Columbia River Project Water Use Plan

Kinbasket Fish and Wildlife Information Plan

Reference: CLBMON-4

Implementation Year 3

Kinbasket Reservoir Fish Stranding Assessment

Study Period: 2010 to 2019

Final Report

LGL Limited environmental research associates
Sidney, BC

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KINBASKET RESERVOIR

Monitoring Program No. CLBMON-4
Kinbasket Reservoir Fish Stranding Assessment




Final Report

Prepared for

BC Hydro

BC Hydro Generation
Water Licence Requirements
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Cover photos:

From left to right: A high elevation isolated pool near Bear Island, a low elevation isolated pool along the lower end of Columbia Reach, adult female Lake Chub (*Couesius plumbeus*) sampled from a high elevation pool near Bear Island; aerial image of a network of isolated pools along Canoe Reach. Photos © Steven Roias, LGL Limited.

EXECUTIVE SUMMARY

The goal of CLBMON-4 was to determine the extent of fish stranding caused by the annual drawdown of Kinbasket Reservoir based on current reservoir operations (i.e., 725 to 754 meters above sea level [mASL]). CLBMON-4 was initiated in 2010 (Year 1) by Summit Environmental Consultants Inc. to identify areas of the reservoir with the greatest risk of fish stranding, and to identify the number of, and area covered by isolated pools in the drawdown zone (DDZ) between elevation 725 and 754 mASL with a slope less than six percent using a digital elevation model (DEM). As part of Year 1 also, a fish-stranding risk ranking model was developed to evaluate the extent of fish stranding and to provide a platform on which to base the field analysis component of the study.

Yucwmenlúcwu (Caretakers of the Land) 2007 LLP, in partnership with LGL Limited environmental research associates (LGL), conducted the three-year field component of this study from 2017 to 2019, to verify the presence of pools and validate the fish-stranding risk model developed in Year 1. LGL also addressed the management questions by determining the presence of fishes stranded in isolated pools. Over-winter fish survival was assessed by deploying dissolved oxygen (DO) data loggers and surveying for fish in isolated pools prior to winter freezing. A helicopter overflight survey was conducted in May 2018, immediately after minimum annual reservoir level (i.e., low pool of 719.33 mASL on 24 April 2018) was reached to verify the presence of pools identified from the DEM in Year 1. Two dedicated fish surveys in spring 2018 and 2019 (both shortly after minimum annual reservoir level – 714.92 mASL on 13 April 2019) were executed in all high risk areas of the reservoir (e.g., Bear Island, Bush Arm, Canoe Reach, Columbia Reach, and Gold River Arm) to assess the presence of fish in isolated pools, and to validate the risk-ranking model.

A total of 143 pools were sampled over two years, which consisted of 97 discrete pools. A discrete pool is an isolated pool unique in position but may vary in volume and surface area of standing water during isolation between each sampling event. Fishes were present in 84% of pools sampled over a 28 m elevation range (725-753 mASL) in 2018 (Year 2) and 54% of pools sampled over a 33 m elevation range (720-753 mASL) in 2019 (Year 3).

Dead fishes were observed in 38% and 14% of sampled pools in 2018 and 2019, respectively. Fishes were observed in pools sampled at all elevations between 720 and 753 mASL and all high risk areas. A total of 4,035 fishes were recorded in both years combined, of which 32% were dead. Eighty-seven percent (n=1,131) of dead fishes could not be identified to species in the field due to advanced deterioration, but most were likely sculpins, since 99% (n=167) of identifiable dead fish were juvenile sculpins. Most dead fishes were observed in low elevation pools (below 735 mASL). Cause of mortality may be the result of pool freezing or dewatering, since nine of the 10 stranded pools surveyed in February 2017 (first data logger trip for CLBMON-4) were completely frozen and stratified layers of ice were apparent, suggesting fluctuating temperatures and water levels.

Twelve species of fishes were identified of which Lake Chub (*Couesius plumbeus*), Redside Shiner (*Richardsonius balteatus*) and Prickly Sculpin (*Cottus asper*) were the most frequently encountered species observed, followed by small numbers of suckers (Largescale Sucker [*Catostomus macrocheilus]* and

Longnose Sucker [*Catostomus catostomus]*), whitefishes (Mountain Whitefish [*Prosopium williamsoni]* and Pygmy Whitefish [*Prosopium coulterii]*) and Peamouth (*Mylocheilus caurinus)*.

BC Hydro identified four fish species of concern (Bull Trout [*Salvelinus confluentus]*, Rainbow Trout [*Oncorhynchus mykiss]*, Kokanee [*Oncorhynchus nerka]* and Burbot [*Lota lota]*), of which only one Bull Trout parr and two Kokanee fry were recorded in isolated pools. As such, the risk of stranding appears low for these species based upon available data. For the predominant species that were not identified as being of concern, juvenile fishes comprised 90% of all stranded fishes sampled. Adult cyprinids, sculpins and few adult suckers were documented.

The fish-stranding risk model developed in Year 1 was revised in Year 3, and based upon an Information Theoretic model selection approach, pool depth was the only variable influencing fish stranding, such that deeper pools are more likely to contain stranded fish. Pools greater than 30 cm deep were rated as high risk to fish stranding, which equated nearly 19% of all pools identified in Year 1 with a total surface area of 77.45 ha (0.54% of total reservoir area between 725 and 754 mASL). Pool depth was measured in the field on 111 of 143 pools sampled in Year 2 and 3 combined, of which 54 pools (76%) were rated as High risk to fish stranding based on the revised model. Of these high risk pools, 76% contained fish. Only one sampled pool was rated as low risk and it did not contain fish.

Six isolated pools (between 748 and 753 mASL) sampled in fall of 2017 containing live fish were re-sampled in spring 2018. Live fish were present in four pools, and dead fish were observed in one pool after repeat sampling in the spring, indicating that fishes can survive through the winter season in isolated pools. There were no observable relationships between daily dissolved oxygen (DO) levels within pools, and the presence of live or dead fishes in these high elevation stranded pools (from the six data loggers deployed between October 2017 and May 2018). This suggests that DO levels are not strongly influencing fish survival in isolated pools.

The overflight survey conducted in May 2018 determined that 77% of pools identified in Year 1 were not present in 2018, suggesting that the DDZ is dynamic and unstable. Non-operational mitigations, (such as channelization to connect pools to the reservoir or reducing pool formation by increasing slope greater than 6% by recontouring the DDZ) to reduce fish stranding would be challenging and not likely to remain effective long-term. The absence of pools in locations identified in Year 1 and the uncertainty of existing pools resulted in field surveys being executed on an opportunistic basis rather than a random stratified approach or with the goal to re-sample the same pool over several years. Rather, sampling effort was primarily guided by reservoir access.

Fish stranding was observed across all geographical areas surveyed but detected more often in pools lower in the DDZ (below 735 mASL) as a result of more occurring pools. Based on the pool inventory generated from the DEM analysis in Year 1, an increase in minimum reservoir level from 725 to 730 mASL would reduce the extent of fish stranding in Kinbasket Reservoir by reducing the number of isolated pools by 35% and the isolated pool surface area by 48%.

The final status of CLBMON-4 is summarized in table form below.

KEYWORDS: CLBMON-4, Fish, drawdown zone, Kinbasket Reservoir, isolated pools, drawdown zone, stranding, elevation.

Objective	Management Question (MQ)	Summary of Key Results
Qualitatively evaluate the extent of fish stranding caused by the annual drawdown of Kinbasket Reservoir.	**MQ1:** What is the extent of fish stranding as a result of annual drawdown of the reservoir?	*Summary* Stranded fishes were observed in all high risk areas (between elevation 725 and 754 mASL [meters above sea level]) with a slope less than six percent that contained isolated pools. Fish stranding increased with decreasing reservoir elevation as more pools were exposed. Fishes were observed 84% of pools sampled over a 28 m elevation range (725-753 mASL) in 2018 (Year 2) and 54% of pools sampled over a 33 m elevation range (720-753 mASL) in 2019 (Year 3). *Uncertainties* The extent of fish stranding is mostly unknown below elevation 725 mASL as the DEM (digital elevation model) analysis was limited to a low elevation of 725 mASL (based on current reservoir operation. Pools could be inventoried using a current LiDAR-based DEM in the DDZ with a slope less than six percent to the minimum licenced operating elevation of 707.41 mASL, to better assess the full extent of fish stranding in Kinbasket Reservoir should the reservoir ever be drawn to this licenced minimum elevation. Although annual minimum reservoir elevation has never reached the licenced minimum, the reservoir has been drawn below 725 mASL in six of the past 10 years (2010-2019) to a low of 714.92 mASL in 2019. To date, the lowest elevation Kinbasket Reservoir has been drawn was 712.29 mASL on 12 April 2002.
	MQ2: Which areas of the reservoir have the greatest risk of fish stranding, and why?	*Summary* Geographical areas of the reservoir between elevation 725 and 754 mASL with a slope less than six percent containing a large proportion of pools included Canoe Reach, Bush Arm, Columbia Reach and Gold River Arm. These areas contained 85% of pools identified from the DEM conducted in Year 1 of CLBMON-4. A study conducted in Trail Bridge Reservoir, Oregon, found that most fishes were stranded in habitats with a slope less than six percent (Bell et al. 2008). Field surveys for CLBMON-4 observed fishes in isolated pools across the 29 m elevation range in all high risk areas mentioned above. *Uncertainties* The sources of uncertainty for MQ1, above, also apply to this MQ.

Objective	Management Question (MQ)	Summary of Key Results
	MQ3: What is the area covered by isolated pools in the dewatered zone during maximum drawdown, relative to the total surface area of the drawdown zone?	*Summary* Based on the 2002 aerial photography-derived DEM conducted in Year 1, the total area covered by isolated pools in the DDZ between elevation 725 and 754 mASL is 151.74 ha which equates to 1.06% of the total reservoir DDZ in that elevation range. *Uncertainties* The sources of uncertainty for MQ1, above, also apply to this MQ. The numeric values stated above can only be accurately applied to year 2002 since the formation and presence of pools in the DDZ of Kinbasket Reservoir appears to be dynamic (i.e., changing overtime) in all high risk fish-stranding areas (e.g., Canoe Reach, Bush Arm, Columbia Reach and Gold River Arm) as few pools documented in the DEM in Year 1 (based on 2002 aerial imagery) remained unchanged. Approximately 93% of pools identified in Year 1 were not observed in 2018 (Year 2 – helicopter overflight and ground level surveys). Routine and regular aerial surveys could monitor these changes to provide current data on pool coverage (i.e., area, number, depth etc.).
	MQ4: What percentage of isolated pools contains stranded fish?	*Summary* In spring 2018, 84% of pools contained fish, while in spring 2019, 54% of pools contained fish. Dead fishes were present in 38% of pools in spring 2018 and 14% of pools in spring 2019. *Uncertainties* The sources of uncertainty for MQ1, above, also apply to this MQ. Dead fishes were likely to have occurred in more pools but were potentially removed by predation or deteriorated prior to field surveys. Additional sampling years could provide an indication of whether the stranding rates observed in 2018 and 2019 were typical for Kinbasket Reservoir under current operations.

Objective	Management Question (MQ)	Summary of Key Results
	MQ5: At what time of year and/or reservoir elevations is stranding risk highest (e.g., at maximum drawdown)?	*Summary* Fish stranding was highest in April when the greatest number of isolated pools was observed, which also coincides with minimum annual reservoir level before refilling of the reservoir. While elevation alone does not appear to influence fish stranding, (i.e., fishes were observed at all elevations in the study areas), most pools identified from the 2002 aerial-based DEM were located below 735 mASL. *Uncertainties* The sources of uncertainty for MQ1, above, also apply to this MQ.
	MQ6: What fish species and life history stages are potentially most affected by stranding as the reservoir is drawn down?	*Summary* Twelve species of fish were documented in isolated pools sampled, of which cyprinids (particularly Lake Chub [*Couesius plumbeus]* and Redside Shiner [*Richardsonius balteatus*]) and sculpins (mostly Prickly Sculpin [*Cottus asper*]) were the most frequent fish groups observed across all elevations and years, and together comprised 52% of all identifiable fishes sampled. Juvenile fishes were most affected and comprised nearly 90% of all stranded fishes observed. The BC Hydro fish species of concern (Bull Trout [*Salvelinus confluentus*], Rainbow Trout [*Oncorhynchus mykiss*], Kokanee [*Oncorhynchus nerka*], Burbot [*Lota lota*]) were not observed to be at high risk of stranding during the two-year field program. *Uncertainties* The sources of uncertainty for MQ1 and MQ4, above, also apply to this MQ.

Objective	Management Question (MQ)	Summary of Key Results
	MQ7: Are operational or non-operational changes recommended to mitigate or to reduce the risk of fish stranding?	*Summary* Reducing the number and surface area of isolated pools by increasing minimum low pool elevation would reduce the number of fishes becoming stranded. Increasing minimum annual reservoir level elevation by 5 m from 725 to 730 mASL would reduce the number of isolated pools by 35% and isolated pool surface area by 48%. The high risk fish-stranding areas (MQ2) were determined to be too unstable for non-operational mitigations. Physical works to increase slope (greater than six percent) and excavate outlet channels to eliminate the formation of pools would not be effective long-term solutions. *Uncertainties* The sources of uncertainty for MQ1 and MQ3, above, also apply to this MQ. To better inform the use of non-operational mitigations (e.g., physical works) to reduce fish-stranding in the DDZ of Kinbasket Reservoir, a more accurate assessment on the dynamics (i.e., pool shifting, presence of pools) of high risk fish-stranding areas is recommended. This would include the use of multi-year and LIDAR based DEM combined with simultaneous visual observations made as part of aerial overflights. The 2002 Year 1 DEM-based methodology was not suited for identification of stranding pools or stranding risk.

LIST OF ABBREVIATIONS

ARIS	Adaptive Resolution Imaging Sonar
CABIN	Canadian Aquatic Biomonitoring Network
CLBMON	Columbia Monitoring
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DEM	Digital elevation model
DDZ	Drawdown zone
DO	Dissolved Oxygen
FISS	Fisheries Information Summary System
GIS	Geographic Information System
GPS	Global Positioning System
LiDAR	Light Detection and Ranging
mASL	Meters at sea level
MQ	Management Question
NTU	Nephelometric Turbidity Units
TOR	Terms of Reference
WUP	Water Use Plan
WUP CC	Water Use Plan Consultative Committee

GLOSSARY OF TERMS

Benthic – Pertaining to the bottom of a body of water.

Cyprinid – Any member of freshwater fish in the Cyprinidae (carp-like) family. In British Columbia these include minnows, dace, chub, shiners, Common Carp (*Cyprinus carpio*), Goldfish (*Carassius auratus*), Tench (*Tinca tinca*), Peamouth (*Mylocheilus caurinus*) and Chiselmouth (*Acrocheilus alutaceus*).

Dewatering – The removal of water through natural or artificial processes.

Discrete Pool - An isolated pool unique in position but may vary in volume and surface area of standing water during isolation between each sampling event.

Drafting – The removal (drawing) of water in a reservoir thereby lowering the water level in elevation.

Drawdown – See Drafting.

Drawdown zone – The dewatered shoreline between the high-water mark and the wetted water level of a reservoir as a result of drafting/drawdown.

Large Woody Debris – Dead and fallen woody material (logs, branches, uprooted stumps etc.) in various stages of decomposition and is usually greater than 7.5 cm in diameter.

Isolated Pool – A wetted depression disconnected from a larger/main body of water (e.g., reservoir) due to a lowering of the main body of water.

Littoral Zone – The vertical distance of a body of water that is close to shore to which light penetrates to the bottom.

Low Pool – The minimum annual reservoir level that is reached before the reservoir begins to re-fill.

Pelagic Zone – The vertical distance of a body of water that is not close to shore and light does not penetrate to the bottom.

Physicochemistry – Of or relating to chemistry that deals with the physical and chemical properties of substances. E.g., pH, temperature, dissolved oxygen of water.

Pseudoreplication – The process of artificially inflating the number of samples or replicates, which are dependent on each other.

Riparian – Relating to or living on the edge of a body of water/shoreline.

Stranding – In the context of this program, it is when a fish occurs in an isolated pool does not have access to the reservoir and thus becomes trapped in the pool.

Taxonomic Richness – A description of the number of taxa (e.g., species, genus, family) present in a given area.

Turbidity – A measure of the degree to which water loses its transparency (cloudiness) due to the presence of suspended particles. Turbidity increases with increasing presence of suspended particles.

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1.0 INTRODUCTION

Dams regulate the flow regime in most of the world's large river systems, and the flooding resulting from dam construction and water storage creates a complex disturbance that can modify entire ecosystems (Nilsson and Berggren 2004; Eskew et al. 2012). These impacts are not restricted to the direct flooding and loss of fish and wildlife habitat upstream of dams, but also extend downstream of dams through disturbance of annual flooding regimes needed to maintain the health of floodplain environments (MacKenzie and Shaw 2000; Nilsson and Berggren 2004; Kupferberg et al. 2011; Eskew et al. 2012; Nagrodski et al. 2012). To date, most fish studies on the effects of impoundment have focused primarily on the instream effects on fish stranding downstream of dams and irrigation projects (Nagrodski et al. 2012). The need to understand the operational aspects of reservoir effects upstream of dams on fish stranding remains high, and that is the focus of this study.

There are 14 dams on the Columbia River, three of which are in B.C. (Mica, Revelstoke, and Hugh Keenleyside); the remainder are in the U.S. Kinbasket Reservoir is one of British Columbia's largest reservoirs and was created when the Columbia River was impounded by Mica Dam in 1973. Mica Dam was built under the Columbia River Treaty to provide water storage for power generation and flood control. The creation of Kinbasket Reservoir flooded ~42,650 ha, resulting in the loss or alteration of eight broad habitat types (lakes: 2,343 ha; rivers: 4,897 ha; streams: 192 ha; shallow ponds: 555 ha; gravel bars: 236 ha; wetlands: 5,863 ha; floodplain [riparian]: 15,527 ha; and upland forest: 13,036 ha; Utzig and Schmidt 2011).

During the Columbia River Water Use Planning Process (WUP), the WUP Consultative Committee (WUP CC) expressed concerns about the potential impacts of the operations of Kinbasket Reservoir on fish, wildlife, and associated habitat. (BC Hydro 2005, 2007a). A lack of qualitative information on the relative abundance, distribution, life history, and habitat use of these animals made it difficult to assess the impact of current operations and operating alternatives. These uncertainties led to the BC Hydro and Power Authority (BC Hydro) initiating a series of long-term monitoring programs, which included a 3-year study to qualitatively evaluate the extent of fish stranding caused by the annual drawdown of Kinbasket Reservoir (BC Hydro 2007a, CLBMON-4). Prior to this study, only anecdotal observations of fish being stranded in isolated pools were reported (Table 1; RSMI 1994; V. Hawkes, LGL Limited, pers. comm.).

This report is a comprehensive assessment of data collected during Years 2 and 3 (2018 and 2019) to answer management questions (MQ) 4, 6, and 7, and to validate the results generated in Year 1 (Hanson and Nadeau 2010) addressing the remaining MQs for BC Hydro's monitoring program CLBMON-4 Kinbasket Reservoir Fish Stranding Assessment. Details of the methods and results of Year 1 of the project can be found on BC Hydro's website[1].

[1] https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/planning_regulatory/wup/southern_interior/2011q1/clbmon-4_yr1_2010-09-01.pdf

Table 1. Pools in the drawdown zone of Bush Arm, Kinbasket Reservoir with fish observed during summer 2017 by LGL Limited while conducting field surveys for CLBMON-58 (V. Hawkes, LGL Limited, pers. comm.). Fishes observed were not identified to species or processed (measured or enumerated) but some photos were obtained (elevation unit mASL).

Location	UTM (11 U) E	UTM (11 U) N	Elevation (mASL)
Bush Arm	474536	5740067	753.4
Bush Arm	474624	5739965	753.1
Bush Arm	474542	5739992	753.0
Bush Arm	474739	5739188	751.4
Bush Arm	474771	5739160	752.5
Bush Arm	474460	5739970	752.6
Bush Arm	461687	5735550	749.3
Bush Arm	461701	5735647	751.5
Bush Arm	461635	5735609	750.8
Bush Arm	461604	5735624	750.9
Bush Arm	461438	5735621	748.2
Bush Arm	474832	5739249	751.1
Bear Island	453221	5736975	751.0
Bear Island	453202	5737017	752.5
Bear Island	453471	5736839	749.4
Bear Island	454425	5736473	747.9

1.1 Objectives

The key objective of this 3-year monitoring program is to qualitatively evaluate the extent of fish stranding caused by the annual drawdown of Kinbasket reservoir. Specific objectives of CLBMON-4 are to:

1. Assess and document key areas of concern in the DDZ of Kinbasket Reservoir to fish stranding.
2. Incorporate a modeling component to determine fish stranding risk.
3. Determine the extent of fish stranding under current reservoir operations.
4. Assess mitigation options for future consideration in the operations of the Kinbasket Reservoir.

2.0 STUDY AREA

2.1 Kinbasket Reservoir

Located in southeastern B.C., Kinbasket Reservoir is approximately 216 km long and is surrounded by the Rocky and Monashee Mountain ranges (Map 1). The Mica hydroelectric dam located 135 km north of Revelstoke, B.C., spans the Columbia River and impounds Kinbasket Reservoir. The original Mica powerhouse, completed in 1973, has a generating capacity of 1,805 MW, and Kinbasket Reservoir has a licensed storage volume of 12 million acre feet (MAF; BC Hydro 2007b). The addition of two new turbines at Mica Dam completed in

2016 increased the generating capacity of Kinbasket Reservoir by roughly 1,000 megawatts (BC Hydro 2007b).

Kinbasket Reservoir has been in operation since 1976, and has a licenced operating elevation range between 707.41 and 754.68 mASL resulting in a maximum drawdown zone elevation change of 46 m. In recent years, the reservoir has been typically operated between 725 and 754 mASL, creating an operating range of 29 m. Analyses conducted in Year 1 focused on pool inventory within this current operating range. While the average minimum reservoir level has been increasing (six meters) in the past 20 years (Figure 1), the reservoir level has been drawn down below 725 mASL six times in the past decade, to a minimum elevation of 714.92 mASL on 13 April 2019 (Figure 2).

2.2 Study Locations

Regions of the drawdown zone of Kinbasket Reservoir between elevation 725 and 754 mASL and where slope was less than six percent was the focus of this study. These areas included Bear Island, Bush Arm, Canoe Reach, Columbia Reach, and Gold River Arm and were the primary focus for field sampling in Years 2 and 3 due to the large numbers of isolated pools identified in Year 1 (Map 1).

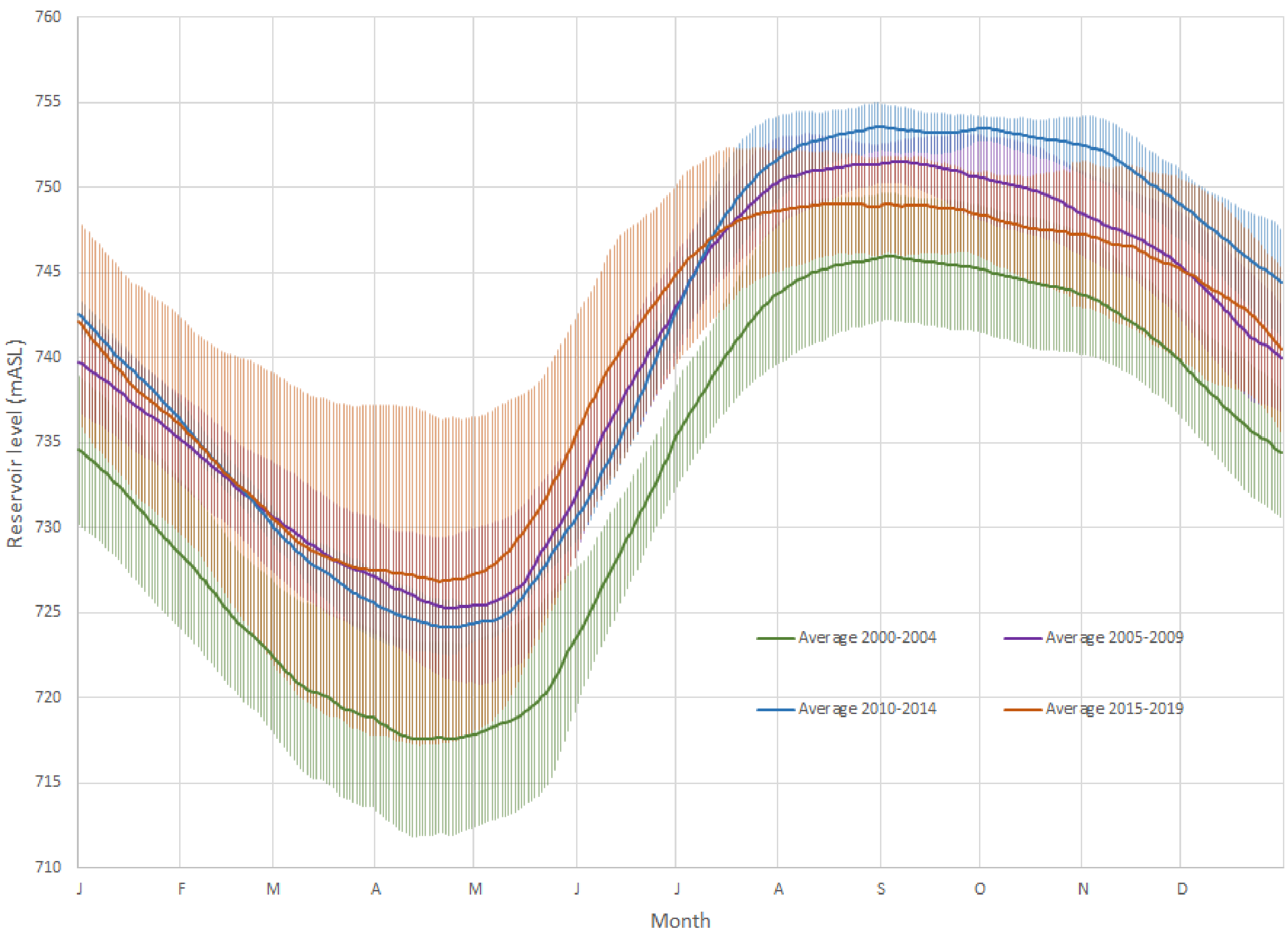


Figure 1. **Kinbasket Reservoir daily average low elevation between 2000 and 2019.** Averages are shown for periods 2000−2004 (green, low average = 717 mASL), 2005−2009 (orange, low average = 725 mASL), 2010-2014 (blue, low average = 724 mASL) and 2015−2019 (red, low average = 727 mASL). Range is shown in the shaded areas for the same respective time frames. Data obtained from BC Hydro. Maximum recorded high pool (754.68 mASL) occurred on 28 August 2012 and minimum recorded low pool (712.29 mASL) occurred on 12 April 2002. Turbines 5 and 6 were entered into operations at Mica Dam on January and December 2015 respectively.

