning continues at least to end of the month.
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 either the previous or next year. Thus changes in flows appeared to be seasonal and not attributable to Unit 5. Longer-term post-operational data may reveal other trends related to the possible effects of Unit 5 on the magnitude of flows from Revelstoke Dam.

6 RECOMMENDATIONS FOR YEAR 5

To continue to further our understanding of Burbot movements and timing and location of the main spawning areas in the Arrow Lakes Reservoir (i.e., to answer the management questions and address the hypotheses of this study), it is recommended that in Year 5:

1. Continue tracking the ~100 tagged Burbot whose transmitters will continue to be functional during Year 5 (2012-2013), but to reduce costs, limit tracking to late February (as was done in Year 4) to determine fish distribution in the study area (Revelstoke-The Narrows); thereafter, track only in Beaton Arm at weekly intervals to locate where the fish are most concentrated to assist in determining timing and location of main spawning areas with the use of other sampling gear mentioned below.
2. Maintain the fixed-station array in the Revelstoke to Beaton Arm reach as it was in Year 4, but consider relocating any receivers in Beaton Arm that are too close to one another to more strategic locations to increase monitoring effectiveness of Burbot movements the during spawning period.
3. Sample Burbot with the use of baited traps and conduct underwater video observations within and around aggregations in the Beaton area from late February to mid March for further assessment of spawning-related activities (e.g., egg-staging analysis; gonad maturity, water depths occupied by fish, stomach contents analysis) to confirm if spawning occurs in this area as suggested from the findings in Years 3 and 4. The frequency of sampling will be weekly to facilitate detection of changes in rate of maturation and timing of spawning as best as possible.
4. Set and retrieve egg mats at regular intervals (~3 d) in areas of high Burbot concentrations in Beaton Arm during late February to mid March to sample

for Burbot eggs to help identify timing and location of Burbot spawning in the reservoir.

7 ACKNOWLEDGMENTS

We express our thanks and appreciation to BC Hydro for the fourth year of funding of this project, and to David DeRosa for his continued support, cooperation, and help in keeping the project running smoothly during all phases, until his departure from BC Hydro in March 2012. The review of the draft by Guy Martel was greatly appreciated.

We thank the following people for their contributions during Year 4 of this study: Bob Bocking and Elmar Plate for scientific advice and review of the draft report; Robin Tamasi for GIS mapping; Mark Thomas and Jim Clarricoates of CCRIFC for technical assistance with fish sampling and mobile tracking; Kate Hosey for assistance with field logistics and data collection, Marco Marello of Terraquatic Resource Management for downloading the fixed-station receivers owned by BC Hydro; and Cam Fitzpatrick for collecting kokanee carcasses for Burbot trapping. Also, thanks to James Crossman (BC Hydro, Castlegar) for use of the VR100 receiver and hydrophone during mobile tracking.

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APPENDICES

APPENDIX A: PHYSICAL CHARACTERISTICS OF TRAP SITES

Appendix Table A1. Select physical characteristics measured during each trap-site visit, by date. The delimitations of the zones can be seen in Figure 2.

Zone	Site	Date	Time	Bottom Temperature (°C)
500	4	12 Oct	13:07	9.9
500	3	12 Oct	13:15	10.0
500	2	12 Oct	13:23	10.1
500	1	12 Oct	13:29	10.8
500	4	14 Oct	13:43	9.4
500	3	14 Oct	14:36	9.4
500	2	14 Oct	14:50	9.6
500	1	14 Oct	15:04	9.8
400	8	15 Oct	12:48	9.0
400	7	15 Oct	12:55	9.1
400	6	15 Oct	13:01	9.1
400	5	15 Oct	13:11	9.2
500	9	15 Oct	13:43	9.4
400	8	17 Oct	14:27	9.0
400	7	17 Oct	14:40	9.0
400	6	17 Oct	14:50	9.2
400	5	17 Oct	15:12	9.2
500	9	17 Oct	15:33	9.1
500	9	18 Oct	10:00	9.2
400	5	18 Oct	11:25	9.1
300	10	18 Oct	14:50	9.4
300	11	18 Oct	14:44	9.5
300	12	18 Oct	14:39	9.5
300	13	18 Oct	14:33	9.5
300	13	20 Oct	13:59	9.2
300	12	20 Oct	14:42	9.2
300	11	20 Oct	15:12	9.3
300	10	20 Oct	15:41	9.4

…continued

Appendix Table A1 continued.