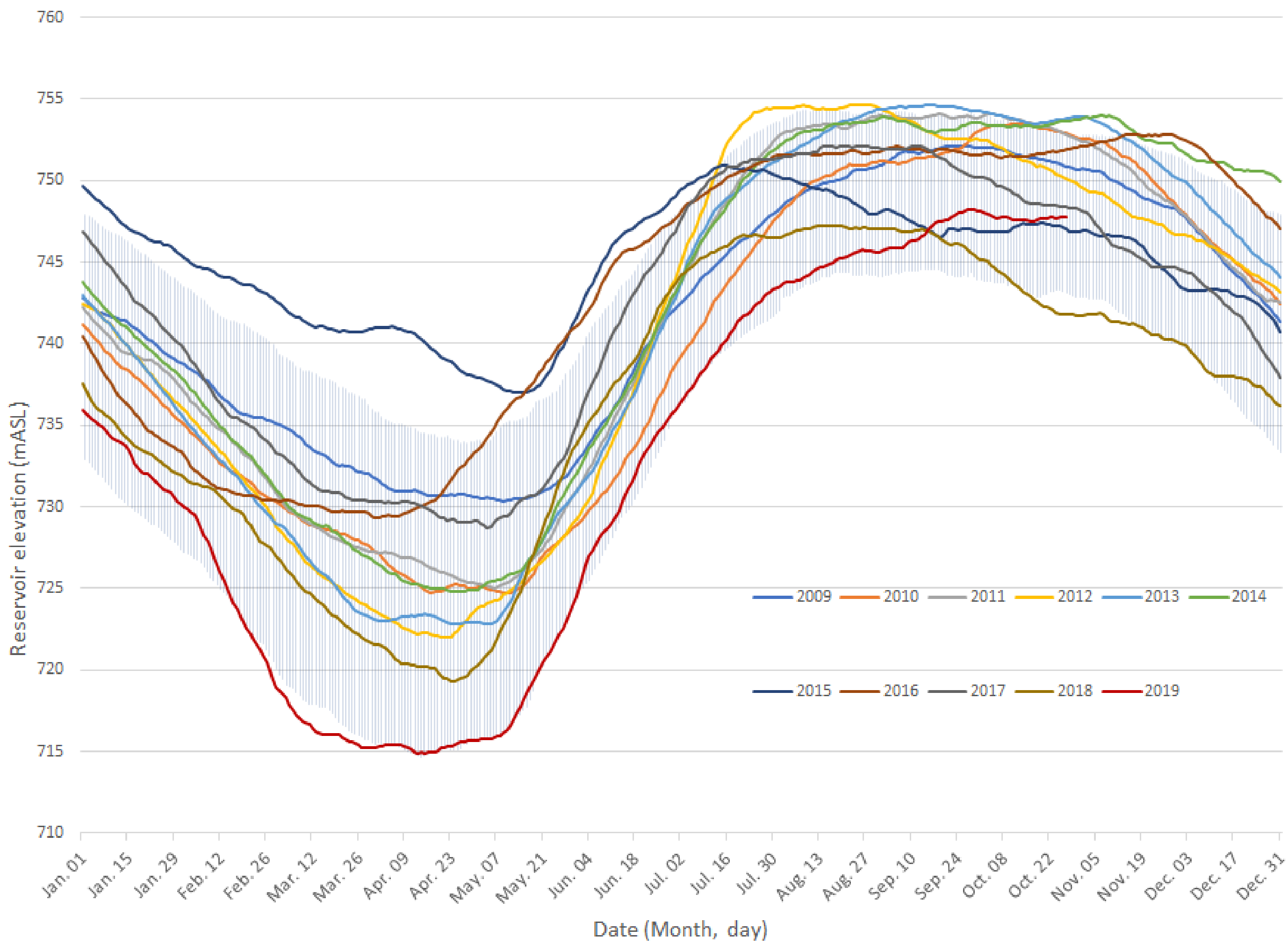
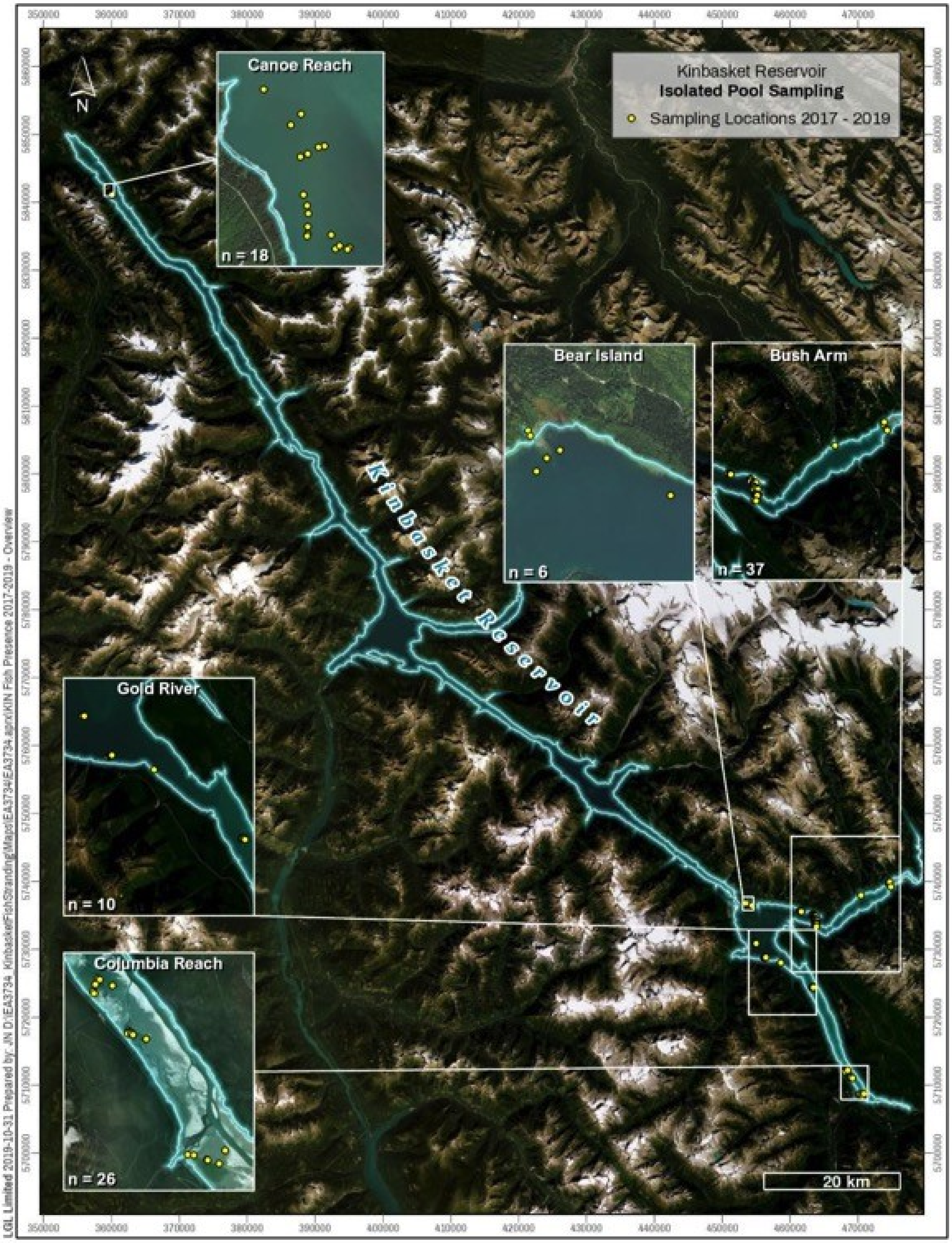


Figure 2. **Kinbasket Reservoir 10-year hydrograph for the period 2009 through 2019.** The shaded area represents the 10th and 90th percentile for the period 1976 to 2019; the dashed red line is the normal operating maximum. Data obtained from BC Hydro. Maximum recorded high pool (754.68 mASL) occurred on 28 August 2012 and minimum recorded low pool (712.29 mASL) occurred on 12 April 2002.



Map 1. **Overview of the location of isolated pools sampled along the drawdown zone of Kinbasket Reservoir in Year 2 (October 2017 and May 2018) and Year 3 (May 2018) of the field program for CLBMON-4.**

3.0 METHODS

3.1 Overview

Year 1 of CLBMON-4 was conducted in January to September 2010 and was a desk top exercise. Field data collection occurred in Years 2 and 3 from February 2017 to May 2019 (Appendix 1). Reports were compiled each year (2010, 2018, 2020) following (Hanson and Nadeau 2010, Roias et al., 2018).

The key objective of this monitoring program (CLBMON-4) was to qualitatively evaluate the extent of fish stranding caused by the annual drawdown of Kinbasket Reservoir under current reservoir operations in a 3-year time frame. Year 1 of this program was implemented in 2010 by conducting a GIS desktop analysis using a digital elevation model (DEM), based on 2002 aerial photography flown at an elevation of 714 mASL, and following the methodology developed by Korman and Buszowski (2000). The desktop analysis aimed to identify the number, size and location of isolated pools formed in the drawdown zone (DDZ) of Kinbasket Reservoir (Hanson and Nadeau 2010). Pools were identified on slopes less than six percent. This slope threshold value was based on the results of a study by Bell et al. (2008) that indicated that most fish stranding occurred on slopes of < 6% gradient. As part of the Year 1 report, a fish stranding risk ranking model was developed using a series of criteria:

- Pool area
- Pool depth
- Number of days pools is isolated
- Time of year pool is isolated

A risk category (low, medium, high) was then assigned to each identified pool to suggest the likelihood/potential risk of the pool to strand fish (Table 2-1 in Year 1). A total of 6,548 pools were identified from the DEM analysis and summarized by risk Table 3-1 in Year 1). Eighty-eight percent of identified pools were located in three broad geographical regions of Kinbasket Reservoir due to their lower gradient slopes of less than six percent. Canoe Reach contained 13.5%, while 74.5% were located between Bush Arm and Columbia Reach. These regions became the focus of field work for Year 2 and 3. Field surveys in Year 2 and 3 were planned to verify the presence of the pools identified in Year 1 via ground-level sampling and aerial overflight surveys and investigate the presence of stranded fish in these pools. In addition, data collected in Year 3 assessed annual fish stranding variability and to suggest non-operational mitigations in MQ7.

Field planning of CLBMON-4 was focused on opportunistic sampling during optimal weather and operational conditions. Under BC Hydro's CLBMON-4 Terms of Reference (BC Hydro 2007a), surveys were to coincide with: drafting of the reservoir prior to snow accumulation and ice cover to obtain counts of newly stranded fish; low minimum pool; and early refill of the reservoir after snow ice melt, and before the majority of high risk areas are re-inundated. Meeting these criteria has proven challenging over the last few years due to extreme weather patterns preventing access, and variation in reservoir operational activities (e.g., increase in average minimum water reservoir level in the past 10 years,

(Figure 1). As such, field surveys were revised in an effort to best respond to the CLBMON-4 management questions.

3.2 Field Schedule

A list of field surveys for Year 2 and 3 are summarized in Table 5 of Appendix 1. Forecasted reservoir level hydrographs (Figure 3) obtained from BC Hydro were incorporated into field scheduling to determine how much of the DDZ would be available for sampling. Field surveys for Year 2 were initiated on 28 February 2017, to deploy dissolved oxygen (DO) loggers in approximately eleven high risk isolated pools below 740 mASL (most high risk pools occurred below 740 mASL) along Bush Arm and Columbia Reach to determine fish survival through winter conditions to help address MQ7 (Appendix 5). These pools were accessed via helicopter. Reservoir water level during the field trip was estimated to be between 731 and 732 mASL. Ten high risk isolated pools with minimum depth of 0.5 m (identified from Year 1) were drilled (with an ice auger) for dissolved oxygen data logger instalment. Of these ten pools, nine were completely frozen (Photo 1) and the tenth pool only contained 10 cm of water, insufficient for a data logger. While winter air temperatures in 2017 were below normal, freezing of isolated pools is likely common, and could occur between November and March for any given year (Figure 4).

Transportation to Bush Arm and Bear Island occurred by pick-up truck (with 4X4 capability) traveling along forestry service roads from Golden, B.C. The objective of this field survey was to obtain counts of newly stranded fish caused by reservoir drawdown prior to winter freezing. Pools were then re-sampled (containing fish) in the spring (after snow melt) to determine if fish survive over winter. Dissolved oxygen (DO) and temperature loggers were deployed in the pools before freezing to assess water quality parameters.

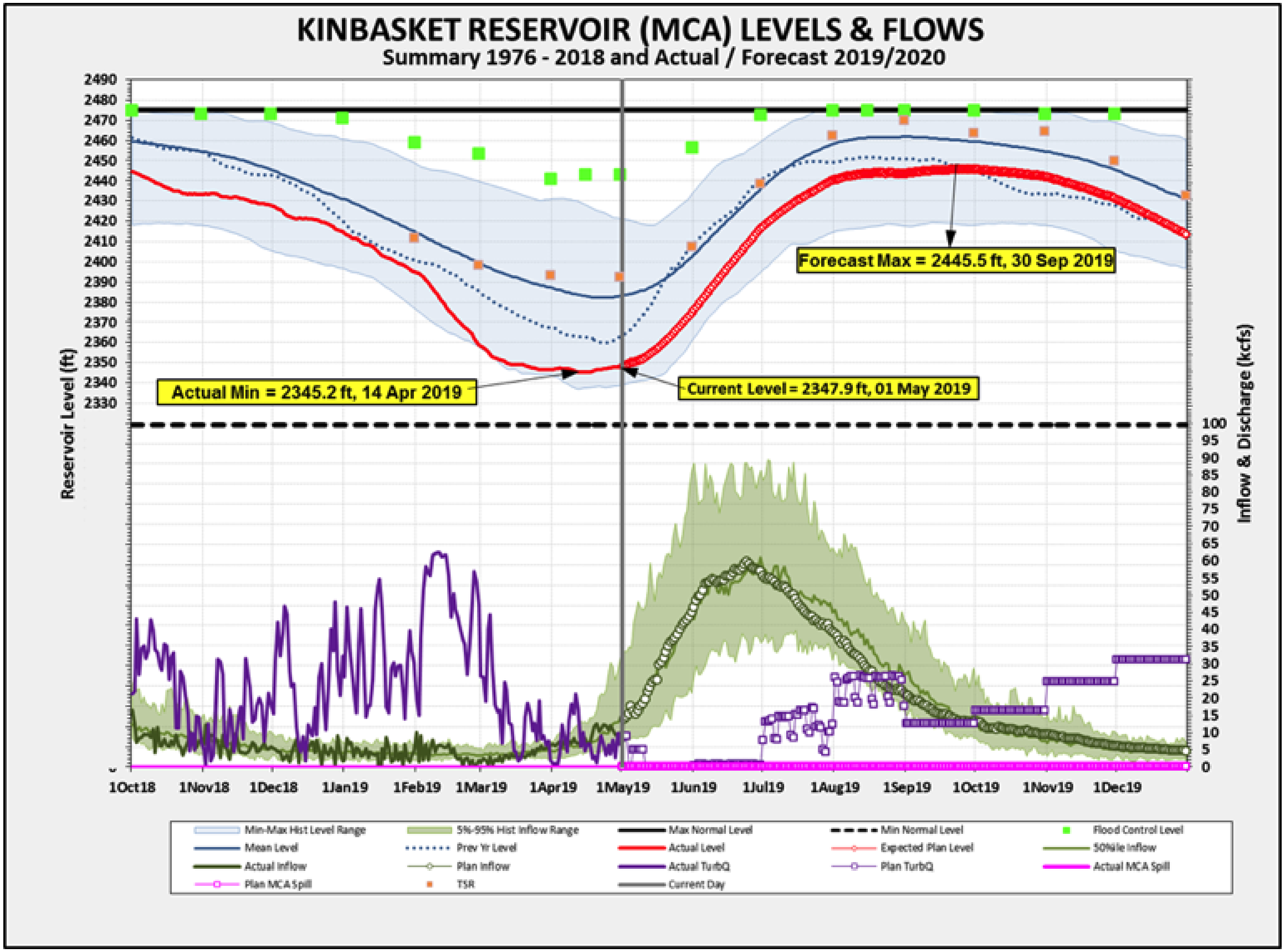


Figure 3. Kinbasket Reservoir elevation levels for Year 3, 2019, updated on 01 May 2019. Provided by BC Hydro. Minimum pool was reached on 13 April 2019 (714.92 mASL).

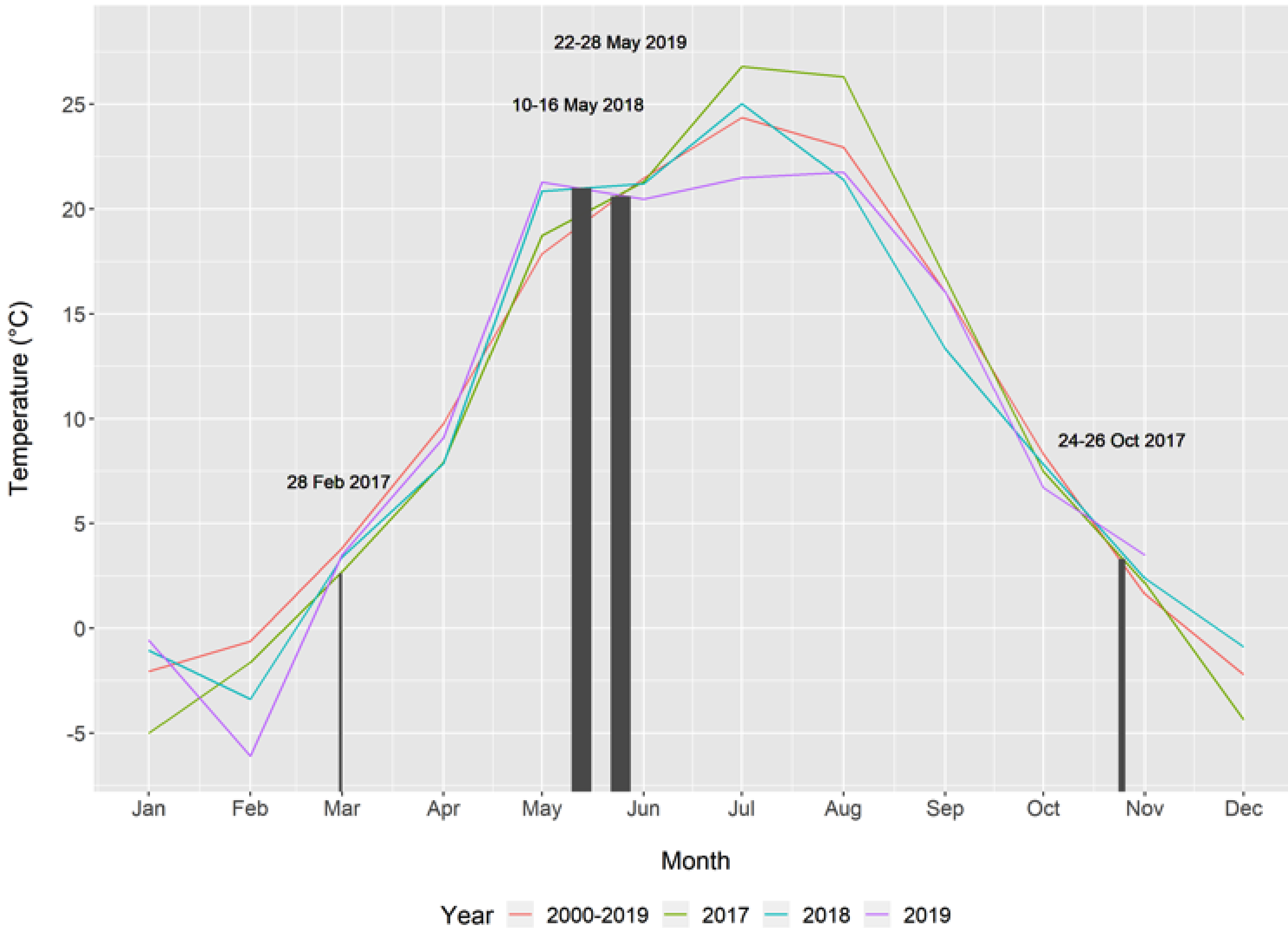


Figure 4. Average monthly air temperatures recorded for Mica Dam during the years sampled in Year 2 and Year 3 for CLBMON-4. Data obtained online from www.climate.weather.gc.ca. Grey vertical bars illustrate when field sampling occurred for Year 2 (2017 and 2018) and 3 (2019).

Similar scheduling logistics used in fall 2017 were adopted in spring 2018 and 2019. Ground-level sampling in Year 2 and data logger retrieval was conducted from 10 to16 May 2018 by a crew of three, and ground-level sampling in Year 3 was conducted from 22 to 28 May 2019. A helicopter was used to access the upper Columbia Reach in 2018 and 2019 and the Gold River Arm in 2019. Data collected from Spring 2018 and 2019 provided the following information:

- Verified the presence of pools identified in Year 1 and evaluated the criteria used to build the fish stranding risk ranking model developed in Year 1.
- Assessed fish survival in pools isolated over the winter period by repeat sampling of pools in spring 2018 with fish observed during the fall 2017 survey.
- Determined the presence of fishes (species, relative numbers, and life stages) in pools over the DDZ elevational range and pool size range to encompass the three fish stranding risk categories developed in Year 1.
- Determined if fish stranding varied by geographical location (Bush Arm, Canoe Reach, Columbia Reach identified as being areas of greatest risk to fish stranding).
- Data collected in Year 3 (2019) assessed annual fish stranding variability.
- In combination with Year 2 answered management questions 4, 6, and 7 and validated the responses to management questions 1, 2, 3, and 5 in Year 1.

3.3 Pool Sampling

Prior to field work, pools identified in Year 1 were organized by fish stranding risk and uploaded onto a field iPad. The software program 'Collector' was used to navigate field staff to pools. Other pool attributes, such as depth, area, and elevation were also uploaded on the iPad, and were used to help select a variety of pools across the DDZ elevational range. Due to access challenges, unsafe conditions (such as very soft and sticky substrate) and varying reservoir elevations during seasonal and annual sampling (Figure 2, 3.2 Field Schedule), pools were sampled opportunistically and in clusters. At each visited pool, maximum wetted length and width were measured using a handheld Tasco 600 range finder. An approximate wetted surface area was then calculated using these values. A maximum wetted depth was measured with a cm-graded measuring pole for all pools one metre deep or less. For deeper pools (and out of safety concern), a maximum depth was estimated visually based on a number of reference points such as local topography, water clarity, and standing objects such as tree stumps. Elevation was determined in the office for each isolated pool sampled via ArcGIS Pro (ESRI 2019) using a LiDAR-derived DEM from 2014. Due to a large proportion of sampled pools not previously identified in Year 1, fish stranding risk was re-calculated (using the same stranding risk ranking model developed in Year 1) for all pools sampled with wetted depth and area measurements. The following criteria used in the stranding risk ranking model were approximated to assign a stranding risk to each sampled pool:

- Pool area – maximum wetted length and width measured at time of field survey.
- Pool depth – maximum wetted depth measured at time of field survey.
- Number of days pool was isolated – based on a 20-year daily average pool elevation from 2000 to 2019 (Year 1 used a 20-year time frame from 1990 to 2010).
- Time of year pool is isolated – two factors were listed in Year 1 report (Hanson and Nadeau 2010), of which "Life History" was adopted with no adjustment, and "Reservoir Levels" were based on a 20-year daily average pool elevation from 2000 to 2019 (Year 1 used a 20-year time frame from 1990 to 2010).

Each sampled pool was photo-documented with a digital camera and its position recorded with a handheld Garmin GPS. The number of isolated pools sampled in each study area during the field sessions of Year 2 and 3 is summarized in Table 2. Sampling was not repeated for all pools in the three field sampling periods. A discrete pool is an isolated pool unique in position but may vary in volume and surface area of standing water during isolation between each sampling event. A total of 97 discrete isolated pools were sampled, each surveyed at least once during this monitoring program (Table 2).

Table 2. Number of isolated pools sampled by geographical location in the drawdown zone (between elevation 719 and 753 mASL) of Kinbasket Reservoir. Repeat sampling of pools between fall 2017 and spring 2018 was conducted to assess winter fish survival while repeat sampling between spring 2018 and spring 2019 was conducted to assess annual variability in fish stranding.

Location	Unique pools sampled	Repeat sampling 2017−2018	Repeat sampling 2018−2019	Pools sampled Oct 2017	Pools sampled May 2018	Pools sampled May 2019
Bear Island	6	5	3	5	5	4
Bush Arm	37	1	20	9	21	28
Canoe Reach	18	0	13	0	14	17
Columbia Reach	26	0	4	0	10	20
Gold River Arm	10	0	0	0	0	10
Total	**97**	**6**	**40**	**14**	**50**	**79**

3.4 Fish Survey Data

All fish sampling was conducted under the Ministry of Forests, Lands and Natural Resource Operations Fish Collection Permit: CB17-282309 for Year 2 (2017/2018) and CB19-458198 for Year 3 (2019).