Zone	Site	Date	Time	Bottom Temperature (°C)
300	13	21 Oct	10:55	9.4
300	12	21 Oct	11:17	9.4
300	11	21 Oct	11:33	9.2
300	10	21 Oct	11:58	9.2
200	14	22 Oct	13:08	9.1
200	15	21 Oct	14:23	9.1
200	16	22 Oct	15:29	9.2
200	17	21 Oct	15:09	9.4
200	17	23 Oct	14:59	9.2
200	16	23 Oct	15:24	9.1
200	15	23 Oct	15:59	9.0
200	14	23 Oct	16:08	9.1
200	17	24 Oct	10:05	8.5
200	16	24 Oct	10:23	8.7
200	15	24 Oct	10:39	8.9
200	14	24 Oct	10:54	9.0
100	18	24 Oct	13:54	9.2
100	19	24 Oct	13:57	9.2
100	20	24 Oct	14:00	8.7
100	21	24 Oct	14:03	9.2
100	21	26 Oct	10:14	9.1
100	20	26 Oct	12:17	8.6
100	19	26 Oct	12:11	9.0
100	18	26 Oct	13:33	8.9
100	18	27 Oct	10:08	8.8
100	20	27 Oct	10:59	8.4

APPENDIX B: MOBILE TRACKING DETECTIONS

Appendix Table B1. Zone numbers of mobile tracking detections (of Burbot implanted in 2009 with Lotek MAP transmitters) made during two mobile-tracking surveys in the winter of 2011-2012. The delimitations of the zones can be seen in Figure 2.

	Release	Survey Date (2012)	
Tag No	Zone	17-20 Feb	3-8 Mar
111	500		550
113	400		700
123	800		700
127	800		700

Appendix Table B2. Zone numbers of mobile tracking detections (of Burbot implanted in 2009 with Vemco transmitters) made during two mobile-tracking surveys in the winter of 2011-2012. The delimitations of the detection zones can be seen in Figure 2.

	Release	Survey Date (2012)	
Tag No	Zone	17-20 Feb	3-8 Mar
721	500	700	700
722	500		700
723	500	700	700
727	500	600	600
732	400		600
735	400		600
737	400		600
738	400		600
740	400		600
743	300	550	
744	300		700
747	300		550
750	300	700	
754	200		600
756	200		550
758	200		700
763	100	550	550

Appendix Table B3. Zone numbers of mobile tracking detections (of Burbot implanted in 2010 with Vemco transmitters) made during two mobile-tracking surveys in the winter of 2011-2012. The delimitations of the detection zones can be seen in Figure 2.

	Release	Survey Date (2012)	
Tag No	Zone	17-20 Feb	3-8 Mar
598	400		550
600	400		600
601	400		550
602	400	600	600
603	400	700	700
605	500		550
606	500	700	
607	500	700	
609	500	700	
611	500	600	600
612	500		600
613	300	600	600
617	300		700
619	300	600	600
620	300	550	550
622	200	550	550
623	200	700	
628	200	600	600
629	100		600
630	100		700
631	100		550
634	100	600	600
636	100	700	550,700
639	800	800	
643	800		700
645	800		700

Appendix Table B4. Zone numbers of mobile tracking detections (of Burbot implanted in 2011 with Vemco transmitters) made during two mobile-tracking surveys in the winter of 2011-2012. The delimitations of the detection zones can be seen in Figure 2.

	Release	Survey Date (2012)	
Tag No	Zone	17-20 Feb	3-8 Mar
311	500	700	700
312	500	550	550, 700
313	500	550	550
314	500		550
315	500	550	550
317	500	550	550
318	500		550
319	500	700	550
320	500	550	700
321	400		550
322	400		600
323	400	600	600
324	400		700
325	400	600	600
327	400		600
328	400	600	
329	400	700	700
330	400	400	
331	300		600
333	300	600	600
334	300	600	600
335	300		550
336	300	700	700
337	300	600	600
340	300	600	
341	200	700	550
342	200	550,600	600
344	200	700	700
346	200		600
349	200	700	
350	200	700	550
352	100	600	600
353	100		700
354	100	700	700
355	100		600
356	100		600
357	100	800	700
358	100		550
359	100		600, 700