For each sampled pool, fish presence was determined from a combination of sampling techniques used opportunistically based on the complexity of the pool (e.g., size and depth of pool, amount of pool cover such as large woody debris) and ease of access to pools (Photo 2; Table 3). Therefore, pool sampling effort was not standardized between pools.

- Minnow traps – 0.6 cm mesh, three per pool, each trap baited with a 3 oz. can of Great Choice wet cat food (seafood flavour). Cans were punctured for slow release of scent. Traps were soaked overnight for a 24-hour period and retrieved the following day. Minnow traps were deployed in pools with thick in-pool cover and in deep pools with a wetted depth greater than 0.5 m (with preference in pools deeper than 1.2 m, which would otherwise prevent beach seining).
- Beach seine – 15 m long by 1.5 m height net with 0.5 cm mesh. This method was used on pools with a wetted depth up to 1.2 m and little to no in-pool cover (most common in mid to low elevation pools).
- Dip netting – 40 cm net frame on a 1.8 m monorail pole, and 0.5 cm mesh. This method was effective in shallow pools or in pools with in-pool cover (except no large woody debris that could snag nets) along the shoreline where juvenile fishes often rear. Also effective in open shallow pools where fishes were visible from the surface.
- ARIS 1200 sonar – effective in deep and turbid pools, however due to the large amount of accessory gear (field laptop, cords and cables) and heavy weight of the sonar unit and accompanying gas-powered generator (Honda 1000), this method was only used in fall 2017 on a single pool (BA29) situated along the forestry service road adjacent to Prattle Creek (Bush Arm).
- Visual survey – very effective in clear shallow pools with limited in-pool cover. Juvenile cyprinids and salmonids often occupy the upper water column and nearshore littoral zone, making them easy to detect. Species identification can be challenging in mixed cyprinid schools, and when trying to distinguish between sculpins and suckers. Since physical handling of fish does not occur with visual surveys, no length measurements were obtained.

Table 3. **Number of isolated pools sampled by fishing technique.** Pools that were not sampled using physical fishing methods but observed visually to contain fish were noted as "Visual". At least one pool per sampling session was not sampled for fish due to unsafe conditions such as very muddy substrate or bear encounter (e.g., spring 2019).

Sampling method	Fall 2017	Spring 2018	Spring 2019
Beach seine	0	16	31
Dip net	9	7	6
Minnow trap	5	7	12
ARIS sonar	1	0	0
Visual	0	15	10
None	2	2	1
Total number of sampled pools	**14**	**50**	**79**

All fishes were identified to the lowest possible taxonomic level (with preference to species), enumerated, and a fork length measurement (total length for sculpins due to rounded caudal fin) was obtained from a set of approximately 30 fish of each taxa per sampling method, per pool. Fish lengths were used to estimate life history stage, particularly for cyprinids, suckers, and sculpins where juvenile features are not conspicuous. All captured fish were released in their respective pools. Presence of dead fishes was also documented, this included taxonomic identification (if possible) and enumeration.

3.5 Data Loggers

Over-winter fish survival: dissolved oxygen (DO)/temperature data loggers were to be installed below ice cover in high fish stranding risk pools (with minimum 50 cm depth water) identified in Year 1.

An initial winter (28 February 2017) trip failed to deploy due to frozen pools (Table 4; Photo 1). Only one pool had 10 cm depth of ice-free water overlain by 50 cm of ice and was too shallow for data logger deployment.

A second data logger deployment trip was carried out on 24–25 October 2017 before ice formation. On 24–25 October 2017, six PME miniDOT (dissolved oxygen and temperature) loggers were deployed opportunistically in six high elevation (between 747 and 753 mASL) pools along the DDZ of Bush Arm (Dataset 04; Appendix 5; Photo 2, Photo 4). These pools were identified either based on CLBMON-4 Year 1 reporting, or based on anecdotal information provided by LGL Limited field staff working on CLBMON-58 (Table 1).

3.6 Helicopter Overflight Survey

Aerial digital photographs of targeted areas in the Kinbasket Reservoir DDZ were taken on 08 May 2018 by a Yucwmenlúcwu biologist to validate the presence of pools identified by Hansen and Nadeau in the Year 1 of CLBMON-4 (Map 2, Photo 5). Pools within the drawdown zone were targeted in the Canoe Reach, Bush Arm, Bush Harbour, Bear Island, Columbia Reach, and Gold River Arm. Information from the twin-engine helicopter aerial survey was also used to inform the ground survey team of potential suitable sampling sites. Flight survey elevation was at 1,000 m altitude at a speed of 60 knots.

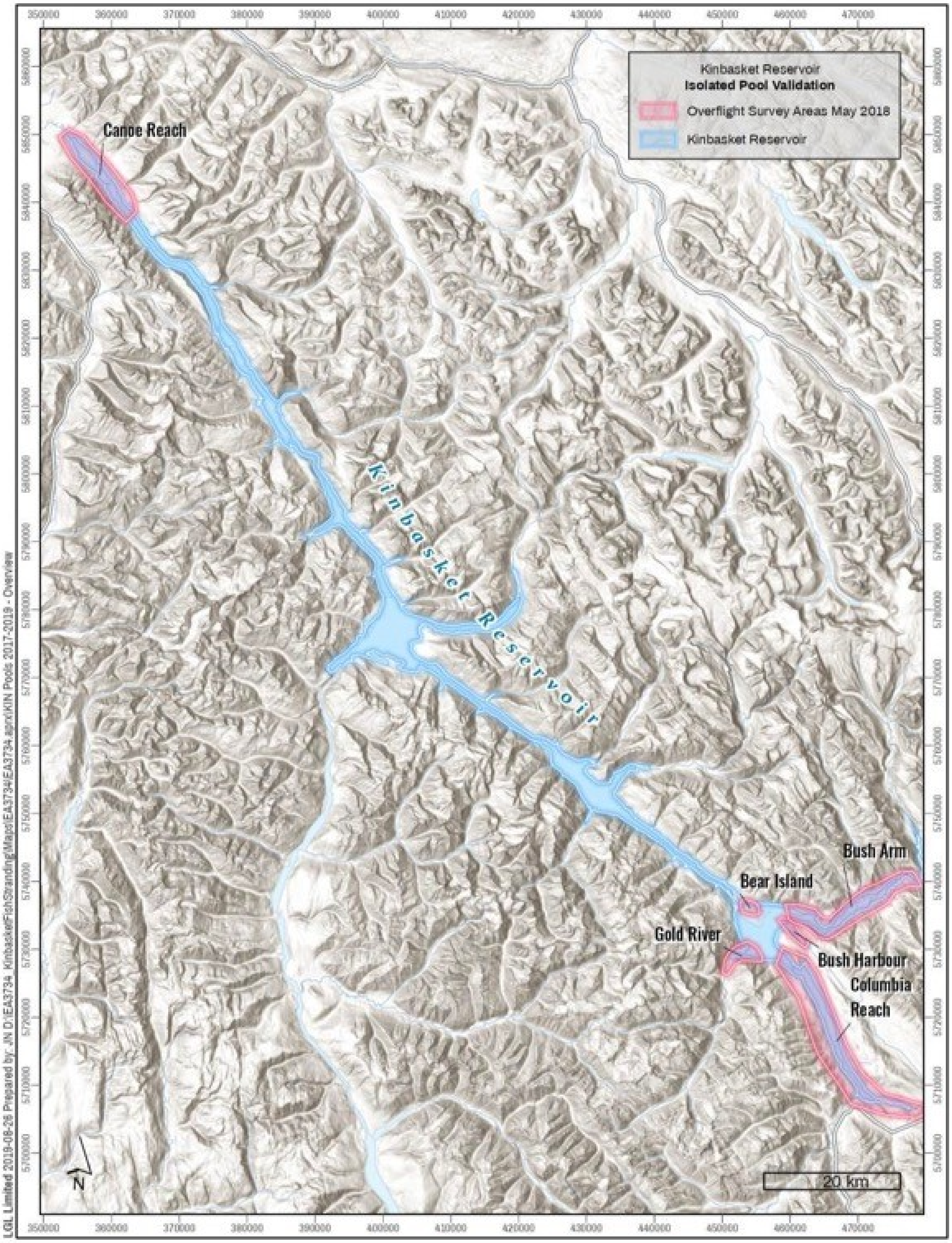
3.7 Environmental Data

Dissolved oxygen (mg/l), pH, water temperature (°C), and turbidity (NTU) were collected at each sampled pool to assess fish habitat quality and potential signs of predation from wildlife. Results are summarised in Appendix 6.

Table 4. **Summary data of the 11 isolated pools sampled with an ice auger in Kinbasket Reservoir on 28 February 2017**, to deploy dissolved oxygen data loggers. Only one isolated pool had water but not deep enough (10 cm) to deploy a data logger. The 11th pool drilled was not isolated but rather sampled for estimating reservoir elevation of ice-free water.

Location	UTM E	UTM N	Elevation (m)	Water present	Water depth (cm)	Total ice thickness (cm)	Clear ice thickness (cm)	Predicted pool depth[a] (cm)	Measured depth[b] (cm)	Pool fullness[c] (%)	Substrate
Columbia Reach	5708624	470084	739	No	0	55	20	177	20	11	Fines/mud
Columbia Reach	5708621	470082	739	No	0	59	20	177	20	11	Fines/mud
Columbia Reach	5709299	470932	735	No	0	48	0	70	20	0	Fines/mud
Bush Arm	5737911	471083	740	No	0	20	0	59	20	0	Fines/mud
Bush Harbour	5733683	459833	735	No	0	52	20	81	20	25	Fines/mud
Bush Harbour	5733776	459726	736	Yes	10	50	20	103	30	29	Fines/mud
Columbia Reach	5708693	471451	735	No	0	65	29	80	20	37	Fines/mud
Columbia Reach	5711550	469353	733	No	0	75	60	140	20	43	Fines/mud
Columbia Reach	5707686	473204	739	No	0	66	60	100	20	60	Fines/mud
Columbia Reach	5711814	469083	732	No	0	49	18	60	20	30	Fines/mud
Columbia Reach	5712066	468259	731	Yes	93	71	55	76	N/A	N/A	Fines/mud

[a] Predicted pool depth – Based from Year 1 CLBMON-4 report by Hanson and Nadeau (2010) – Appendix III High Risk Pools.
[b] Measured depth – Watered depth of the pool (sampled in February 2017) based on the sum of clear ice thickness and depth of liquid water (if present).
[c] Pool fullness – Percent of predicted pool depth holding water/clear ice prior to snow precipitation.
N/A – This pool was not stranded therefore pool water depth and fullness could not be determined.



Map 2. **Kinbasket Reservoir.** Isolated pool validation was conducted in the pink highlighted regions via an aerial overflight survey on 08 May 2018. Approximately 90 percent of pools identified in Year 1 were located in these regions within an elevation of 725−753 mASL. The drawdown zone in these regions were identified in Year 1 as having a slope of less than six percent.

4.0 DATASETS

4.1 Dataset 01 – Isolated Pool Verification

This dataset was created in ARCGIS to validate the presence of isolated pools identified in Year 1 against digital imagery obtained during the 08 May 2018 aerial overflight survey to answer management questions (MQ) 1 and 2. This dataset includes all 6,548 pools identified in Year 1, their elevation and coordinates, as well as three additional columns that pertain to the findings from the 2018 overflight survey. These columns include the presence and absence of pools identified in Year 1, new pools not identified in Year 1, and unknown (pools that were identified in Year 1 but not captured in digital imagery). These data were also used to answer MQ7 by determining which regions of the DDZ pools remained stable, which would be the areas focused for non-operational mitigations. The results of this dataset are summarized in Appendix 2.

4.2 Dataset 02 – Review and Revision of the Fish-stranding Risk Model

The dataset used to validate the fish-stranding risk model developed in Year 1 included all pools sampled in Year 2 and 3. This dataset comprises of 111 data points (sample pools) collected from all three field sessions (fall 2017, spring 2018 and 2019). A total of 143 pools (this includes repeat sampling) were sampled in all years combined, however physical measurements (e.g., depth, and/or area) were not obtained for 32 pools. Repeat sampling of pools in Years 2 and 3 were considered as independent data points given the substantial observed variation in pool parameters between years, especially with regards to depth and area. In effect, even though pools may be in similar geographical areas between years, the large variation in their physical extent and depth results in them representing variable stranding risks between years. The results of this dataset are summarized in Appendix 3 and assists in addressing MQ2.

4.3 Dataset 03 – Fish Presence and Annual Variability

This dataset was used to address MQs 4 and 6 and to determine if additional species of fish (particularly the four species of concern identified by BC Hydro) were being stranded in Year 3 that were not detected in Year 2 of field sampling. The results of this study are summarized in Appendix 4. While the focus of the field program was to sample as many pools as possible for fish presence, effort was not equal between years and between pools (Table 2, Table 3, 3.3 Pool Sampling, 3.4 Fish Survey Data).

Fishes were identified to the lowest possible taxonomic level. For those that were not identifiable to species, family or order was assigned. Dead and live fishes were documented; however, the true extent of dead fishes (i.e., number of pools containing dead fish as a result of stranding) in isolated pools could not be completely assessed due to probable predation and deterioration of dead fishes.

Two field sessions were performed in Year 2 – a fall 2017 and a spring 2018. Total pool sample size for Year 2 was the total number of pools sampled minus repeat sampling of pools in order to prevent pseudoreplication (i.e., an artificially inflated sample size) (Table 2). Sampling methods and fish data collection are described in Methods section 3.4 Fish Survey Data. Observed fish taxa were evaluated against elevation of the sampled pools to assess if elevation had an effect on species stranding.

4.4 Dataset 04 – Over-winter Fish Survival

The results of this dataset are summarized in Appendix 5 and are used to assist in answering MQ7. There are two components in this dataset:

1. Daily oxygen (mg/l) and temperature (°C) data (collected every 10 min during deployment) recorded on data loggers deployed in fall 2017 (one logger per pool) from six high elevation pools (between 747 and 753 mASL) that become isolated prior to winter freezing to evaluate conditions to support fish. These pools either contained fish (see Appendix 4), as observed from fish sampling directly prior (same day) to logger installment, or historically contained fish as anecdotal evidence from previous studies (Table 1).
2. Presence of fishes from repeat sampling of high elevation isolated pools (747−753 mASL) in fall 2017 prior to winter freezing and in spring 2018 after ice melt. Observed fishes from the sampling periods were identified to species and enumerated. Live fishes observed in spring 2018 suggested pools can support over-winter fish survival.

5.0 MANAGEMENT QUESTIONS

We summarize below our ability to address each of the management questions (MQ) as per the Terms of Reference (TOR; BC Hydro 2007a). Cumulative data analysis of Years 2 and 3 is primarily used to support each management question. These analyses are appended to this report as requested in a template provided by BC Hydro.

In addition to reporting relevant knowledge to address each MQ, recommendations are discussed.

5.1 MQ1: What is the extent of fish stranding as a result of annual drawdown of the reservoir?

Stranded fishes were observed to be widespread across all elevational ranges (720−753 mASL) in isolated pools in the drawdown zone (DDZ) of Kinbasket Reservoir and in high risk stranding areas (MQ2, Appendix 4). Fishes were stranded in 84% and 54% of pools sampled in spring of 2018 and 2019 respectively and varied considerably between reaches (25 to 95%). The risk of stranding did not differ with elevation, time of year pool becomes isolated, or pool surface area, but did increase with pool depth (MQ2, MQ5, Appendix 3).

Deeper pools (>30 cm) were rated as high risk to fish stranding and comprised of nearly 19% of all pools identified in Year 1 with a total surface area of 77.45 ha (0.54% of total reservoir area between 725 and 754 mASL), (Appendix 3; Hanson and Nadeau 2010). These pools occurred across the 29 m DDZ elevation within all identified high risk areas. As a result, the extent of fish stranding increased as the reservoir DDZ increased and exposing more pools. (MQ3, MQ4, MQ5). This suggests that the DDZ is the main factor affecting fish stranding in Kinbasket reservoir. The extent of fish stranding increased between January and May, and peaked during minimum annual reservoir level (i.e., low pool) which occurs in April (based on the most recent 20-year average hydrograph of Kinbasket Reservoir (Figure 1).

Fishes observed in this study were comprised of 12 species, of which Lake Chub (*Couesius plumbeus*), Redside Shiner (*Richardsonius balteatus*) and Prickly Sculpin (*Cottus asper*) were the most abundant and widespread, followed by smaller numbers of suckers (Largescale Sucker [*Catostomus macrocheilus*] and Longnose Sucker [*Catostomus catostomus*], whitefishes (Mountain Whitefish [*Prosopium williamsoni*] and Pygmy Whitefish [*Prosopium coulterii*]) and Peamouth (*Mylocheilus caurinus*) (MQ6, Appendix 4). Only three fishes of special concern (BC Hydro 2007a) were observed in isolated pools - one Bull Trout [*Salvelinus confluentus]* parr and two Kokanee [*Oncorhynchus nerka]* fry).

Recommendations:

The extent of fish stranding should be assessed to the minimum licensed operating elevation of 707.41 mASL as low pool reservoir elevation below 725 mASL was reached in six of the past 10 years (2010-2019) to a low of 714.92 mASL in 2019 (Figure 2). Pool inventory below 725 mASL can follow the same methodology as in Year 1 based on Korman and Buszowski (2000) using a LiDAR-based DEM from the most recent imagery available. Aerial surveys should be conducted to verify pool presence if reservoir elevation ever reaches near the minimum licensed operating elevation (<715 mASL). Likewise, field sampling of isolated pools could be conducted to assess fish presence. Based on previous low pool records, this would likely to occur between April and May.

Stranding rates observed in this study could be a concern as an important source of mortality if this level of stranding is persistent across years. Additional years of sampling would provide an indication of whether the observed stranding rates are typical or anomalous. In natural experiments, such as CLBMON-4, we rely on nature to provide a randomization of environmental factors that may be of interest. As such, additional years of sampling could provide exposure to differing environmental factors that may impact stranding rates, that can be used to better understand the mechanism behind stranding. To maximize sampling effort across the elevational gradient and when fish stranding is highest, field surveys should occur near low pool which is observed between April and May. This time period also allows improved access to reservoir reaches and pools as snow/ice has melted (Figure 4).

5.2 MQ2: Which areas of the reservoir have the greatest risk of fish stranding, and why?

Bush Arm, Canoe Reach, Columbia Reach and Gold River Arm of Kinbasket Reservoir were deemed areas of greatest risk to fish stranding due to the high proportion of isolated pools present in the DDZ between an elevational range of 725 and 754 mASL with a slope less than six percent (Appendix 2; Hanson and Nadeau 2010). The assumption for using a six percent slope as a threshold value was based on the results of a study by Bell et al. (2008), which investigated stranding mortality associated with water level fluctuations within a reservoir (Hanson and Nadeau 2010). A total of 6,548 pools were identified in Year 1, of which 4,989 (76%) pools were concentrated in Canoe Reach, Bush Arm, and Columbia Reach

Fish were present in 84% and 54% of pools sampled across this elevational gradient in all of these high risk areas in May 2018 and 2019 respectively (Appendix 4). Revision of the fish-stranding risk model developed in Year 1 (Hanson and Nadeau 2010) identified “pool depth” as the most important factor affecting fish stranding in the DDZ of Kinbasket reservoir (Appendix 3). A positive correlation was observed between pool depth and the presence of stranded fish, such that as depth increases, the likelihood of a fish being stranded increases. Pools with a depth greater than 30 cm were assigned high risk of stranding (derived from the fish stranding risk model) and comprised over 18% (Table 12) of pools identified in Year 1 which were distributed across all elevations in the high risk geographical areas mentioned above.

Recommendations:

The CLBMON-4 program addressed this MQ but is limited to a minimum elevation of 725 mASL that reflects current reservoir operations. See recommendation for MQ1.

5.3 MQ3: What is the area covered by isolated pools in the dewatered zone during maximum drawdown, relative to the total surface area of the drawdown zone?

Based on the digital elevation model (2002 aerial photography) conducted in Year 1, the total area covered by isolated pools in the DDZ of Kinbasket reservoir between elevation 725 and 754 mASL was 151.74 ha, which equated to 1.06% of the total reservoir DDZ area in that elevation range (Figure 5; Table 12; Hanson and Nadeau 2010). The minimum pool elevation cut-off of 725 mASL was based on current average-low operating levels (BC Hydro 2007a).

The helicopter overflight survey conducted on 08 May 2018 estimated that approximately 93% of pools identified in the DEM in Year 1 were not observed visually in 2018, which represented 31.4 ha (66%) of the total surface area covered by isolated pools (Table 8, Table 9). In addition, the 2018 aerial survey identified 227 new isolated pools distributed throughout the surveyed high risk fish-stranding areas. This suggests that the extent of fish stranding in Kinbasket Reservoir will vary temporally as the number and area of pools in the DDZ of Kinbasket Reservoir change indefinitely due to the dynamics of the DDZ and surrounding area (e.g., inflowing tributaries).

Recommendations:

The formation of pools down to Kinbasket Reservoir’s minimum licenced elevation of 707.41 mASL should be assessed as low pool has reached below 725.00 mASL six times in the past decade (2009−2019) (Figure 2). This can be performed using a LiDAR-based DEM using the most recent LiDAR imagery available, and through hydroacoustic surveys using a Biosonics MX Echosounder. These hydroacoustic surveys can be carried out any time of the year, thus avoiding winter conditions and ice cover. Hydroacoustic bathymetry mapping has a topographic delineation accuracy of 1.7 cm to a maximum depth of 100 m below the water’s surface.

LiDAR-based DEM analyses should also be conducted on a regular basis to better evaluate the extent of fish stranding over time since the six-percent low-gradient DDZ zone has been shown to be dynamic, affecting the presence of pools, which in turn will affect the extent of fish stranding as frequent as annually.

5.4 MQ4: What percentage of isolated pools contains stranded fish?

Eighty-four percent (n=42) and 54% (n=43) of isolated pools sampled in spring of 2018 and 2019 respectively contained fish, while sixty-eight percent (n = 66 of 79) of discrete pools sampled across both years contained fish (Appendix 4).

The revised fish-stranding risk model (Appendix 3) suggests that fish stranding risk increases with pool depth and that pools less than 10 cm deep pose the least risk to fish stranding. Therefore approximately 18% of pools identified in Year 1 are rated low risk to fish standing, and the remaining pools (>10 cm depth) have a moderate to high risk of fish stranding.

Dead fishes were observed in 16% (n = 16) of discrete pools sampled across both sampling years combined (Appendix 4) but did vary between years. Dead fish were present in 38% (n = 19) of sampled pools in spring 2018 and 14% (n = 11) of sampled pools in spring 2019. Dead fishes likely occurred in more pools but were removed by predation (Appendix 6) or deteriorated to the point of not being recognizable as fish.

Over-winter mortality is likely a major occurrence in isolated pools (Figure 16). As part of the data logger trip in February 2017 (Table 4), it was discovered that nine of the ten pools sampled between elevation 731 and 739 mASL were frozen from surface to bottom and any fishes stranded in these pools would have died.

Another likely factor in fish mortality is dewatering of pools. Over 70% of dried pools surveyed contained dead fishes, which comprised 79% of all dead fishes observed. Pool dewatering is likely common, as observed during the February 2017 data logger survey by observing the depth of clear ice (presence of liquid water prior to freezing) present in the drilled holes. The proportion of clear ice to snow ice indicated that pools contained less than 60% depth (average = 25%) of liquid water prior to freezing.

Recommendations:

The data collected in Year 2 and 3 have addressed this MQ; however, additional years of field sampling could further assess annual stranding variability, particularly under different ramping rates to determine if the rate of drawdown has any influence on fish stranding.

5.5 MQ5: At what time of year and/or reservoir elevations is stranding risk highest (e.g., at maximum drawdown)?

Fish stranding is highest in April when the greatest number of isolated pools was observed, a period of time that coincides with maximum low pool before refilling of the reservoir (Figure 1). Based on the DEM analysis in Year 1 that assessed the number and area of isolated pools between elevation 725 and 754 mASL, more than 60% of pools that become isolated from late January to mid April occur below 735 mASL (Figure 13, Figure 5). Although stranded fishes were observed in all elevations (e.g., 720−753 mASL), the greatest number (i.e., species and abundance) were present below 735 mASL (Appendix 4).

Recommendations:

CLBMON-4 addressed this management question. Additional years of field-level monitoring would better identify any apparent patterns in fish stranding, particularly with respect to the BC Hydro fish species of concern that were mostly absent in this study (Appendix 4).

5.6 MQ6: What fish species and life history stages are potentially most affected by stranding as the reservoir is drawn down?

Twelve species of fish were documented stranded in isolated pools of which cyprinids (mostly Lake Chub and Redside Shiner) and sculpins (Prickly Sculpin) were the most common species (across all elevations and years). Together these fishes comprised 57% of all identifiable fishes observed (Appendix 4). Forty-two percent of fish were not identifiable, of which 68% were dead and at in advanced state of decomposition. It is believed that most of these unidentifiable dead fish were sculpins, since nearly all dead identifiable observed fish were sculpins. Juvenile fishes comprised nearly 90% of all observed stranded fishes, however, a few adult suckers, cyprinids (Lake Chub, Redside Shiner, and Peamouth) and sculpins were also present. It was expected that cyprinids and sculpins would be the taxa most affected by stranding as the reservoir is drawn down since these species occupy the shallow (less than 10 m) littoral zone throughout the year, with minimal vertical or offshore movement (McPhail 2007). Sculpins are most at risk of mortality due to their benthic ecology (e.g., often bury in soft substrate, underneath rocks and woody debris) and more likely, than other species, to occupy shallower depressions, which dry out faster than deeper pools when exposed (McPhail 2007). Juvenile suckers (Longnose Sucker and Largescale Sucker) and whitefishes (Mountain Whitefish and Pygmy Whitefish) were also present in isolated pools in small numbers. Whitefishes (both species) were only observed in low elevation pools below 735 mASL while suckers were present at all elevations.

BC Hydro identified four fish species of concern (Bull Trout, Rainbow Trout [*Oncorhynchus mykiss*], Kokanee, and Burbot [*Lota lota*]) for which monitoring programs have been developed by the Columbia River WUP CC to better understand the risk of stranding for these species in Kinbasket Reservoir. Only two Kokanee fry and one Bull Trout parr were observed in isolated pools suggesting that these species are not at high risk of stranding in Kinbasket Reservoir. After spring emergence, Kokanee fry migrate to the pelagic zone of lakes, avoiding shallow areas where isolated pools are forming (McPhail 2007; Sebastian and Weir 2013). Habitat assessments conducted for CLBMON-6 indicated that juvenile Bull Trout in Kinbasket Reservoir occupy nearshore areas with abundant cover (e.g., cobble, large woody debris, and vegetation) (Kang and Warnock 2017). The single Bull Trout parr observed during the fall survey occurred in a high elevation pool (752.2 mASL) adjacent to the Bush River causeway that contained cobble, large woody debris, and aquatic vegetation. Vegetation cover was restricted to isolated pools above elevation 747 mASL. Studies conducted for CLBMON-5 suggested that Burbot might be at risk of stranding due to their spawn timing (January to April) in shallow littoral waters that coincides with the reservoir's highest drawdown rate (Kang et al. 2017). Despite this, no Burbot were observed in isolated pools surveyed for CLBMON-4.

Recommendations:

Although a few species of fish were not present in both sampling years (e.g., Kokanee, Bull Trout, Northern Pikeminnow (*Ptychocheilus oregonensis*) that occurred in very small numbers), the data collected in this program provided the information to address this management question. Additional years of sampling are suggested to identify any new fishes not previously documented in this study and to better assess the stranding risk and annual variability of certain species of interest (e.g., BC Hydro species of concern).

5.7 MQ7: Are operational or non-operational changes recommended to mitigate or to reduce the risk of fish stranding?

Operational Mitigation

Increasing maximum low pool elevation would reduce the number of stranded fishes by reducing the number and area of pools becoming isolated (Figure 5).

Fish stranding was observed at all elevations in high risk areas (Appendix 2; Hanson and Nadeau 2010) along the DDZ of Kinbasket Reservoir (Appendix 4). A greater number of fishes were observed below 735 mASL because this is where most pools were formed (Figure 5, Figure 13). According to the DEM analysis performed in Year 1, 61% of identified pools occurred within an elevation band of 725−735 mASL. Increasing low pool by 5 m from 725 to 730 mASL would reduce the number of isolated pools by 35% and isolated pool surface area by 48%.

Based on the two years of field surveys conducted for CLBMON-4, the four fish species of concern identified by BC Hydro are not at high risk of stranding (Appendix 4). However, the diet of Bull Trout, Rainbow Trout, and Burbot include fish species (e.g., minnows, sculpins, suckers, and whitefishes) that were observed stranded in large numbers in the DDZ of Kinbasket Reservoir (McPhail 2007).

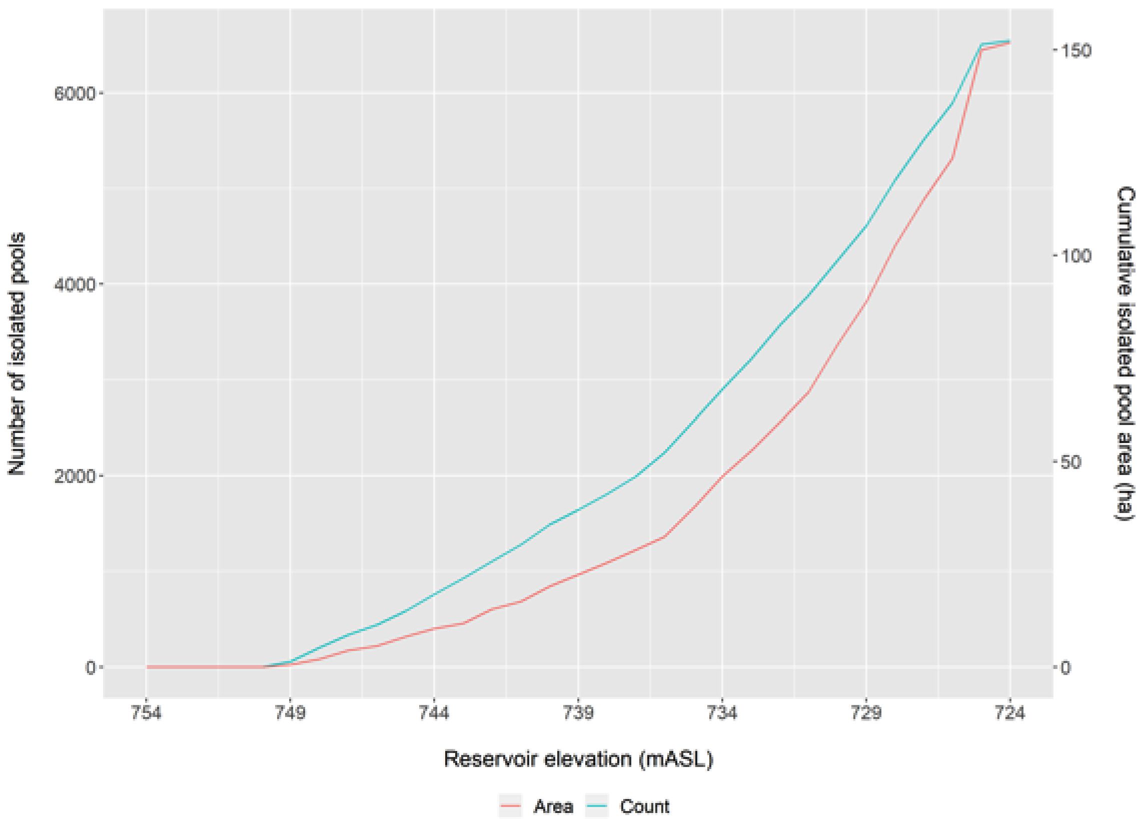


Figure 5. Area (ha) covered and number of isolated pools in the drawdown zone of Kinbasket Reservoir between elevation 725 and 754 mASL. Pool inventory developed in Year 1 from digital elevation model analysis based on 2002 aerial photography. Highest elevation pool was recorded at 749.3 mASL in a slope less than six percent. A total of 6,548 pools were identified with a total surface area of 151.74 ha.

Non-operational Mitigation

Physical works such as increasing slope (greater than six percent) and excavating outlet channels, to eliminate the formation of pools and reduce the risk of fish stranding, would likely only remain effective long-term in static environments (Bell et al. 2008; Nagrodski et al. 2012). The aerial overflight survey conducted on 08 May 2018 (to inventory isolated pools identified in Year 1) found that most pools (77%) that were documented in 2002 (DEM used in Year 1) were no longer present in the high risk fish stranding areas surveyed (Appendix 2). These findings concluded that all high risk fish stranding areas of Kinbasket Reservoir (between elevation 725 and 754 mASL with a slope less than six percent) are too dynamic for long-term effective physical work mitigations.

Recommendations and Uncertainties:

It is unknown whether stranding in Kinbasket reservoir has an overall negative impact on fish populations, or on the trophic relationships (i.e., indirect impact) between species and the BC Hydro fish species of concern (Bull Trout, Rainbow Trout, Kokanee, Burbot). Future studies are recommended to better understand species distribution and habitat use to evaluate the impact of reservoir drawdown on the species most affected and those indirectly affected.

To better inform the use of non-operational mitigations (e.g., physical works) to reduce fish-stranding in the DDZ of Kinbasket Reservoir, a more accurate assessment on the dynamics (i.e., pool shifting, presence of pools) of high risk fish-stranding areas is recommended. This would include a DEM comparison between the 2002 aerial imagery (used in Year 1) and the most current LiDAR imagery available. Only areas that appeared to remain mostly unchanged over time should be the focus of physical works such as re-contouring and channelization in order for those changes to remain effective long-term.

6.0 CONCLUSION

This monitoring program (CLBMON-4) is the first systematic study to investigate the extent of fish stranding in Kinbasket Reservoir, and the methods deployed found that fish stranding in isolated pools in the DDZ is widespread in its major reaches (e.g., Canoe Reach, Columbia Reach, Bush Arm) deemed high risk to fish stranding (slope less than six percent). The extent of stranding was observed across the vertical distance of the DDZ sampled (720-753 mASL), which suggests that elevation does not appear to be a factor in a fish becoming stranded in an isolated pool. However, the greatest presence of stranded fish was observed below 735 mASL due to the increased number of pools available. Sixty percent of all pools identified through the DEM analysis in Year one occurred in a 10 m range between 725 and 735 mASL. A revised fish-stranding risk-ranking model determined that depth was the only variable influencing fish stranding, such that deeper pools are more likely to contain stranded fish. Pools with a depth of less than 10 cm were considered low risk, while pools greater than 30 cm were considered high risk to fish stranding.

Most isolated pools likely contain stranded fish since 84% and 54% of pools sampled in 2018 and 2019 respectively, contained fish. Twelve species of stranded fish comprising of 4,035 individuals sampled across both years were identified. Sculpins (Prickly Sculpin was the only identifiable species) and cyprinids (mostly Redside Shiner and Lake Chub) comprised 52% of all identifiable fish observed. Of the four species of concern identified by BC Hydro, a single Bull Trout and two Kokanee were documented, which represents a low risk of stranding for these species. Bull Trout is a provincial species of special concern (blue-listed) and a federal species of concern (COSEWIC 2012). Ninety percent of fish were of juvenile age class. Dead fish comprised 32% of all fish observations, of which 99% were sculpins. The benthic behaviour of sculpins likely poses this group the greatest risk of stranding in Kinbasket Reservoir. It is unknown if stranding has a significant impact on local species populations or with trophic relationships between other species, but it appears anecdotally that sculpins and cyprinids are abundant throughout the reservoir, and that stranding may not have a serious impact to these species. Additional years of sampling with controls in non-isolated waters, and trophic-level studies (with larger species) would provide the necessary data to respond to this subject.

Mitigation measures to reduce fish stranding are limited and mostly uncertain, but the most effective approach would be an operational shift that reduces the number of isolated pools by increasing minimum low pool level as much as possible. For example, increasing minimum low pool by 5 m from 725 to

730 mASL would reduce the number of pools by 35% and a pool surface area by 48%. The helicopter overflight survey in May 2018 determined that 77% of pools identified in the Year 1 DEM (based on 2002 imagery) analysis were not present. Thus, non-operational mitigations such as surface re-contouring and increased pool connectivity via channelization are not likely to maintain effective long term due to the dynamic environment of the DDZ.

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8.0 PHOTOS

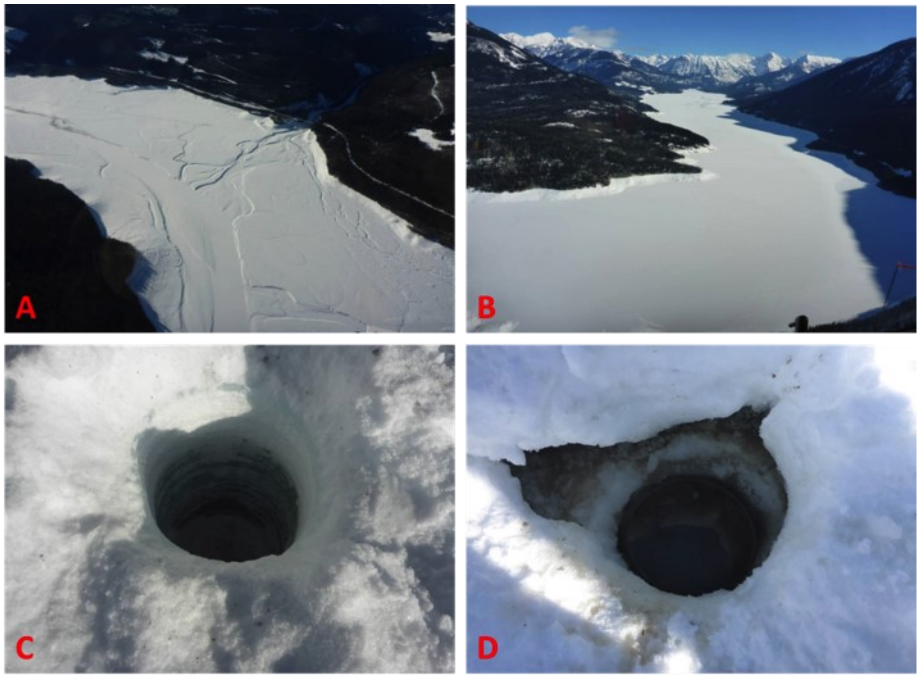


Photo 1. Winter conditions during the 28 February 2017, data logger survey. A. Looking upstream at Columbia Reach at the confluence with Beaver River. B. looking upstream in Bush Arm. C. Drilled hole of a completely frozen isolated pool. D. Drilled hole of an isolated pool with presence of liquid water (only 10 cm deep).

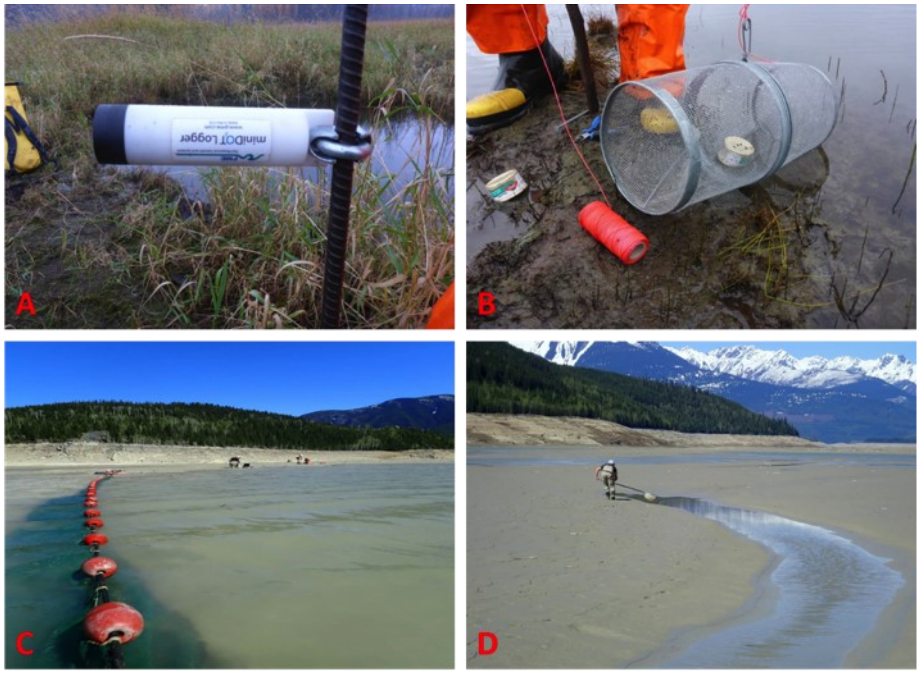


Photo 2. **Example of sampling methods conducted in isolated pools along the drawdown zone of Kinbasket Reservoir.** A. MiniDOT data logger deployed in a high elevation pool in fall 2017. B. Minnow trap baited with canned cat food. C. Beach seine net deployed in a large low elevation isolated pool. D. Dip netting was an effective method for catching fish in shallow isolated pools.

Photo 3. **Isolated pools sampled in the drawdown zone of Kinbasket Reservoir near Bear Island.** A. High elevation pool (752.47 mASL) with hydrologic connectivity via beaver dam in October 2017, and B. May 2018. C. High elevation (750.66 mASL) isolated pool in October 2017, and D. May 2018.

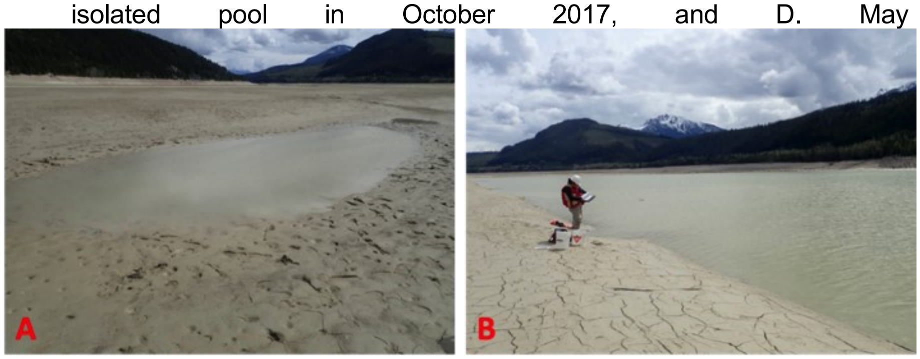


Photo 4. **Isolated pools located at low elevation (below 735 mASL) sampled in May 2018.** All isolated pools below 747 mASL were bare of vegetation. Fifty percent of pools identified in Year 1 were located below 733 mASL.

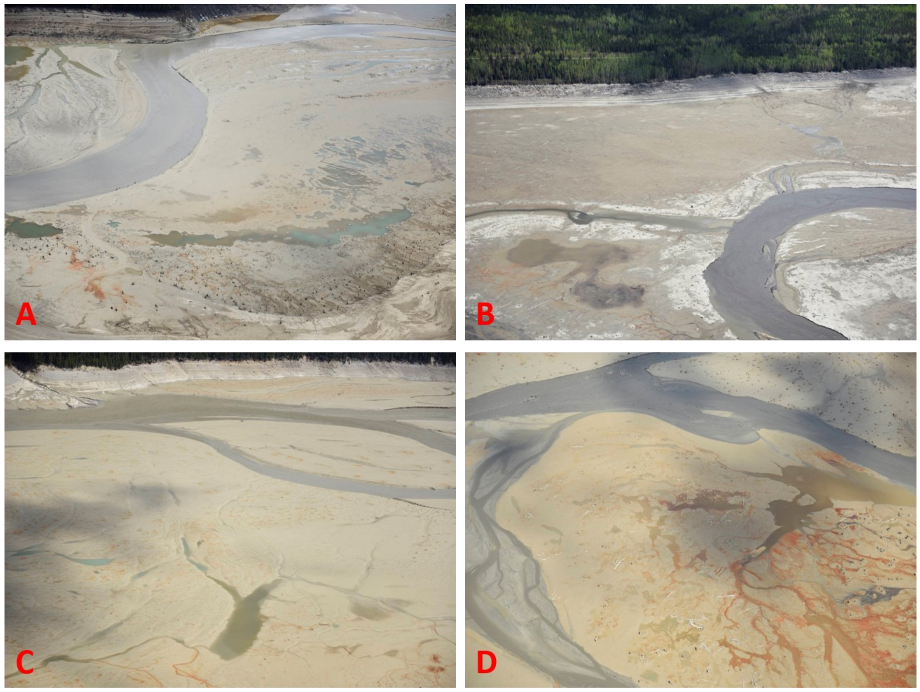


Photo 5. Aerial imagery of the drawdown zone of Kinbasket Reservoir from the 08 May 2018 helicopter overflight survey. A. Bush Arm B. Canoe Reach C. Columbia Reach D. Gold River Arm. Reservoir elevation at 722.34 mASL.

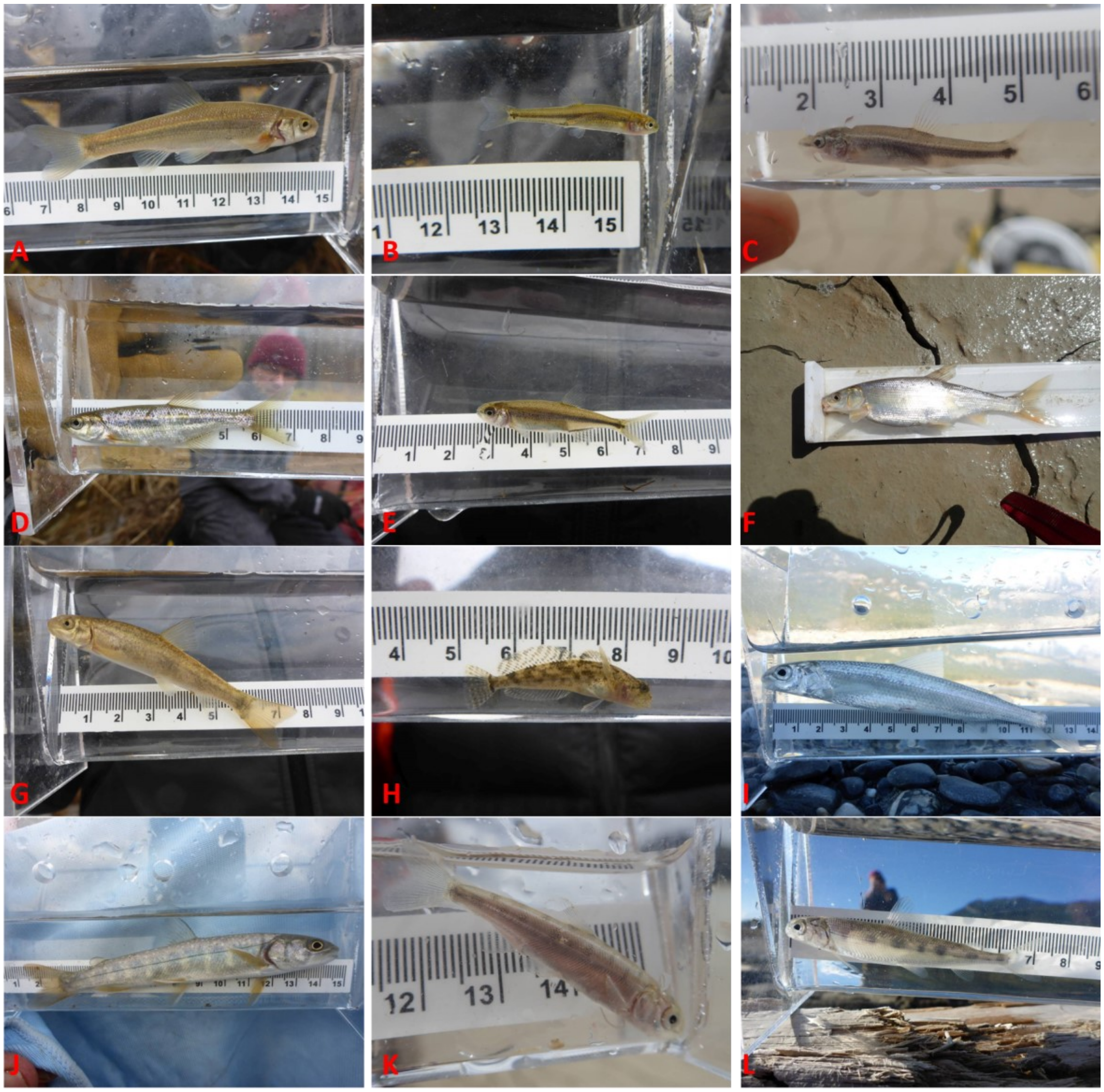


Photo 6. **Fishes captured in isolated pools.** A. Lake Chub (*Couesius plumbeus*) adult. B. Lake Chub juvenile. C. Longnose Dace (*Rhinichthys cataractae*) juvenile. D. Redside Shiner (*Richardsonius balteatus*) adult. E. Redside Shiner juvenile. F. Peamouth (*Mylocheilus caurinus*) adult. G. Longnose Sucker (*Catostomus catostomus*) juvenile. H. Prickly Sculpin (*Cottus asper*) juvenile. I. Pygmy Whitefish (*Prosopium coulterii*). J. Bull Trout (*Salvelinus confluentus*) parr. K. Kokanee (*Oncorhynchus nerka*) fry, L. Mountain Whitefish (*Prosopium williamsoni*).

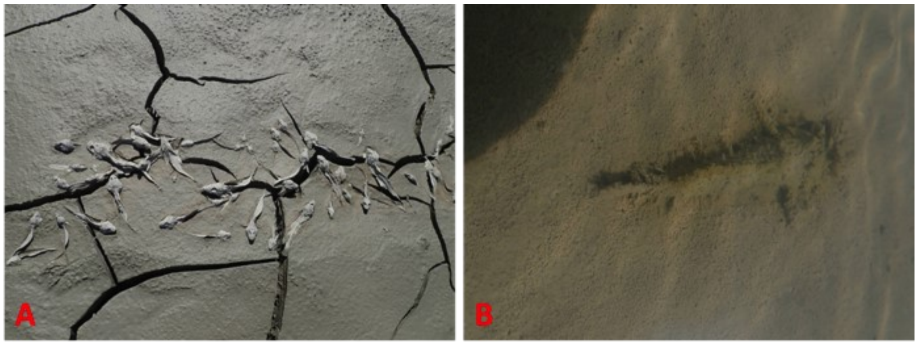


Photo 7. **Dead fish comprised 25% of all fishes observed and were present in 15% of pools sampled.**

Photo 8. **Tracks were the most common sign of wildlife observed at isolated pools in the drawdown zone of Kinbasket Reservoir.**

APPENDICES

Appendix 1. Timeline of CLBMON-4

Although anecdotal observations of juvenile fishes stranded in isolated pools have been reported (RSMI 1994), there have been no systematic studies undertaken to determine the extent of fish stranding in the DDZ of Kinbasket Reservoir under various discharges and drawdown conditions, nor the impact of fish stranding on fish populations (BC Hydro 2007a). During the Columbia River Water Use (WUP) planning process, the WUP Consultative Committee (WUP CC) acknowledged that further work was required to assess the effects of reservoir drawdown on pool formation and potential fish stranding. They proposed a 2-year study to inform future water use planning decisions.

In 2007, CLBMON-4, a 3-year program was submitted to qualitatively evaluate the extent of fish stranding caused by the annual drawdown of Kinbasket Reservoir and included the following seven management questions:

MQ1: What is the extent of fish stranding as a result of annual drawdown of the reservoir?

MQ2: Which areas of the reservoir have the greatest risk of fish stranding, and why?

MQ3: What is the area covered by isolated pools in the dewatered zone during maximum drawdown, relative to the total surface area of the drawdown zone?

MQ4: What percentage of isolated pools contains stranded fish?

MQ5: At what time of year and/or reservoir elevations is stranding risk highest (e.g., at maximum drawdown)?

MQ6: What fish species and life history stages are potentially most affected by stranding as the reservoir is drawn down?

MQ7: Are operational or non-operational changes recommended to mitigate or to reduce the risk of fish stranding?

The Kinbasket Reservoir fish stranding assessment program was initiated with a desktop assignment (Year 1) in 2009/2010, conducted by Summit Environmental Consultants Inc. (Hanson and Nadeau 2010). This component of the program was composed of a stranding risk assessment to identify key areas of the reservoir at high risk of fish stranding and to inventory all pools within a 29 m elevation zone between 725 and 754 mASL. A fish-stranding risk model was developed from four criteria to facilitate planning of the field component of the program. The results of Year 1 addressed MQ1, 2, 3, and 5.

The field component (Year 2 and 3) was conducted by Yucwmenlúcwu and LGL Limited and served to validate the results produced in Year 1 and to address MQ 4, 6, and 7. Ground level surveys for Year 2 and 3 commenced in February 2017 through to May 2019 (Table 5). The initial trip in February 2017 to deploy data loggers in low elevation (and high risk) isolated pools was unsuccessful as all pools sampled were completely frozen. A second data logger trip was performed in October 2018 in high elevation pools prior to winter freezing. Fish sampling of isolated pools occurred in October 2017 and May 2018 and 2019. Gold River Arm and lower Columbia Reach were only sampled in May 2019 as they were accessed by helicopter. Results from the field data collected in Year 2 did not fit the fish-stranding risk model developed in Year 1. A revision of the model was made in Year 3 and incorporated data collected in Year 3. The result suggested that pool depth was the only reviewed criterion that influenced fish stranding. A helicopter overflight survey (to obtain photography imagery) of the high risk areas identified in Year 1 was executed on 08 May 2018, just prior to ground-level pool sampling, to verify and inventory the presence of pools identified in Year 1 (digital elevation model based on 2002 aerial imagery). Results from the 2018 helicopter overflight, and observations made by the ground crew, discovered that most previously identified pools no longer existed and that new pools formed. Field sampling in Year 3 was based on an opportunistic approach, as pool inventory from Year 1 was no longer reliable. Sampling was conducted on as many pools as possible in each high risk area across the exposed DDZ elevation within the budgeted time frame.

Table 5. Field surveys and associated tasks conducted in 2017−2019 for Year 2 and Year 3 of CLBMON-4. Reservoir elevation was obtained from BC Hydro and pool elevation was based on a LiDAR-derived digital elevation model from 2014.

Survey date	Project year	Reservoir elevation (mASL)	Main tasks
2017			
28 February	Year 2	731.0	DO Logger Deployment in low elevation pools (below 740 mASL) in Bush Arm and Columbia Reach. No loggers deployed. Nine pools frozen. Tenth pool only contained 10 cm of water.
24−26 October	Year 2	748.4	Deployed six DO loggers and surveyed 14 isolated pools at high elevation (747.0−752.4 mASL) in Bush Arm.
2018			
5 May	Year 2	721.2	LGL wildlife crew retrieved three DO loggers from Bush Arm.
8 May	Year 3	722.3	Helicopter aerial overflight of Kinbasket Reservoir. Digital photos obtained along DDZ of Bear Island, Bush Arm, Bush Harbour, Canoe Reach, Columbia Reach, Gold River Arm to inventory isolated pools.
10 May	Year 2	723.2−726.0	Surveyed 50 isolated pools (elevation 724.0−752.4 mASL) in Bear Island, Bush Arm, Canoe Reach and Columbia Reach.
11−16 May	Year 2	723.6	Final three DO loggers retrieved from Bush Arm/Bear Island.
2019			
22−28 May	Year 3	720.7−723.0	Surveyed 79 isolated pools (elevation 720.0−752.2 mASL) in Bear Island, Bush Arm, Canoe Reach, Columbia Reach and Gold River Arm (not sampled in 2018).

Appendix 2. Validation of Pool Presence Identified in Year 1

Introduction

The extent of fish stranding in isolated pools formed in the drawdown zone (DDZ) of hydroelectric reservoirs is poorly known. Pool identification and enumeration in the DDZ of Kinbasket Reservoir between elevation 725 and 754 mASL with a slope less than six percent was performed in Year 1 to address management questions (MQ) 1, 3, and 5. An aerial survey obtaining digital photographs of the DDZ was then executed to verify the presence of these pools and determine if any of the high risk areas (regions concentrated with pools) showed minimal shifting of pools (i.e., small change in number and location of pools) between the date of the DEM used (2002) and the aerial survey (2018) to address any potential non-operational mitigation measures (MQ7) to minimize fish stranding.

Methods

Details on the methods identifying DDZ regions of the reservoir with a slope less than six percent and pool identification/enumeration are found in the Year 1 report. This appendix details the methods performed in Years 2 and 3 to validate pools identified in Year 1.

Minimum annual reservoir level was recorded on 24 April 2019 at an elevation of 719.33 mASL. A helicopter overflight survey was conducted on 08 May 2019 at a reservoir elevation of 722.34 mASL and targeted areas identified as high risk of fish stranding due to the presence of large numbers of pools (Year 1; Map 2; Table 6, Table 7; Photo 5). Flight survey elevation was at 1,000 m altitude at a speed of 60 knots. A geospatially referenced track of the flight path was recorded by the pilot with a Garmin GPS unit. The flight path travelled along the reservoir, facing the DDZ beginning along a north–south direction looking westward, and then pivoting 180° and going south–north looking eastwards. Geospatially referenced digital photographs were taken using a Nikon D810 with AF-S Nikkor 24–70 mm f/2.8G lens. Photos were taken from the rear left position of the helicopter at a frequency of 5−9 seconds per frame in order to capture overlap of pool and shoreline features. Time between frames varied as the autofocus of the camera established focus. Camera position was offset by approximately 60° from the direction of the flight path and at a downward angle (approximately 15–20°) to capture the entire extent of the DDZ. A total of 570 digital photos were obtained during this survey.

Table 6. **Geographical regions of Kinbasket Reservoir surveyed on 08 May 2018**, via helicopter overflight to inventory presence of isolated pools, identified in Year 1, formed in the drawdown zone. Reservoir area based on the maximum licenced reservoir elevation of 754.4 mASL.

Location/Reach	Area (km^2)	% of reservoir area
Bear Island	3.11	0.72
Bush Arm	27.04	6.29
Bush Harbour	2.35	0.55
Canoe Reach	24.05	5.59
Columbia Reach	38.25	8.89
Gold River Arm	6.60	1.53
Total surveyed area	101.40	23.57
Unsurveyed area	328.90	76.43
Total reservoir area	430.30	100.00

Table 7. **Helicopter overflight survey transects** of the study areas (regions identified as having high concentrations of isolated pools) conducted along the drawdown zone of Kinbasket Reservoir on 08 May 2018.

Location/Reach	UTM 11 (E) Start	UTM 11 (E) End	UTM 11 (N) Start	UTM 11 (N) End
Bear Island	455419	452722	5735871	5736390
Bush Arm	474989	459612	5739752	5735280
Bush Harbour	462166	458783	5730780	5734638
Canoe Reach	362858	353494	5837771	5850103
Columbia Reach	477522	458449	5706437	5729079
Gold River Arm	450599	455083	5727111	5730344

Dataset

See 4.1 Dataset 01 – Isolated Pool Verification. This dataset was generated in ArcGIS and created to validate the presence of pools identified in Year 1, and to identify which high risk areas of the reservoir pools were static or variable (i.e., pools are absent since the DEM used in Year 1). Pools that were not identified in Year 1 (likely formed afterwards) were assigned as new pools and are included in this dataset. UTM 11 coordinates and elevation were assigned to each new pool.

Analyses

To contrast the presence of pools identified in Year 1 against pools documented in digital imagery obtained during the aerial overflight, a visual assessment was conducted to compare the shape and location of pools in the georeferenced photos (along a georeferenced track line collected from the helicopter) to pool shape files (Year 1) in the ArcGIS map. The discrete shapes of larger pool shapefiles and the georeferenced track line served as a starting point to document existing pools. If pools in the photos and ArcGIS map matched shape and location, then the pool shapefile in ArcGIS (Year 1) was re-designated as present. If a pool identified in Year 1 was not located in the photo, then that pool was designated as not present. The aerial photos, however, did not capture all surfaces of the target study areas, therefore pools from Year 1 in these missed areas were designated as unknown. The appearance of pools in the aerial photographs that were not located in ArcGIS (Year 1) were designated as new pools. The presence of existing Year 1 pools and new pools were tallied for each of the six high risk areas identified in Year 1:

- Bear Island
- Bush Arm
- Bush Harbour
- Canoe Reach
- Columbia Reach
- Gold River Arm

Pool shifting dynamics were evaluated by determining the proportion of Year 1 pools absent in each study high risk area to assign focus-areas for potential non-operational mitigations. High risk areas where Year 1 pool presence was greater than 50% (i.e., most pools) were deemed probable suitable sites for mitigation measures.

Results

Of the 570 digital photographs taken during the helicopter aerial survey in the six geographical areas deemed high risk fish stranding (Map 2), approximately 5,559 Year 1-identified pools were assessed for presence and absence (Table 8, Table 9). This equates to 85% of all pools identified from the 2002 DEM of Kinbasket Reservoir along elevation 725−754 mASL and nearly a quarter of the surface area of the reservoir at maximum licenced full pool of 754.38 mASL (Table 6). Only 7.3% of Year 1 pools remained present in the high risk areas, ranging from 2.8% (Bush Harbour) to 15.5% (Gold River Arm) in the six geographical areas surveyed. The presence of an additional 15% of pools remained unknown. Over 77% of pools were absent, ranging from 70.2% (Gold River Arm) to 88.3% (Canoe Reach) across the survey areas. New pools were documented in all survey areas in elevation above 725 mASL, counts ranged from 14 (Canoe Reach) to 89 (Bush Arm) for a total of 181 new pools in the 101 km^2 of surveyed area.

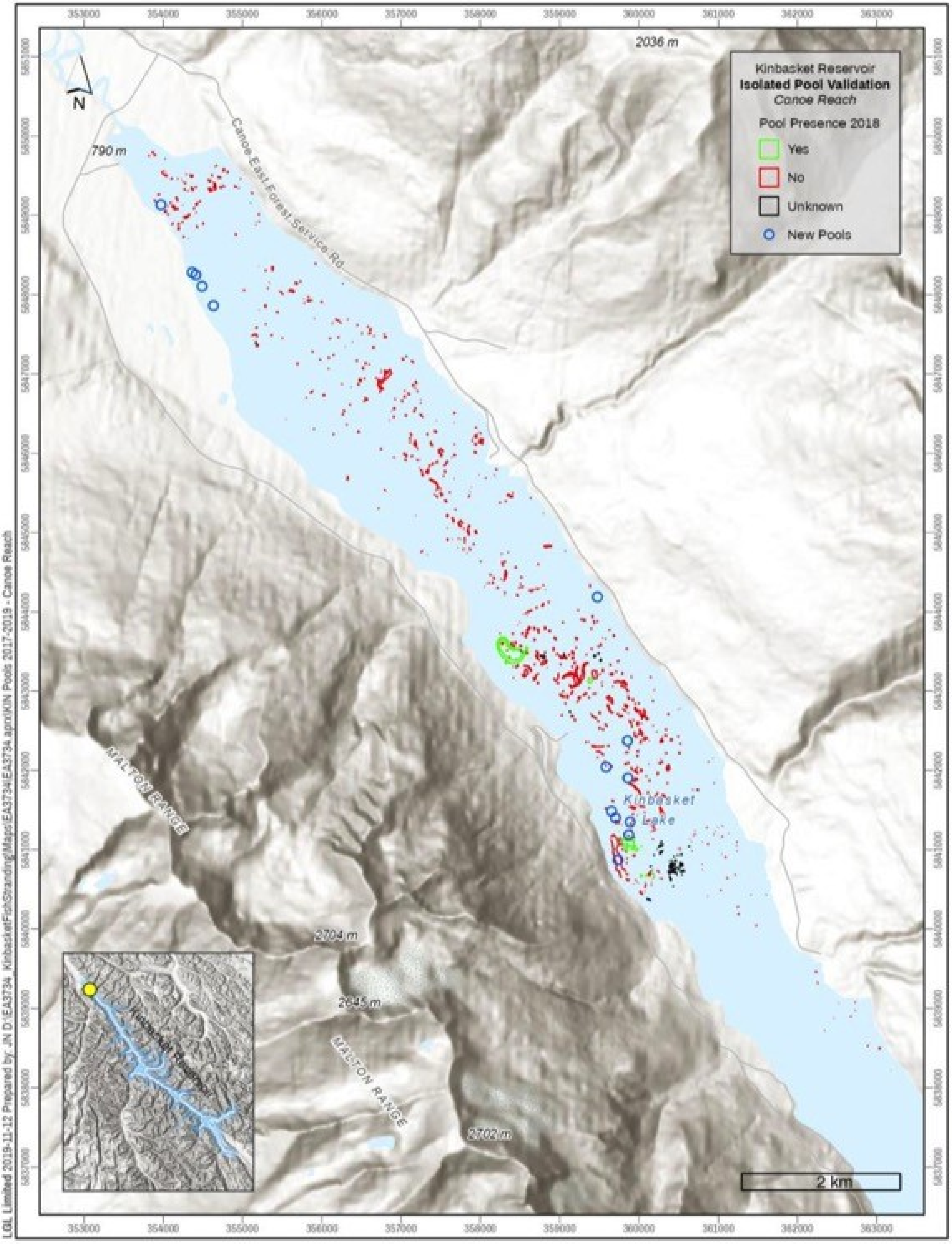
Table 8. The number of isolated pools present in the drawdown zone of Kinbasket Reservoir during the 08 May 2018 aerial survey. Reservoir elevation was 722.34 mASL. Year 1 identified pools between elevation 725 and 754 mASL. Percentages are in brackets. Digital elevation model (DEM) based on 2002 aerial photography, flown at an elevation of 714 mASL.

Location/Reach	Year 1 (DEM 2002)	08 May 2019 survey			
		Present	Not present	Unknown	New pools ≥725 mASL
Bear Island	85	8 (9.4)	69 (81.2)	8 (9.4)	16
Bush Arm	1,825	139 (7.6)	1,291 (70.7)	395 (21.6)	89
Bush Harbour	109	3 (2.8)	73 (67)	33 (30.3)	18
Canoe Reach	848	15 (1.8)	749 (88.3)	84 (9.9)	14
Columbia Reach	2,131	151 (7.1)	1,729 (81.1)	251 (11.8)	22
Gold River Arm	561	87 (15.5)	394 (70.2)	80 (14.3)	22
Total surveyed	5,559	403 (7.3)	4,305 (77.4)	851 (15.3)	181
Unsurveyed	989				
Total	6,548				

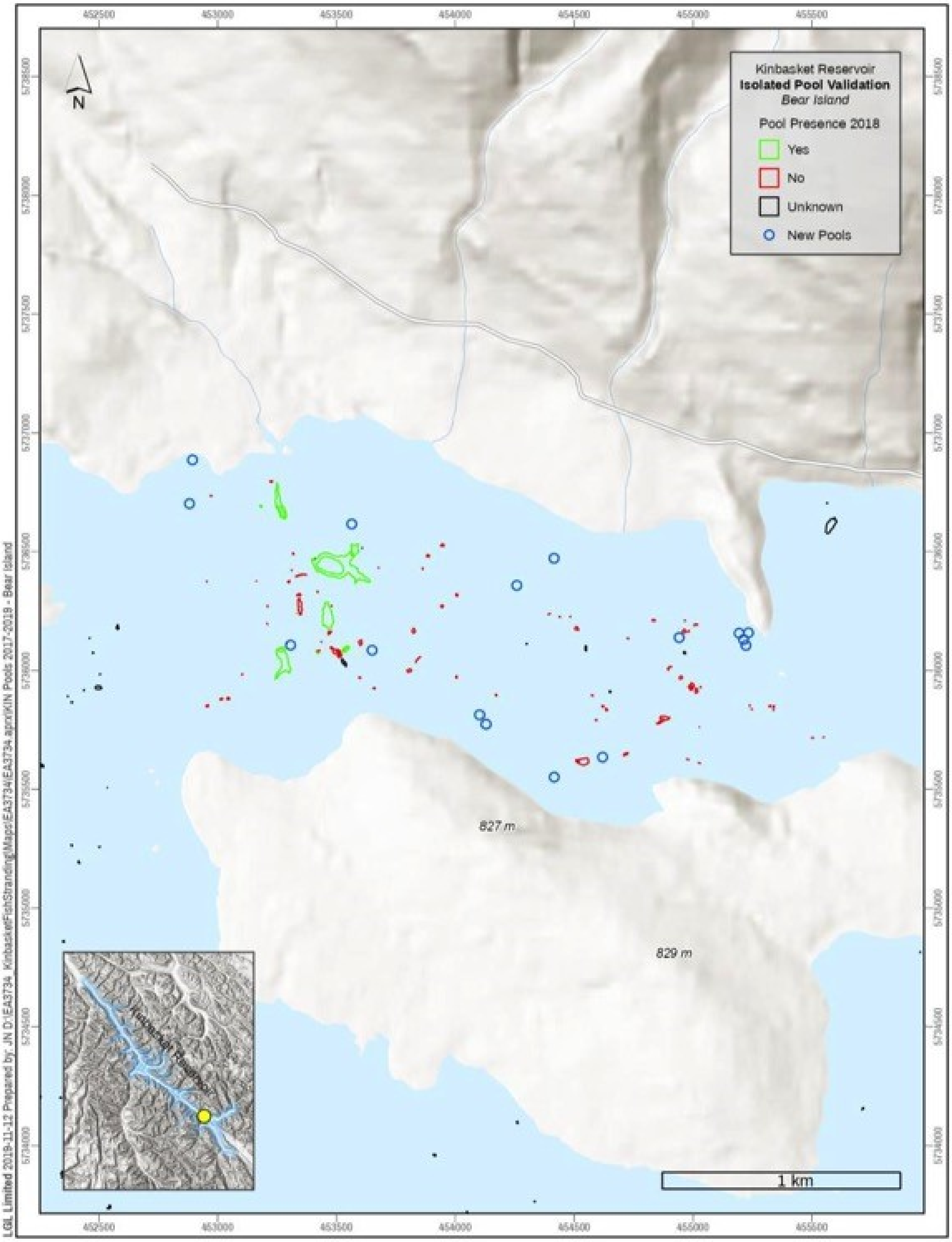
Table 9. Area cover (ha) of isolated pools present in the drawdown zone of Kinbasket Reservoir during the 08 May 2018 aerial survey. Reservoir elevation was 722.34 mASL. Year 1 identified pools between elevation 725 and 754 mASL. Percentages are in brackets. Digital elevation model (DEM) based on 2002 aerial photography, flown at an elevation of 714 mASL.

Location/Reach	Year 1 (DEM 2002)	08 May08 2019 survey		
		Present	Not present	Unknown
Bear Island	2.70	2.0 (74.1)	0.6 (22.2)	0
Bush Arm	49.40	10.2 (20.6)	32.5 (65.8)	6.7 (13.6)
Bush Harbour	0.90	0.2 (22.2)	0.5 (55.6)	0.2 (22.2)
Canoe Reach	15.80	1.4 (8.9)	13.5 (85.4)	0.9 (5.7)
Columbia Reach	63.80	15.6 (24.5)	44.4 (69.6)	3.8 (6.0)
Gold River Arm	12.60	2.0 (15.9)	8.3 (65.9)	2.3 (18.3)
Total surveyed	145.10	31.4 (21.6)	99.7 (68.7)	14.0 (9.6)
Unsurveyed	6.64			
Total	151.74			

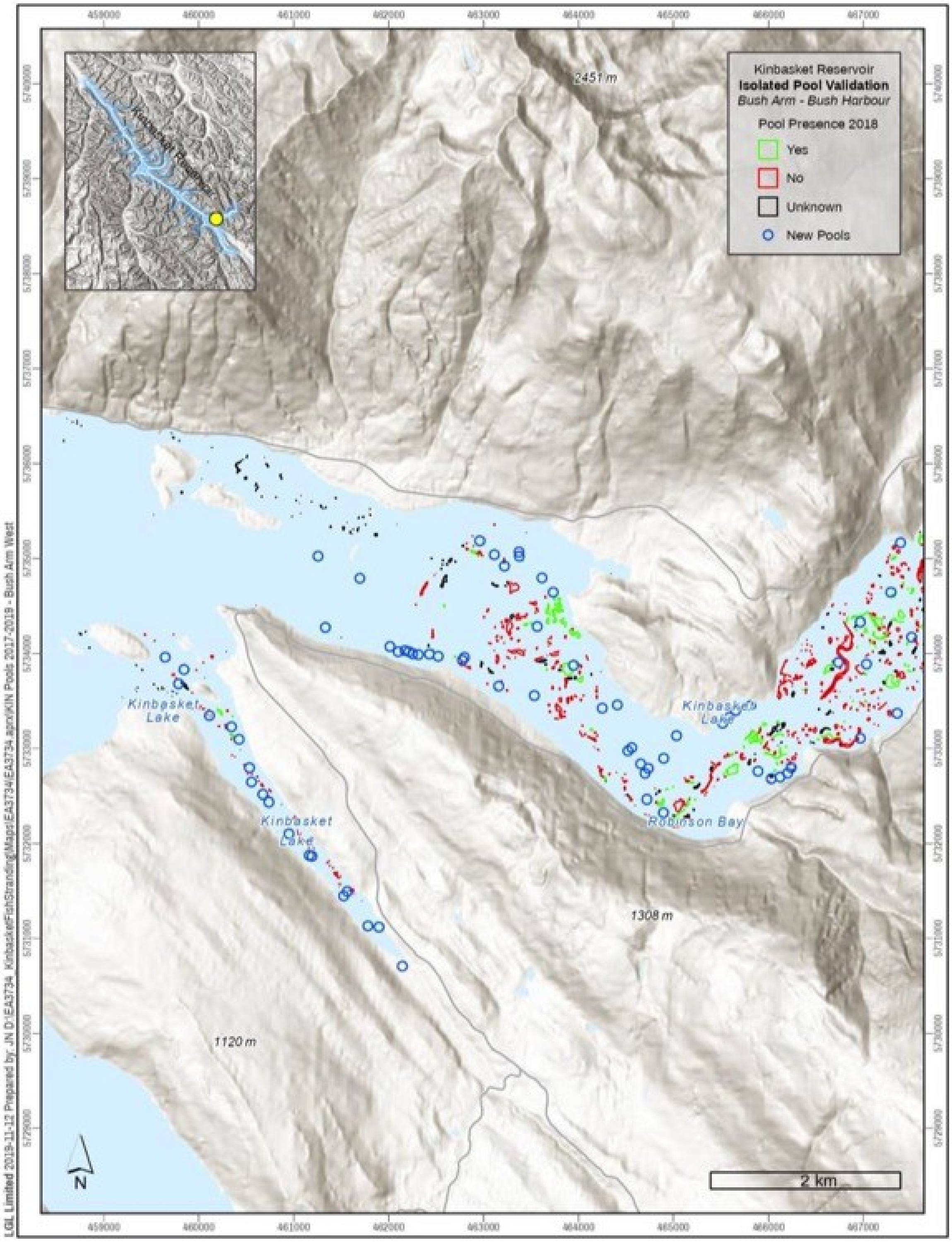
The distribution of existing pools (identified in Year 1) ranged across the elevational gradient (Map 4 to Map 7). The presence of existing Year 1 pools in Bush Arm was primarily concentrated in the southwestern bend near Robinson Bay. New pools were likewise widely distributed and did not appear to be concentrated in any particular section of each surveyed area.



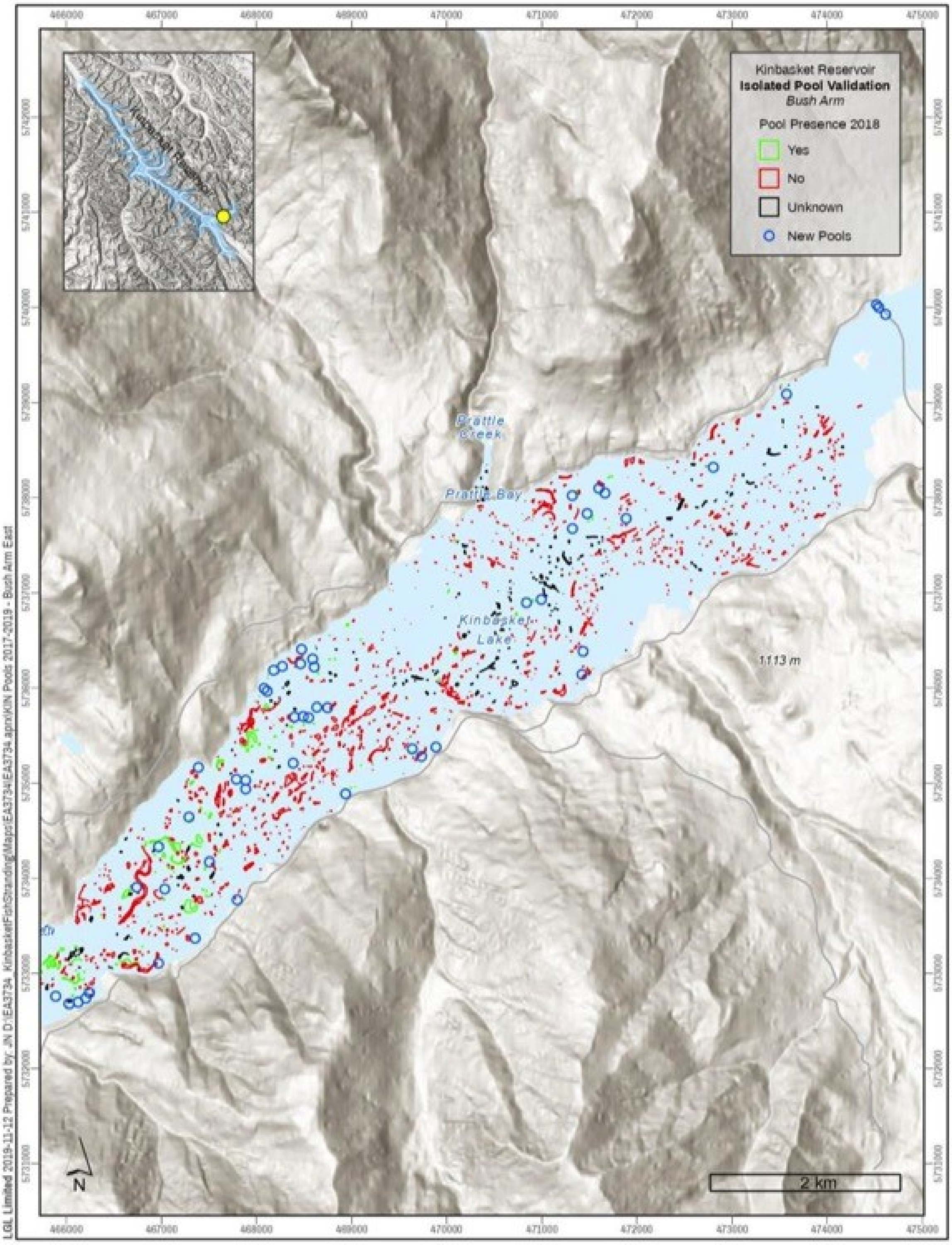
Map 3. **Canoe Reach of Kinbasket Reservoir.** The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.



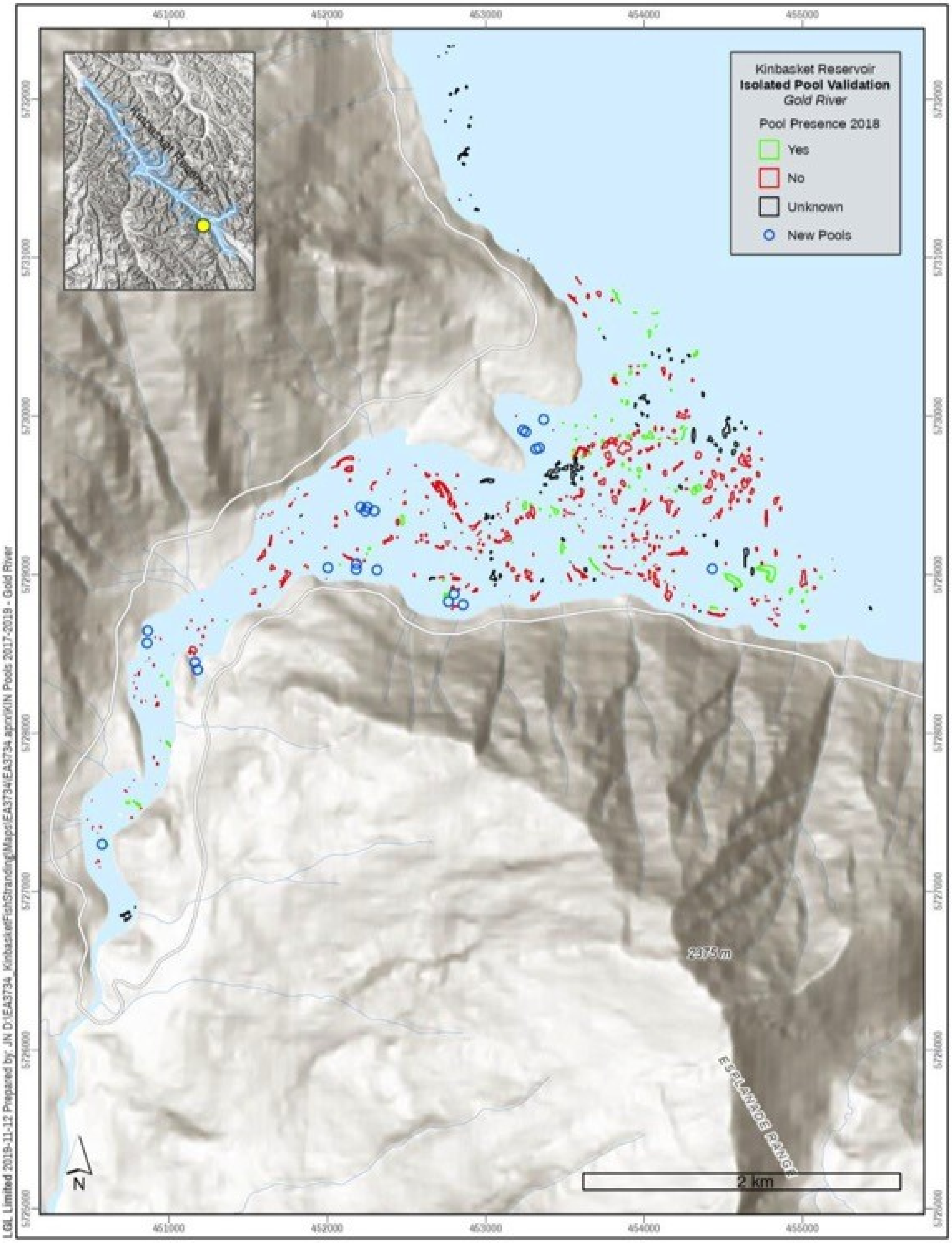
Map 4. **Bear Island (KM88 along Bush River FSR) of Kinbasket Reservoir.** The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles “New Pools” denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.



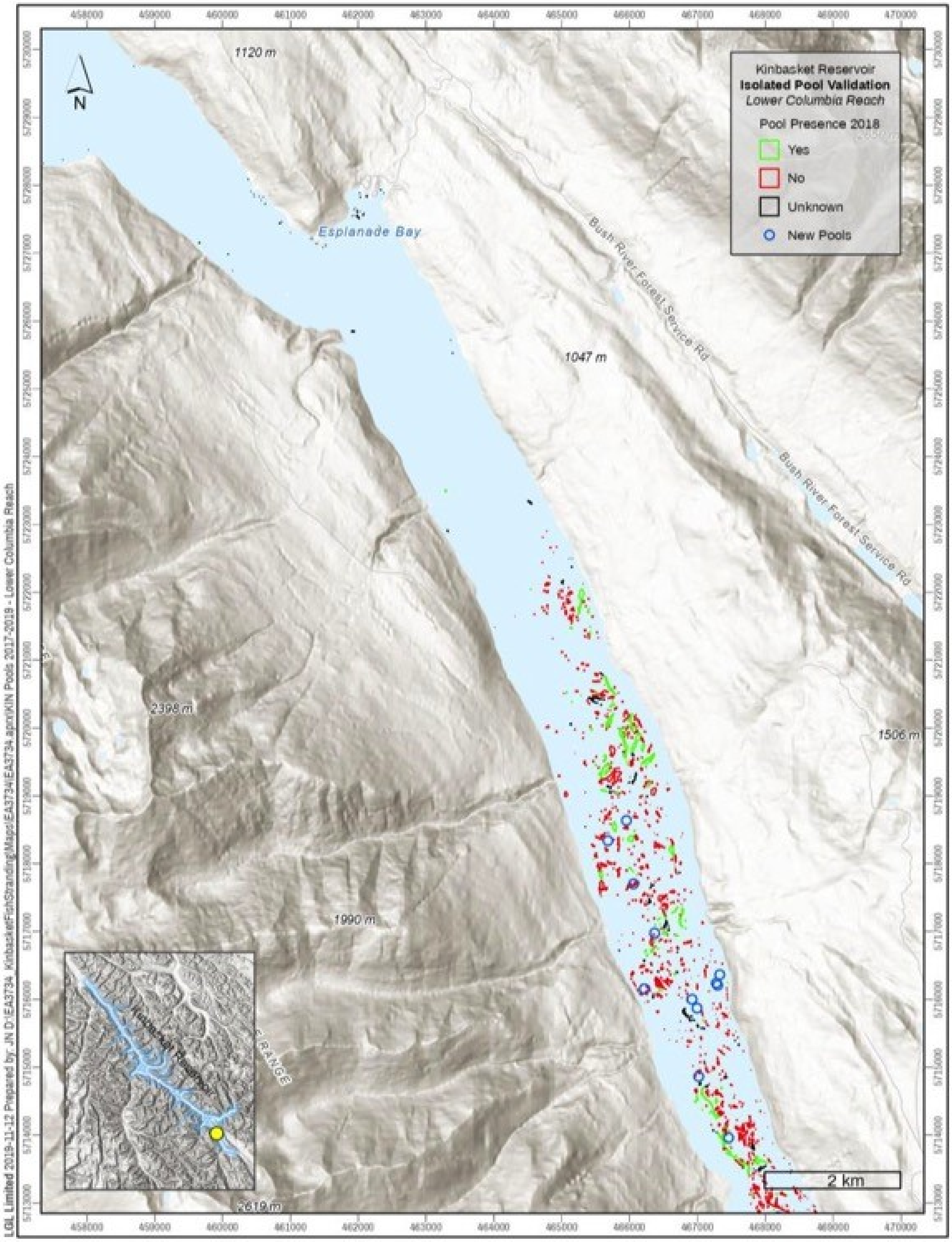
Map 5. **Lower Bush Arm (KM79 along Bush River FSR) and Bush Harbour of Kinbasket Reservoir.** The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles “New Pools” denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.



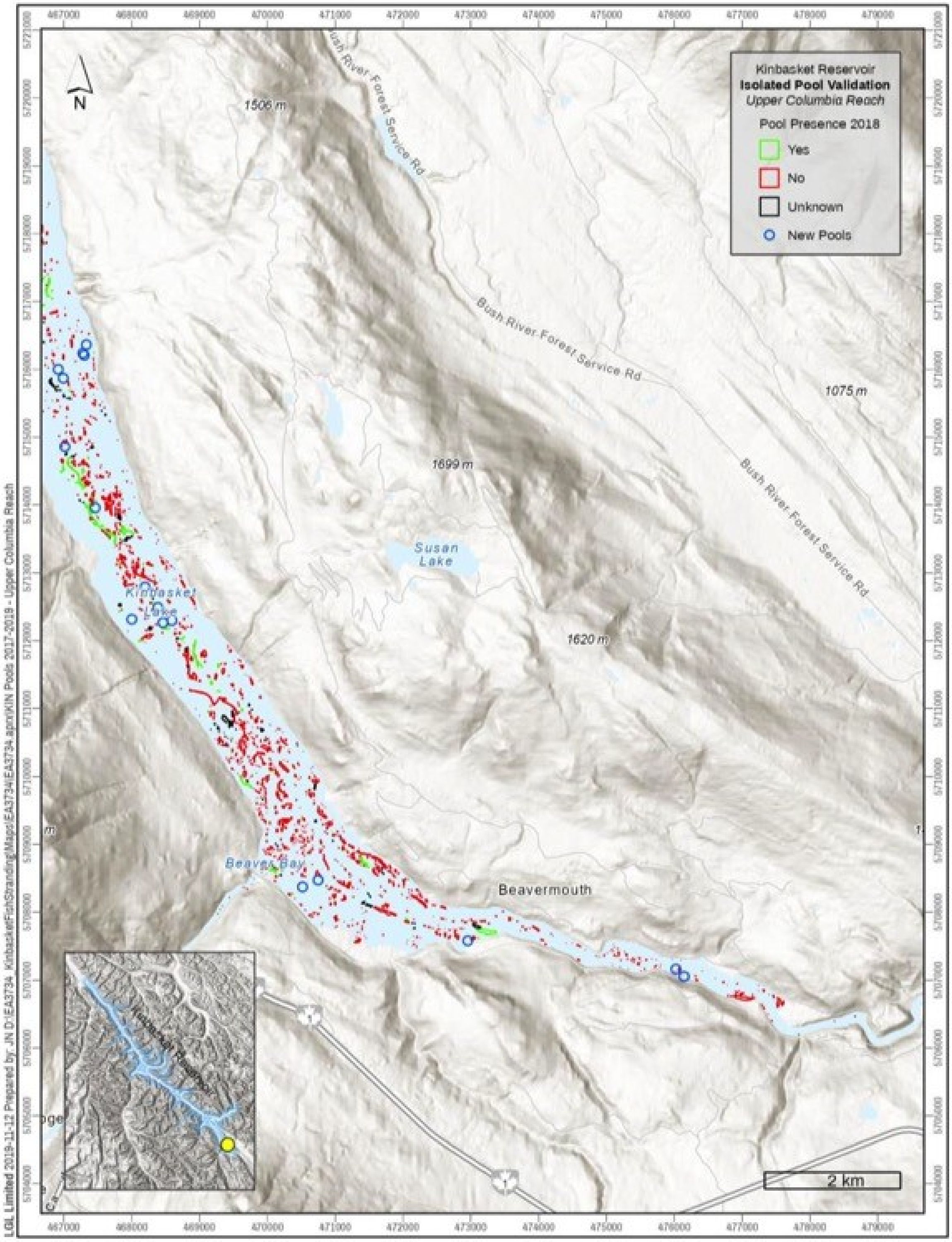
Map 6. Upper Bush Arm (including Bush River causeway) of Kinbasket Reservoir. The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.



Map 7. **Gold River (mouth) of Kinbasket Reservoir.** The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.



Map 8. **Lower Columbia Reach of Kinbasket Reservoir.** The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.



Map 9. **Upper Columbia Reach of Kinbasket Reservoir.** The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were observed from the aerial overflight imagery but not identified in the DEM analysis.

Discussion

The formation and presence of pools in the DDZ of Kinbasket Reservoir appears to be dynamic in all high risk fish-stranding areas. Few pools remained unchanged since the 2002 aerial survey, and several new pools have formed since. There were no concentrated areas of new pools or pre-existing pools in all high risk areas, suggesting that pool stability is relatively low across the surveyed elevation gradient.

Physical non-operational mitigations including pool channelization and pool/DDZ slope re-contouring could be effective in static landscapes where pools remain unchanged for long periods of time (e.g., years/decades); thereby extending the temporal lifespan and effectiveness of the applied physical works. The highly variable nature of the pools observed in this study suggest that physical non-operational mitigations are not recommended.

This study demonstrated that pool formation in the DDZ of Kinbasket Reservoir is dynamic across the surveyed elevation gradient (725−754 mASL), however, the methods deployed did come with some limitations:

- Pool depth was not possible to measure with digital photography; therefore, we cannot assign a fish-stranding risk (Year 1 model or new-revised model) to a newly documented pool.
- Pool elevation cannot be determined through digital photography without the aid of pre-existing adjacent pools with known elevation and location (coordinates). Therefore, we cannot assign a fish-stranding risk (Year 1 model) to a newly documented pool.
- Water permeability/evaporation likely varies between pools, seasons, and years. As such, water in a pool may or may not be present during an aerial survey. Shallow surface depressions (less than 30 cm) will likely be undetected in digital photography thereby underestimating the true number of formed isolated pools.

To accurately inventory pools and their physical attributes (e.g., depth, area, elevation), analysis using a LiDAR-derived digital elevation model (DEM) at minimum annual reservoir level (i.e., low pool) is recommended. The development of annual high-resolution DEM can demonstrate changes on a temporal scale.

Appendix 3. Revision of the Fish-stranding Risk Model

Introduction

A fish-stranding risk model was developed in Year 1 to address MQs 2 and 5, and to facilitate field planning for Years 2 and 3. Year 1 fish-stranding model was developed from a series of four criteria, the rationale thoroughly explained in the Year 1 report:

- Pool area
- Pool depth
- Number of days pool is isolated
- Time of year pool is isolated (i.e., day of calendar year pool becomes isolated, based on a 20-year average from 1990 to 2009).

Field data collected from Years 2 and 3 were applied to this model (Figure 6). If the Year 1 fish-stranding risk model was supported by data, Figure 6 would show an increase in fish presence (i.e., the presence of a fish occurring in a pool, irrespective of abundance) with risk category; however, this was no trend. All pools categorized as low risk contained fish; however, care must be taken to not over interpret this finding, as only three pools were classified in the low risk category. While stranding frequency does increase from moderate to high risk pools (Moderate: 23 pools contain fish out of n=46: 50%; High: 44 contain fish out of n=62: 71%), the misidentification of low risk pools suggests that the stranding risk model required refinement. Fish abundance was not included in the analyses due to inconsistencies in fish sampling effort (Table 3, Appendix 4).This appendix describes the methods used to develop a revised fish-stranding risk model that is supported by field data collected in Years 2 and 3.

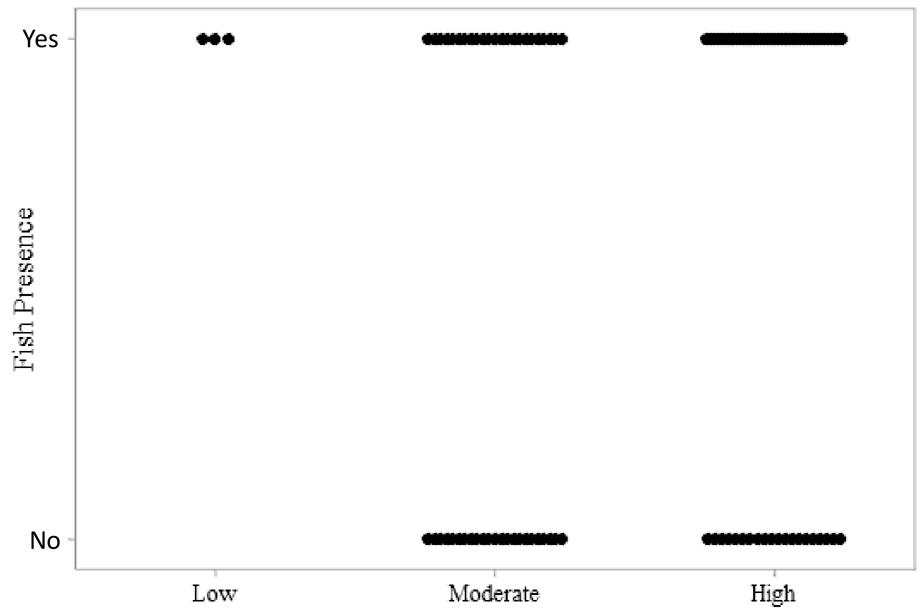


Figure 6. **Dot plot representing the success of the fish-stranding risk model developed in Year 1** predicting fish stranding (low, moderate, high) in individual pools and based on field data collected in Years 2 and 3.

Methods

To assess which variables (i.e., criteria) should be included within the revised conceptual model of fish stranding risk, we first constrained our dataset to only sampled pools associated with all required variables:

- Pool depth.
- Pool area.
- Pool elevation (LiDAR-derived DEM from 2014 imagery was used for sample pools not identified in Year 1).
- Number of days pool is isolated – Based on BC Hydro hydrographs from Mica Dam, and pool elevation. Defined by the sum of days between the first day a pool becomes isolated during reservoir drafting (late summer to spring prior to sampling) and the day when a pool was sampled. For example, a pool situated at 735 mASL and sampled on 22 May 2019 would have been isolated for 134 days when it became isolated on 09 January 2019 (734 mASL)
- Average date pool becomes isolated – Based on a 20-year hydrograph average of Kinbasket Reservoir from 2000 to 2019. Year 1 used a 20-year average from 1999 to 2009, since their study was conducted in 2010. This variable is similar to the fourth criterion used in the Year 1 model – “Time of year pool is isolated”.

Dataset

This dataset (Dataset 02) comprises 111 data points (sample pools) collected from all three field sessions (fall 2017, spring 2018 and 2019) combined. A total of 143 pools were sampled in all years combined, however physical measurements (e.g., depth, and/or area) were not obtained for 32 pools. Repeat sampling of pools in Years 2 and 3 were considered as independent data points given the substantial observed variation in pool parameters between years (see Dataset 03, especially with regards to depth and area). In effect, even though pools may be in similar geographical areas between years, the large variation in their physical extent and depth results in them representing variable stranding risks between years.

Analyses

Statistical analyses were conducted using the program R (R Studio Team 2015). To refine the suite of variables to include within the revised conceptual fish-stranding risk model a series of linear regression models were conducted. An Information Theoretic Model Selection approach was used to contrast different models (Burnham and Anderson 2002; Burnham et al. 2011). Contrasted models were generated *a priori*, with each model representing a specific combination of variables (pool depth, area, elevation, days isolated, average days isolated, average date first isolated) that based upon previous knowledge of the system (Roias et al. 2018), could be important in explaining fish stranding. Models (R Package – AICc modavg) were contrasted using Akaike's Information Criterion (AIC) values, corrected for small sample sizes (AICc), a value that evaluates model performance while considering the number of terms included in each model to avoid over fitting (Anderson et al. 2000; Burnham and Anderson 2001; Johnson and Omland 2004; Richards 2005). Models with a smaller AICc perform better, however, models with a difference in AICc values (Δ AICc) less than or equal to 2 are assumed to be equivalent (Anderson et al. 2000). In this case, the most parsimonious model, or the model that contains the fewest terms was selected as the top ranked model (Burnham and Anderson 2002).

For each statistical model, binomial generalized linear regression (Richards 2008; Gerwing et al. 2012) was used, pooling data from all years and reaches in order to create a single conceptual model. The response variable for all models was whether or not (0 or 1) a fish of any species, living or dead was observed stranded in the pool. The proportion of the variation each model explained was also presented (R^2).

Results

Of the assessed models (Table 10), six were within two AIC_C units of the model with the smallest AIC_C value. As such, these models are considered to be equivalent, and are the top performing models. The most parsimonious model within this subset is the model containing only the term depth, and therefore, this model was selected as our top ranked model. When examined in more detail, the positive coefficient associated with the depth term (Table 11) indicates that as depth increases, a pool is more likely to contain a stranded fish. However, this model only explains a small proportion of the observed variation in fish stranding (5.43%; Table 10).

Table 10. **Summary table of evaluated models of fish stranding.** AICc: Akaike's Information Criterion values corrected for small sample sizes. ΔAICC: Difference in AICC values between the model and the model with the smallest AICC value. R2: Proportion of the variation each model accounted for. Terms: Number of variables in the model, not counting the constant. Top ranked model is indicated in bold.

Model	ΔAIC_C	AIC_C	R^2	Terms
Depth + Area	0	141.61	8.49	2
Depth	**0.37**	**141.98**	**5.43**	**1**
Depth + Area + Average Days Isolated	0.65	142.26	9.66	3
Area + Depth + Days Isolated	0.65	142.26	9.66	3
Depth + Area + Average Date First Isolated	1.21	142.82	9.03	3
Depth + Area + Elevation	1.49	143.10	8.84	3
Area	2.53	144.14	5.44	1
Depth + Area + Elevation + Days Isolated	2.83	144.44	9.67	4
Area + Days Isolated	2.83	144.44	6.74	2
Depth + Area + Days Isolated + Average Date First Isolated	2.84	144.45	9.67	4
Depth + Area + Average Days Isolated + Average Date First Isolated + Elevation	3.43	145.04	10.78	5
Depth + Average Days Isolated	3.61	145.22	6.21	2
BC Hydro (Depth + Area + Average Days Isolated + Average Date First Isolated)	3.78	145.00	9.03	4
Depth + Elevation	4.68	146.29	5.49	2
Depth + Area + Average Days Isolated + Average Days Isolated + Average Date First Isolated + Elevation	5.44	147.05	10.96	6
Days Isolated	9.55	151.16	0.70	1
Average Days Isolated	10.19	151.80	0.27	1
Elevation	10.31	151.92	0.19	1
Average Date First Isolated	10.59	152.20	0	1
Days Isolated + Elevation	11.77	153.38	0.71	2

Table 11. Details of the top ranked model (Table 1) assessing fish stranding. Coef = coefficient, SE = standard error, CI = Confidence interval.

Term	Coef	SE Coef	95% CI	Z-value	P-value
Constant	-0.23	0.31	(-0.850, 0.38)	-0.74	0.46
Depth	1.10	0.56	(-0.007, 2.20)	1.95	0.05

When reassigning pools to the risk categories in the revised fish-stranding risk model (depth only) and comparing these to the Year 1 model, the number of high risk pools decreased by 25%, moderate pools remained relatively unchanged (<1%) and the number of low risk pools increased by 69% (Table 12). The total surface area of high risk pools decreased by 32%, and the surface area of moderate and low risk pools increased 94% and 82% respectively.

Table 12. Pool inventory developed from the 2002 DEM (Year 1) applied to the Year 1 fish-stranding risk model and the revised model developed in Year 3 from field-collected data in Year 2 and 3.

Pool risk category (Year 1)	Number of pools evaluated	Percentage of total	Total surface area (SA; ha)	Percentage of total reservoir SA between 754 m and 725 m (14,382.22 ha)
High	1,601	24.45%	113.39	0.79%
Moderate	4,146	63.32%	36.16	0.25%
Low	801	12.23%	2.19	0.02%
Total	**6,548**	**100.00%**	**151.74**	**1.06%**

Pool risk category (Year 3)	Number of pools evaluated	Percentage of total	Total surface area (SA; ha)	Percentage of total reservoir SA between 754 m and 725 m (14,382.22 ha)
High	1,194	18.23%	77.45	0.54%
Moderate	4,186	63.93%	70.32	0.49%
Low	1,168	17.84%	3.98	0.03%
Total	**6,548**	**100.00%**	**151.74**	**1.06%**

Discussion

While the proportion of the observed variation in the depth model is low, there is no evidence to include any term save depth into a conceptual model of fish stranding. As such, and utilizing the depth categories proposed in the original (Year 1) conceptual fish-stranding risk model, we proposed a new conceptual model only including depth (Table 13).

Table 13. Revised conceptual model of fish-stranding risk based upon pool depth. Cases refer to the number of pools sampled in Year 2 and 3 observed with fish.

Depth category (m)	Cases	# of pools	Proportion	Risk
<0.1	0	1	0	Low
≥0.1 ≤0.3	27	56	0.48	Moderate
>0.3	41	54	0.76	High

Within this model pools shallower than 0.1 m are classified as low risk, ≥0.1 ≤0.3 m deep pools are classified as moderate risk, and pools deeper than 0.3 m are classified as high risk. This new conceptual model is more parsimonious than the previously proposed model and appears to solve the issue of the low risk pools. In the previous model, low risk pools all contained stranded fish (Figure 6), however, the new conceptual model contains no fish in the low risk pools (Table 13). However, only three low risk pools sampled in Year 2 and 3 were included in the assessment of the previous model (Year 1) and using the new conceptual model only a single pool was classified as of low risk. More data is required to properly assess if low risk pools have been correctly classified using the new conceptual model.

With regards to the sampled moderate and high risk pools, the previous (Moderate: 50%. High: 71%) and new (Moderate: 48%. High: 75%) conceptual models have similar frequencies of occupancy. However, the new conceptual model is more parsimonious, including only the depth variable As such, it appears that variables such as elevation, area, date isolated, and number of days isolated are not required to predict the risk of fish stranding within these pools.

Based on the 2002 DEM used to identify the number of isolated pools in the DDZ of Kinbasket Reservoir between elevation 725 and 754 mASL and the application of the revised fish-stranding risk model, the extent of fish stranding risk between models has changed.

This study has developed a fish-stranding risk model specific to Kinbasket Reservoir based on field data, however, the dataset used does come with limitations:

- Pool depth in Year 1 dataset based on 2002 DEM, while pool depth dataset from Year 2 and Year 3 field surveys were based on wetted measurements. Pool permeability and evaporation is likely significant in the DDZ and has been observed during the winter 2017 data logger deployment. Very shallow pools are likely to be devoid of water shortly after isolation and thus difficult to locate in the field.
- The extent of fish stranding (numeric values) evaluated from both models only applies to 2002 (year of the aerial photography used for the Year 1 DEM) as pool presence varied significantly in the past 16 years (Appendix 2).
- The extent of fish stranding was limited to a low elevation of 725 mASL. The extent of fish stranding could be assessed down to the minimum licenced pool elevation of 707.41 mASL.

An increase in sample size of pools in each depth category would better validate the revised fish-stranding risk model. To assist in field planning in obtaining data to test the model, sampling should be conducted within a year of LiDAR surveys and a LiDAR-based DEM using these current data. Pools should be surveyed regardless of whether water is present or not. Dried surface depressions, identified as a pool from the LiDAR data, may indicate that water does not remain in the pool during some period of isolation. This observation could be used as another test variable to apply to developing a fish-stranding risk model.

Appendix 4. Fish Presence and Annual Variability

Introduction

Prior to CLBMON-4, fish stranding in the DDZ of Kinbasket Reservoir was mostly unknown aside from a few anecdotal reports. Two years of fish sampling in isolated pools along the DDZ provided information on species of stranded fishes and the extent of fish stranding throughout the reservoir. The data collected in this study was used to address MQ 1, 4 and 6.

Methods

Isolated pools were sampled to determine fish presence in Year 2 (24−26 October 2017, 10−16 May 2018), and Year 3 (22−28 May 2019). See sampling methodology 3.4 Fish Survey Data for more details. Fish presence was assessed by reach (study areas identified as having the highest risk of fish stranding – Year 1) and elevation (increments of 5 m from 515 to 755 mASL) for each year of sampling.

Datasets

Repeat sampling of pools between fall 2017 and spring 2018 in Year 2 were treated as single data points since pools were not re-inundated between sampling periods. A total of 58 pools were sampled in Year 2 and 79 pools were sampled in Year 3 (spring 2019) (Table 2). Sampling effort was not standardized between sampling years or between pools (therefore, could not be directly compared) due to the following:

- Fishing methods not standardized due to pool accessibility. ARIS sonar, minnow traps, and beach seine nets are heavy and cannot be transported over large walking distances where DDZ mud is deep and prevalent (Table 3). Minnow traps were not functional in shallow pools (<30 cm depth). Beach seining was not possible in pools with abundant woody debris.
- Reservoir low pool elevation in 2018 reached 719 mASL while it reached 714 mASL in 2019, therefore more pools were accessible in Year 3.
- Helicopter transport in Year 3 to access Gold River Arm and lower reaches of Columbia Reach.

To account for the difference in effort between years and pools, analyses included percent of pools containing fish rather than number of pools containing fish. All fishes captured or observed (visually) were recorded and enumerated. An approximate subset of 30 fish per species captured were measured for length. Fork lengths were used to approximate life history stage (juvenile/adult) for all cyprinids, suckers, and sculpins, while superficial features such as the presence of parr marks were used in addition to length to approximate life history stage (juvenile/adult) of salmonids and whitefishes. The following juvenile-to-adult length thresholds were applied to all species measured in our study (Scott and Crossman 1973; McPhail 2007; Sebastian and Weir 2013; Kang and Warnock 2017):

- Salmonidae
    - Bull Trout (*Salvelinus confluentus*) – 400 mm
    - Kokanee (*Oncorhynchus nerka*) – 200 mm

  - Mountain Whitefish (*Prosopium williamsoni*) – 200 mm
  - Pygmy Whitefish (*Prosopium coulterii*) – 150 mm
- Cyprinidae
  - Lake Chub (*Couesius plumbeus*) – 70 mm
  - Longnose Dace (*Rhinichthys cataractae*) – 70 mm
  - Northern Pikeminnow (*Ptychocheilus oregonensis*) – 200 mm
  - Peamouth (*Mylocheilus caurinus*) – 150 mm
  - Redside Shiner (*Richardsonius balteatus*) – 70 mm
- Catastomidae
  - Largescale Sucker (*Catostomus macrocheilus*) – 200 mm
  - Longnose Sucker (*Catostomus catostomus*) – 200 mm
  - Sucker sp. (Catostomus sp.) – 200 mm
- Cottidae
  - Prickly Sculpin (*Cottus asper*) – 70 mm
  - Sculpin sp. (Cottus sp.) – 70 mm

Most observed fishes were identified. In the case of unidentified fishes, species identification was not performed due to the following reasons:

- The absence of key features from the decomposition of dead fishes.
- Identifiable characteristics of juvenile cyprinids (minnows) and suckers were obscure and difficult to distinguish, and a decision was made to release fish alive before positive and stressful identification to species level could be made.
- Air temperatures in spring 2019 were very warm and captured fishes were released immediately to reduce risk of mortality.
- Beach seine nets performed on pools containing very muddy bottoms often collected large amounts of mud with trapped fishes within. These samples were enumerated but to avoid further stress on the fish, species identification was not conducted.

As a result of varying levels of taxonomic identification, we adopted the term “taxonomic richness” to describe the number of taxa (e.g., species, genus, family) observed in pools (Gerwing et al. 2015; Gerwing et al. 2016; Gerwing et al. 2017).

Analyses

Number of isolated pools containing fish (live and dead) per year were qualitatively summarized in tables organized by geographical study areas (regions identified as high risk to fish stranding in Year 1), number of discrete pools (an isolated pool unique in position but may vary in volume and surface area of standing water during isolation between each sampling event), and repeat sampling of pools in Year 2 to assess over-winter survival. Maps of each geographical study area surveyed were produced to illustrate the distribution of sampled pools containing fish.

Bar graphs summarize taxonomic richness in isolated pools containing fish, percent of pools containing fish by taxonomy, and the average number of fish observed in any given pool containing fish to assess which species of stranded fish were most frequently encountered. Box plots were used to qualitatively assess taxa occurrence (live and dead) by elevational range. To aid the reader in interpreting boxplot graphs, the boxes represent between 25 percent and 75 percent of the ranked data. The horizontal line inside the box is the median. The length of the boxes is their interquartile range (Sokal and Rohlf 1995). A small box indicates that most data are found around the median (small dispersion of the data). The opposite is true for a long box; the data are dispersed and not concentrated around the median. Whiskers are drawn from the top of the box to the largest observation within 1.5 interquartile range of the top, and from the bottom of the box to the smallest observation within 1.5 interquartile range of the bottom of the box. Boxplots display the differences between groups of data without making any assumptions about their underlying distributions and show their dispersion and skewness. For this reason, they are ideal in displaying ecological data. Length frequency histograms were produced to illustrate the proportion of juvenile to adult fishes observed and compared by year to assess any annual variability. All graphs were produced in R (R Core Team 2018).

Results

A total of 143 pool samples were collected (Year 2 and 3 combined) in the field program of CLBMON-4 that included 97 discrete isolated pools sampled across a DDZ elevation of 34 m (Table 2). Fishes were observed in 68% of discrete pools (all years combined) sampled and were present in all geographical areas identified as high risk to fish stranding (Table 14, Map 1 and Maps 11 to 14). Fishes were observed stranded in 84% of pools sampled in spring 2018 and 54% of pools in spring 2019. Live and dead fish were observed in 54% and 16% of discrete pools sampled respectively and were observed in all high risk stranding areas. Dead fishes were only observed in three of the five study areas sampled in May 2019 (Year 3), this does not imply that fish mortality did not occur in other areas during pool isolation.

Table 14. **Number of isolated pools (percentage in brackets pertains to all sampled pools) containing fish** by geographical location in the drawdown zone (between elevation 719 and 753 mASL) of Kinbasket Reservoir. Repeat sampling of pools between fall 2017 and spring 2018 was conducted to assess winter fish survival, while repeat sampling between spring 2018 and spring 2019 was conducted to assess annual variability in fish stranding. A discrete pool is an isolated pool unique in position but may vary in volume and surface area of standing water during isolation between each sampling event

2a. Pools containing live and dead fish combined

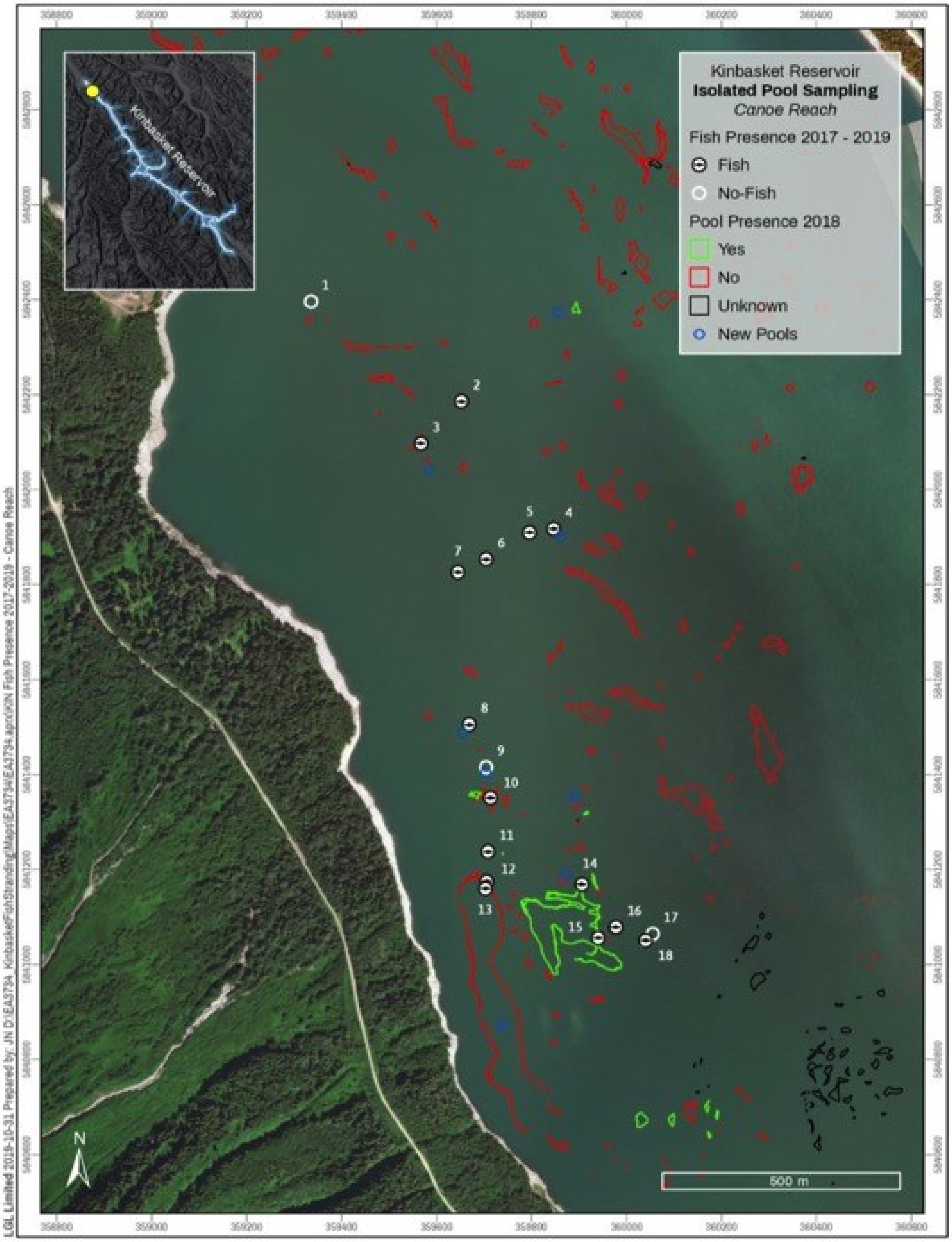
Location	Discrete pools	Repeat 2017−2018	Repeat 2018−2019	Year 2 Oct 2017	Year 2 May 2018	Year 3 May 2019
Bear Island	5 (83)	4 (80)	1 (33)	5 (100)	4 (80)	1 (25)
Bush Arm	23 (62)	1 (100)	13 (65)	3 (33)	20 (95)	14 (50)
Canoe Reach	15 (83)	0	5 (38)	0	12 (86)	8 (47)
Columbia Reach	19 (73)	0	1(25)	0	6 (60)	14 (70)
Gold River Arm	4 (40)	0	0	0	0	4 (40)
Total	**66 (68)**	**5 (83)**	**20 (50)**	**8 (57)**	**42 (84)**	**43 (54)**

2b. Pools containing live fish only

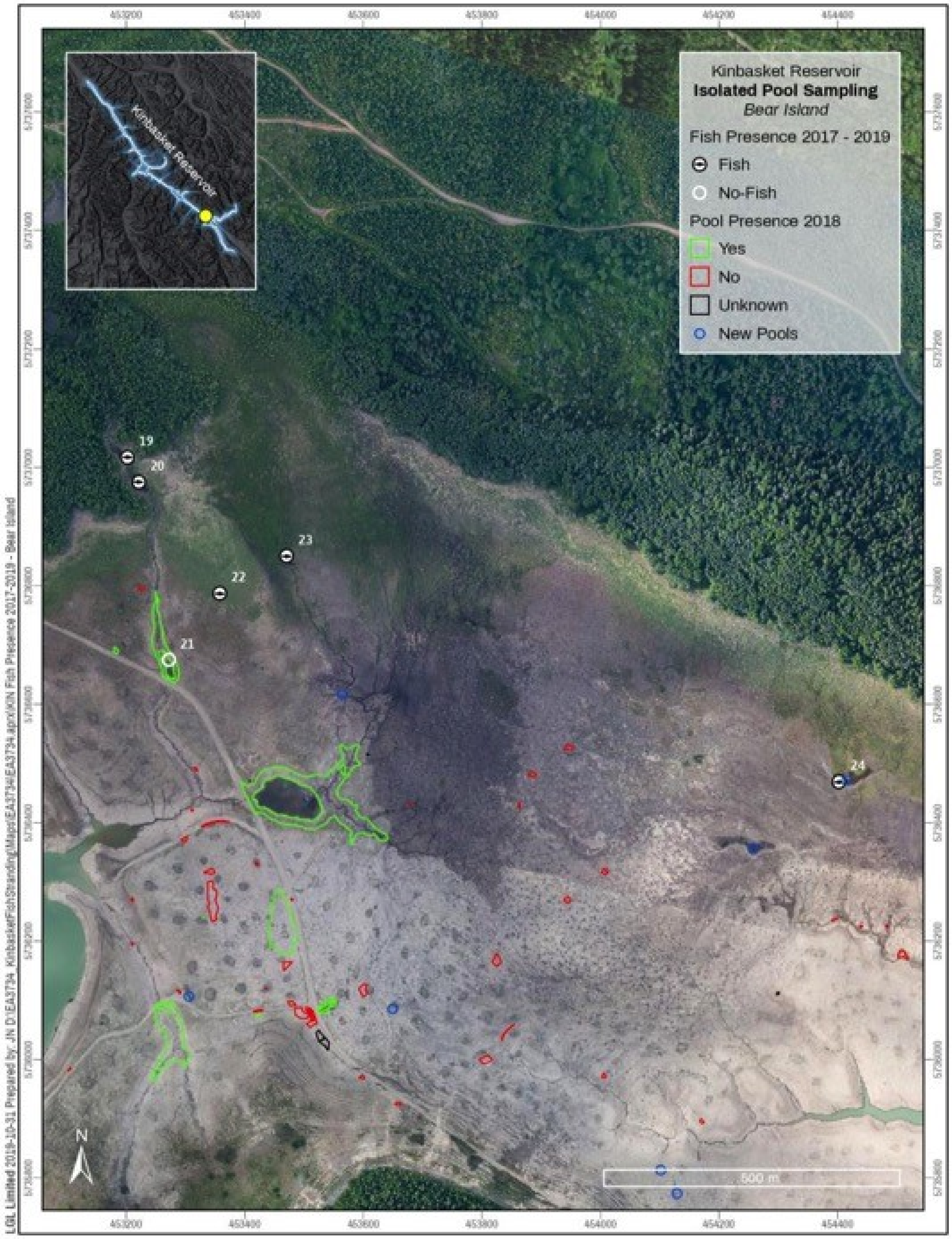
Location	Discrete pools	Repeat 2017−2018	Repeat 2018−2019	Year 2 Oct 2017	Year 2 May 2018	Year 3 May 2019
Bear Island	5 (83)	4 (80)	1 (33)	5 (100)	4 (80)	1 (25)
Bush Arm	14 (38)	1 (100)	7 (35)	3 (33)	12 (57)	7 (25)
Canoe Reach	12 (67)	0	5 (38)	0	9 (64)	8 (47)
Columbia Reach	17 (65)	0	1(25)	0	5 (50)	13 (65)
Gold River Arm	4 (40)	0	0	0	0	4 (40)
Total	**52 (54)**	**5 (83)**	**14 (35)**	**8 (57)**	**30 (60)**	**33 (42)**

2c. Pools containing dead fish only

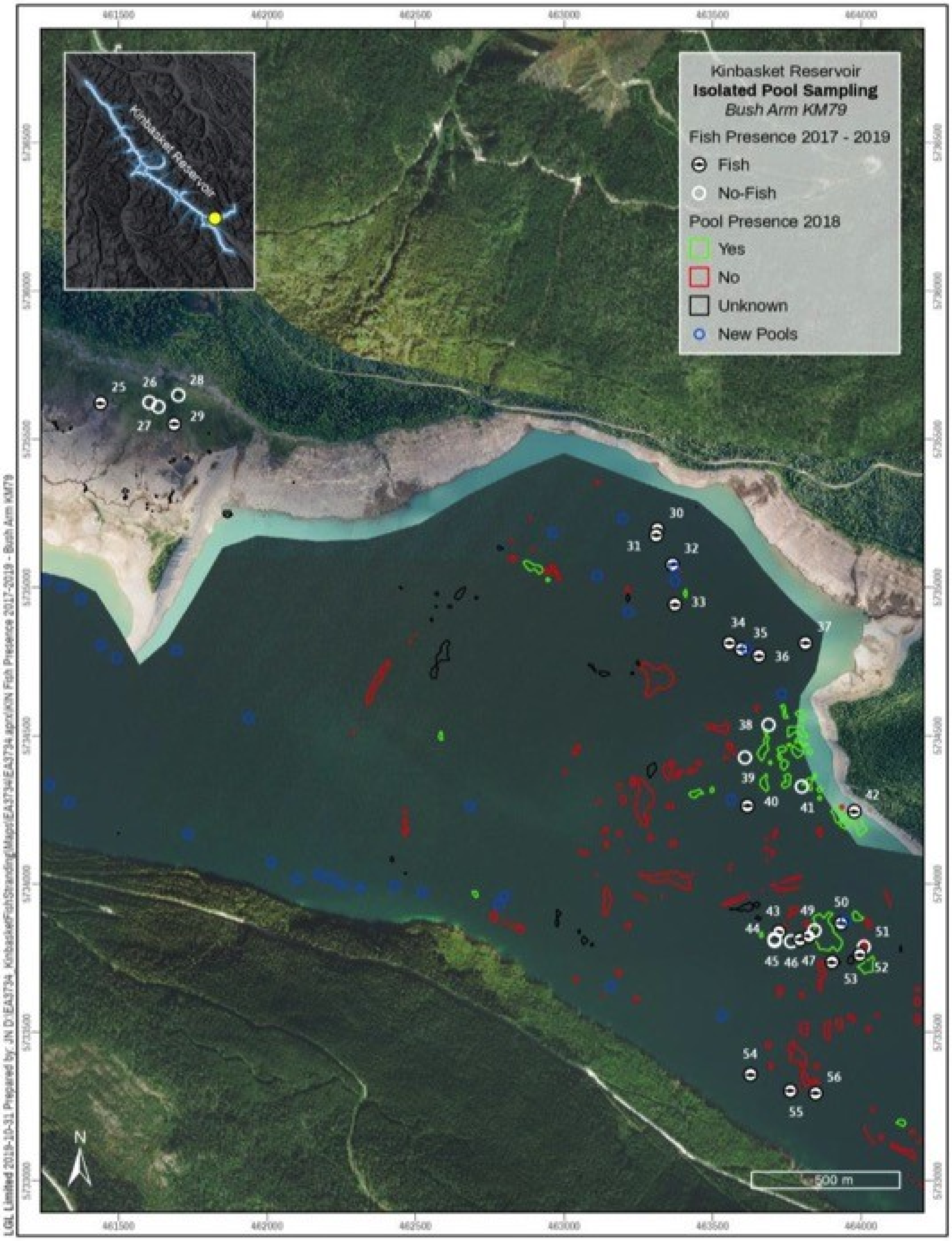
Location	Discrete pools	Repeat 2017−2018	Repeat 2018−2019	Year 2 Oct 2017	Year 2 May 2018	Year 3 May 2019
Bear Island	0 (0)	0 (0)	0 (0)	0 (0)	1 (20)	0 (0)
Bush Arm	11 (48)	0 (0)	6 (30)	0 (0)	10 (48)	8 (29)
Canoe Reach	3 (17)	0	0 (0)	0	7 (50)	0 (0)
Columbia Reach	2 (8)	0	1(25)	0	1 (10)	2 (10)
Gold River Arm	0 (0)	0	0	0	0	1 (10)
Total	**16 (16)**	**0 (0)**	**7 (18)**	**0 (0)**	**19 (38)**	**11 (14)**



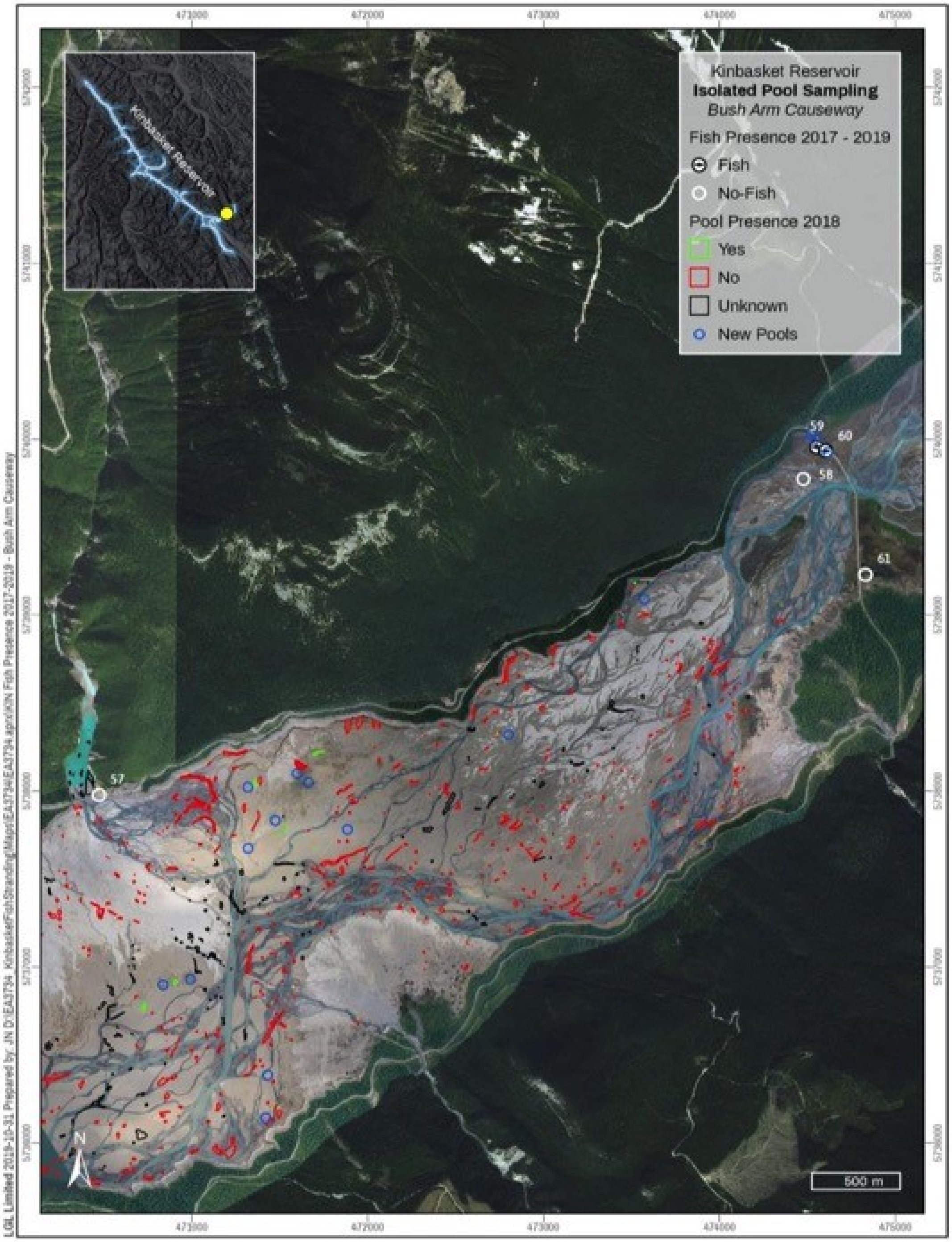
Map 10. Fish presence in sampled isolated pools (Year 2 and 3 combined) in the drawdown zone (DDZ) of Canoe Reach of Kinbasket Reservoir. Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south The coloured polygons illustrate isolated pools in the DDZ identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were conducted from the aerial overflight imagery but not identified in the Year 1 DEM analysis.



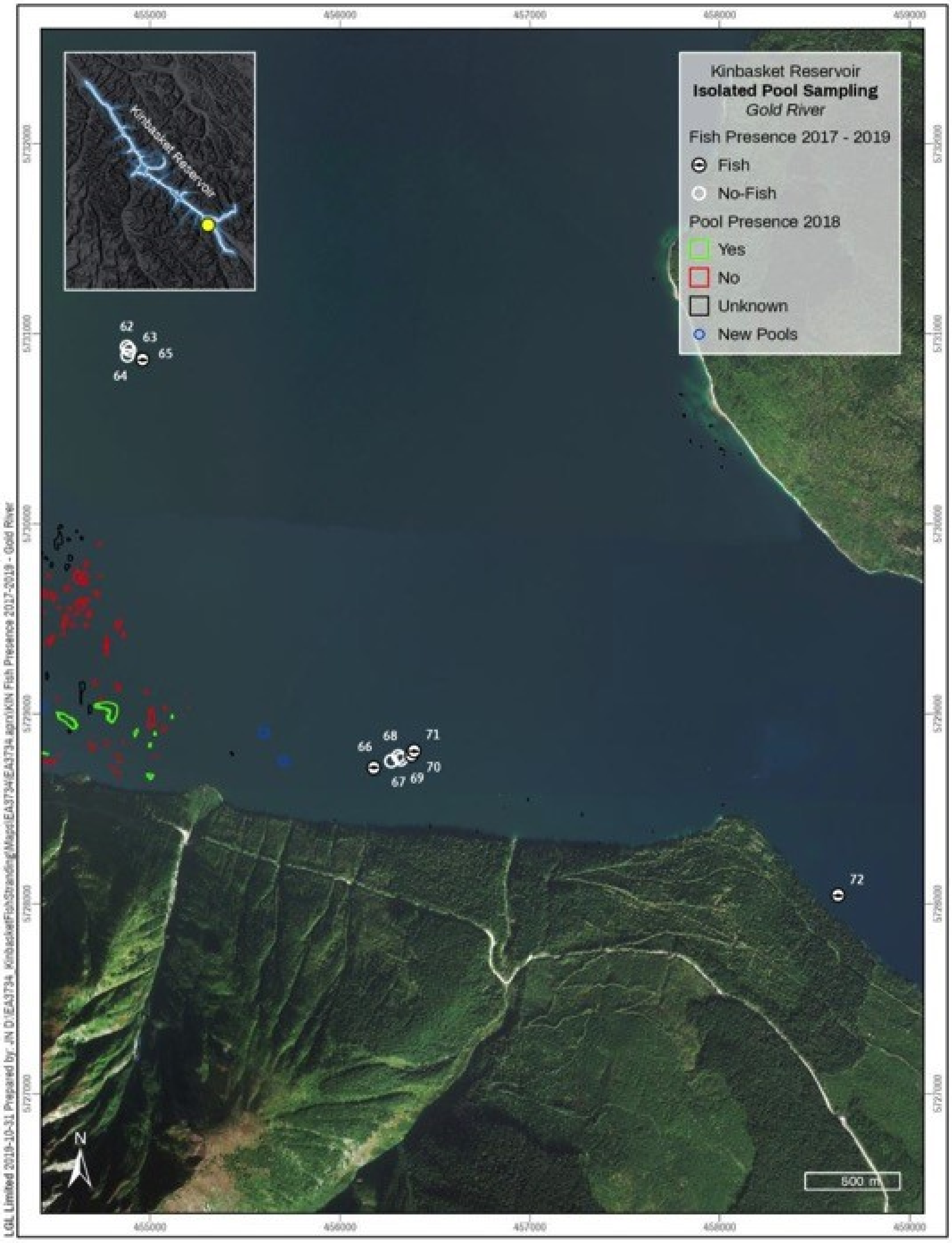
Map 11. Fish presence in sampled isolated pools (Year 2 and 3 combined) in the drawdown zone (DDZ) north of Bear Island (KM88 along Bush River FSR) of Kinbasket Reservoir. Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south. The coloured polygons illustrate isolated pools in the DDZ identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were documented from the aerial overflight imagery but not identified in the Year 1 DEM analysis.



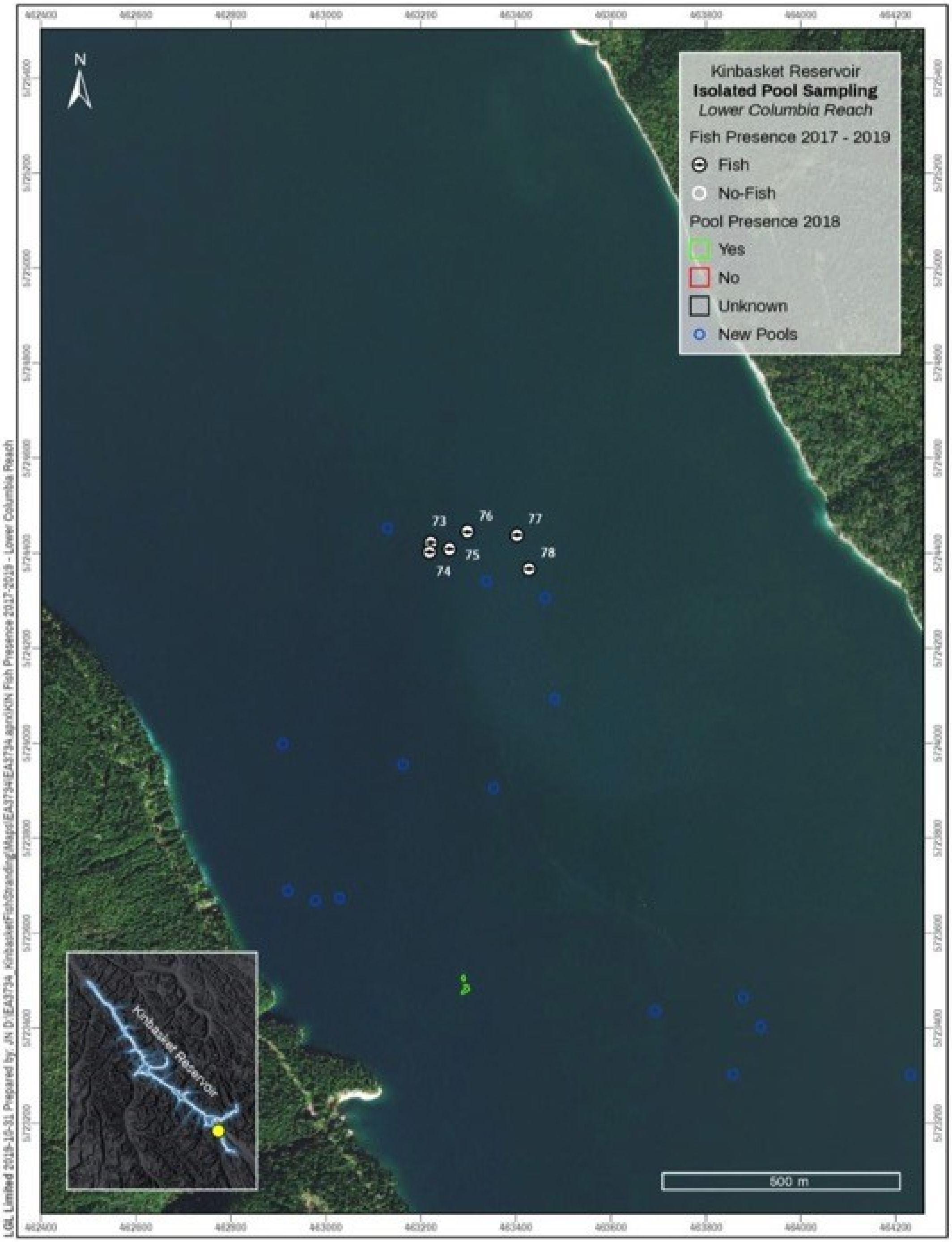
Map 12. Fish presence in sampled isolated pools (Year 2 and 3 combined) in the drawdown zone (DDZ) of Bush Arm (lower – KM79 along Bush River FSR) of Kinbasket Reservoir. Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south The coloured polygons illustrate isolated pools in the DDZ identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles “New Pools” denote pools that were documented from the aerial overflight imagery but not identified in the Year 1 DEM analysis.



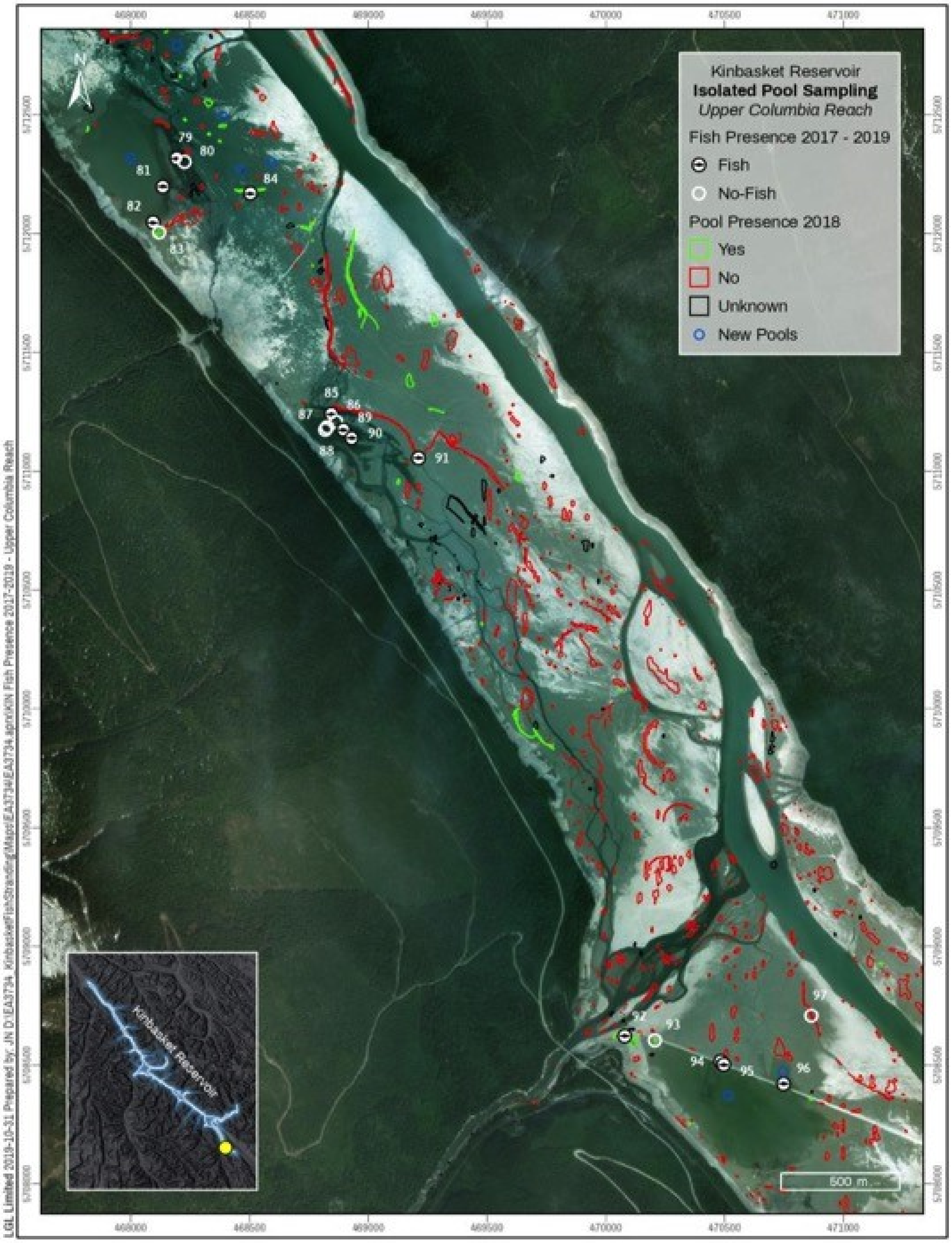
Map 13. Fish presence in sampled isolated pools (Year 2 and 3 combined) in the drawdown zone (DDZ) of Bush Arm (upper including Bush River causeway) of Kinbasket Reservoir. Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south. The coloured polygons illustrate isolated pools in the drawdown zone identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were conducted from the aerial overflight imagery but not identified in the Year 1 DEM analysis.



Map 14. Fish presence in sampled isolated pools (sampled only in Year 3) in the drawdown zone (DDZ) of Gold River Arm of Kinbasket Reservoir. Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south. The coloured polygons illustrate isolated pools in the DDZ identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were conducted from the aerial overflight imagery but not identified in the Year 1 DEM analysis.



Map 15. **Fish presence in sampled isolated pools (Year 2 and 3 combined) in the drawdown zone (DDZ) of Columbia Reach (lower) of Kinbasket Reservoir.** Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south. The coloured polygons illustrate isolated pools in the DDZ identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were conducted from the aerial overflight imagery but not identified in the Year 1 DEM analysis.



Map 16. **Fish presence in sampled isolated pools (Year 2 and 3 combined) in the drawdown zone (DDZ) of Columbia Reach (upper) of Kinbasket Reservoir.**

Each sampled pool was assigned with a unique number identifier ranging from 1 to 79 (total number of discrete pools sampled) starting from Canoe Reach in the north to Columbia Reach to the south. The coloured polygons illustrate isolated pools in the DDZ identified by the digital elevation model (DEM) analysis performed in Year 1 of CLBMON-4 and validated by a helicopter overflight survey conducted on 08 May 2018. The blue circles "New Pools" denote pools that were conducted from the aerial overflight imagery but not identified in the Year 1 DEM analysis.

Fifteen fish taxa (not including unknown sp.) were observed in the sampled isolated pools (all years combined) of which 12 were identified to species (Table 15, Photo 6). The number of taxa observed per study area ranged from four (Bear Island) to 12 (Columbia Reach). Cyprinids, in particular Lake Chub (*Couesius plumbeus*) and Redside Shiner (*Richardsonius balteatus*), and Prickly Sculpin (*Cottus asper*) were the most widespread species observed, and occurred in all high risk stranding areas, while most salmoniformes, such as Bull Trout (*Salvelinus confluentus*), Kokanee (*Oncorhynchus nerka*) and Mountain Whitefish (*Prosopium williamsoni*), were infrequent and only observed in one high risk area each. A single live juvenile Bull Trout was observed in a high elevation pool (752 mASL) connected to the Bush River near the Bush River causeway on 25 October 2017. Repeat sampling of this pool in May 2018 did not observe any Bull Trout. Two live Kokanee fry were captured in a low elevation pool (735 mASL) in Columbia Reach on 10 May 2018. No other species of concern identified by BC Hydro were observed in the field program of CLBMON-4.

Table 15. Fishes occurrence in the high risk fish-stranding regions (study areas) along the DDZ of Kinbasket Reservoir from isolated pools sampled in Year 2 and 3 combined. Pool sample size is denoted as "n" under each specified study area and includes the number of repeat sample pools for a total of 143 samples. Pool elevation ranged between 720 and 753 mASL. Gold River Arm was only sampled in spring 2019. Field sampling in October 2017 only occurred in Bear Island and Bush Arm.

	Survey area				
Species	**Bear Island (n = 14)**	**Bush Arm (n = 58)**	**Canoe Reach (n = 31)**	**Columbia Reach (n = 30)**	**Gold River Arm (n = 10)**
Salmoniformes					
Bull Trout		●			
Kokanee				●	
Mountain Whitefish				●	
Pygmy Whitefish		●		●	●
Cyprinidae					
Lake Chub	●	●	●	●	●
Longnose Dace				●	
Minnow sp. live		●	●	●	●
Minnow sp. dead		●			
Northern Pikeminnow		●			
Peamouth		●	●	●	
Redside Shiner	●	●	●	●	●
Catastomidae					
Largescale Sucker				●	●
Longnose Sucker	●	●	●		
Sucker sp.		●	●	●	
Cottidae					
Prickly Sculpin	●	●	●	●	●
Sculpin sp. dead		●	●	●	
Unknown					
Unknown sp. live	●	●	●	●	
Unknown sp. dead	●	●	●	●	●

The most widespread species across the geographical study areas were also the most frequently encountered and abundant species in isolated pools (Figure 7, Figure 8, Table 16). Thirty-two percent of all fishes observed were dead (Table 16, Photo 7). As all identifiable dead fishes were either cyprinids or sculpins, it is most likely that the unidentified dead fishes (and live unknown fishes for that matter) belong to these groups. The observed BC Hydro species of concern (Bull Trout and Kokanee) were only documented in Year 2. Three species of fish were observed in Year 3 that were not recorded in Year 2: Mountain Whitefish, Largescale Sucker, and Northern Pikeminnow, increasing the documented total number of fish species stranded in isolated pools in the DDZ of Kinbasket Reservoir. The number of taxa observed in isolated pools containing fish in all years sampled ranged from one to five, with most pools containing one or two taxa (Figure 9). Taxonomic diversity between years did not vary considerably aside from more pools in Year 3 (spring 2019) containing no fish.

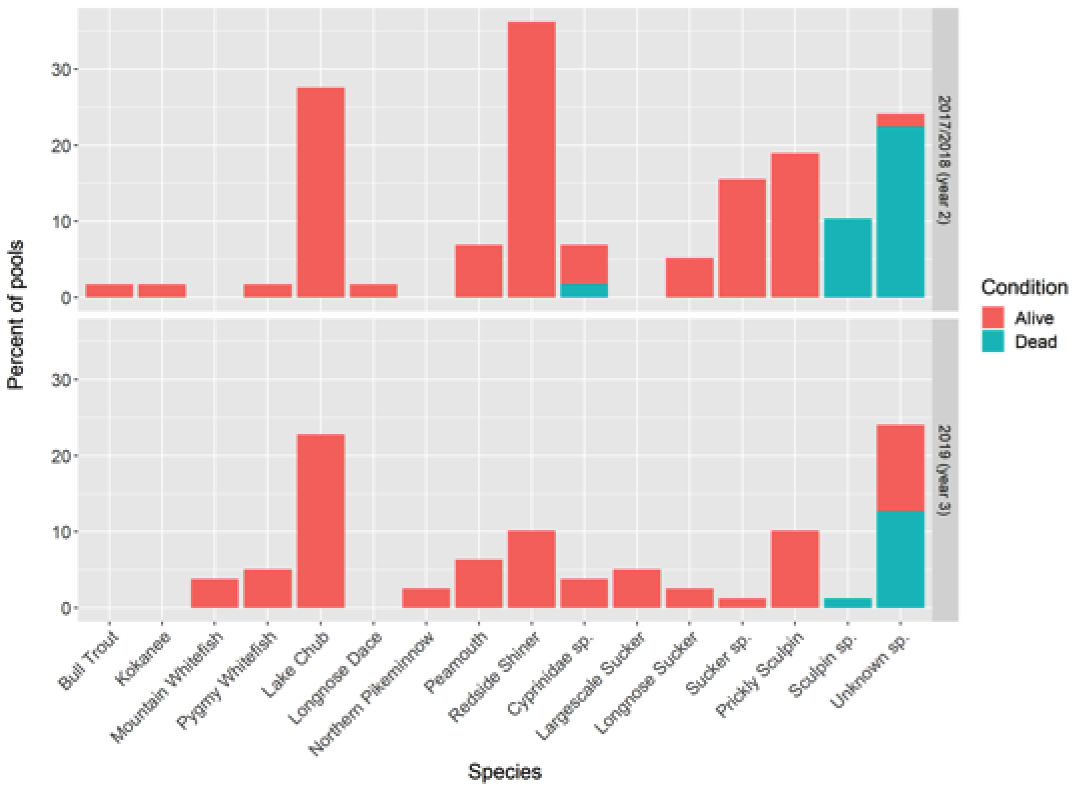


Figure 7. **Stacked bar graph illustrating the presence of fish taxa (live and dead) in all isolated pools (Year 2: n = 64 and Year 3: n = 79) sampled along the DDZ of Kinbasket Reservoir.** Sampling effort was not standardized between years (varying annual reservoir elevation) or between many pools (due to varying combination of fishing methods conducted between pools as dictated by pool characteristics [see 3.3 Pool Sampling and 3.4 Fish Survey Data]), therefore, direct comparison cannot be made. Species arranged by taxonomic relationship.

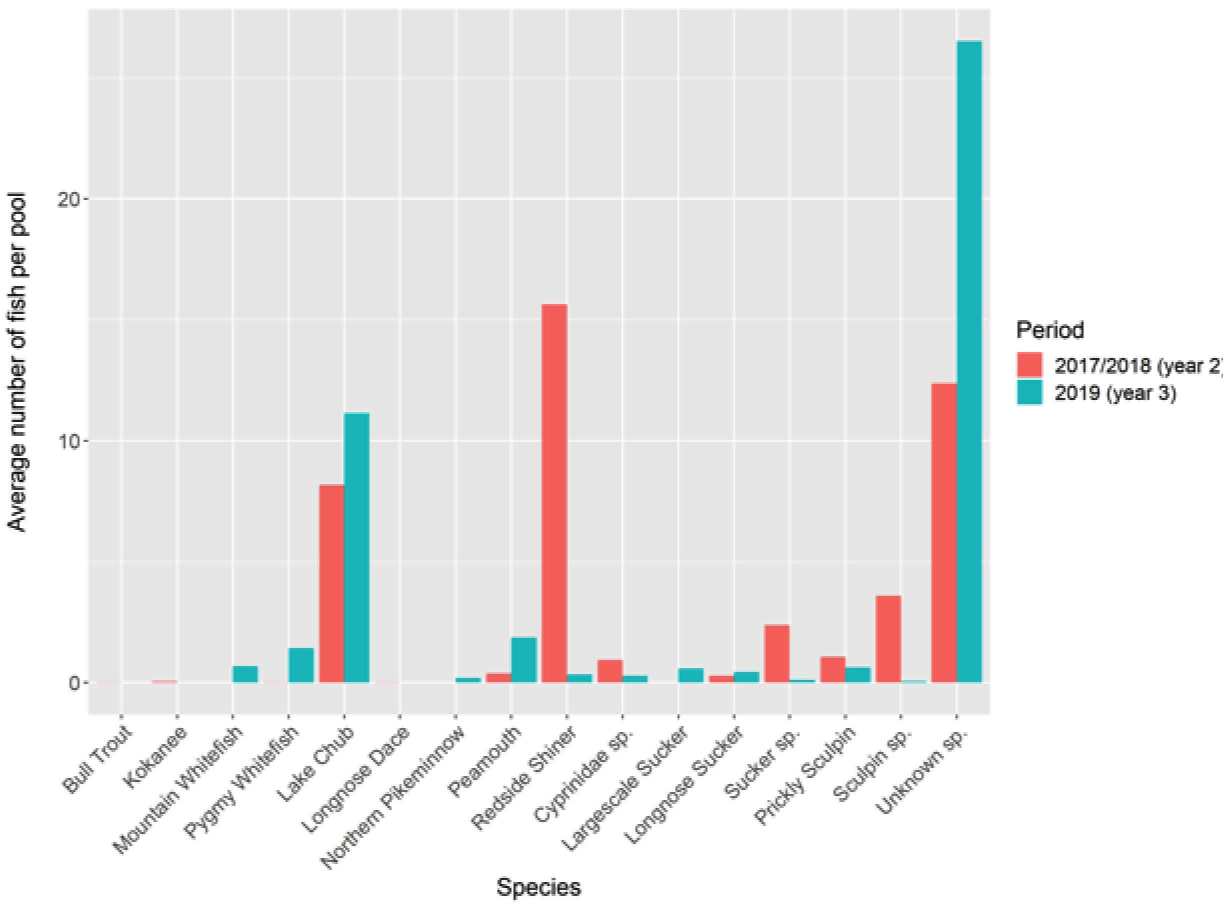


Figure 8. **Average number of fish by taxa observed in isolated pools sampled containing fish (Year 2: n = 46 and Year 3: n = 43) along the drawdown zone of Kinbasket Reservoir.** Sampling effort was not standardized between years (varying annual reservoir elevation) or between many pools (due to varying combination of fishing methods conducted between pools as dictated by pool characteristics [see 3.3 Pool Sampling and 3.4 Fish Survey Data]), therefore, direct comparison cannot be made. Species arranged by taxonomic relationship.

Table 16. **Fish counts (live and dead) from fishes observed in sampled pools along the drawdown zone of Kinbasket Reservoir** for CLBMON 4 in Year 2 and Year 3. Bull Trout is provincially blue listed and ranked a Species of Special Concern in Canada (COSEWIC 2012). Bull Trout and Kokanee were identified by BC Hydro (2007) as species of concern. Species are arranged by taxonomic relationship.

Species	Total count	Year 2		Year 3	
		Live	Dead	Live	Dead
Bull Trout (*Salvelinus confluentus*)	1	1			
Kokanee (*Oncorhynchus nerka*)	2	2			
Mountain Whitefish (*Prosopium williamsoni)*	29			29	
Pygmy Whitefish (*Prosopium coulterii*)	62	1		61	
Lake Chub (*Couesius plumbeus*)	795	316		479	
Longnose Dace (*Rhinichthys cataractae*)	1	1			
Northern Pikeminnow (*Ptychocheilus oregonensis)*	8			8	
Peamouth (*Mylocheilus caurinus*)	157	77		80	
Redside Shiner (*Richardsonius balteatus*)	837	822		15	
Minnow sp. (Cyprinidae)	55	42	1	12	
Largescale Sucker (*Catostomus macrocheilus)*	25			25	
Longnose Sucker (*Catostomus catostomus*)	32	13		19	
Sucker sp. (*Catostomus* sp.)	114	109		5	
Prickly Sculpin (*Cottus asper*)	72	45		27	
Sculpin sp. (*Cottus* sp.)	167		165		2
Unidentified fish	1,678	0	538	547	593
Total count	**4,035**	**1,429**	**704**	**1,307**	**595**

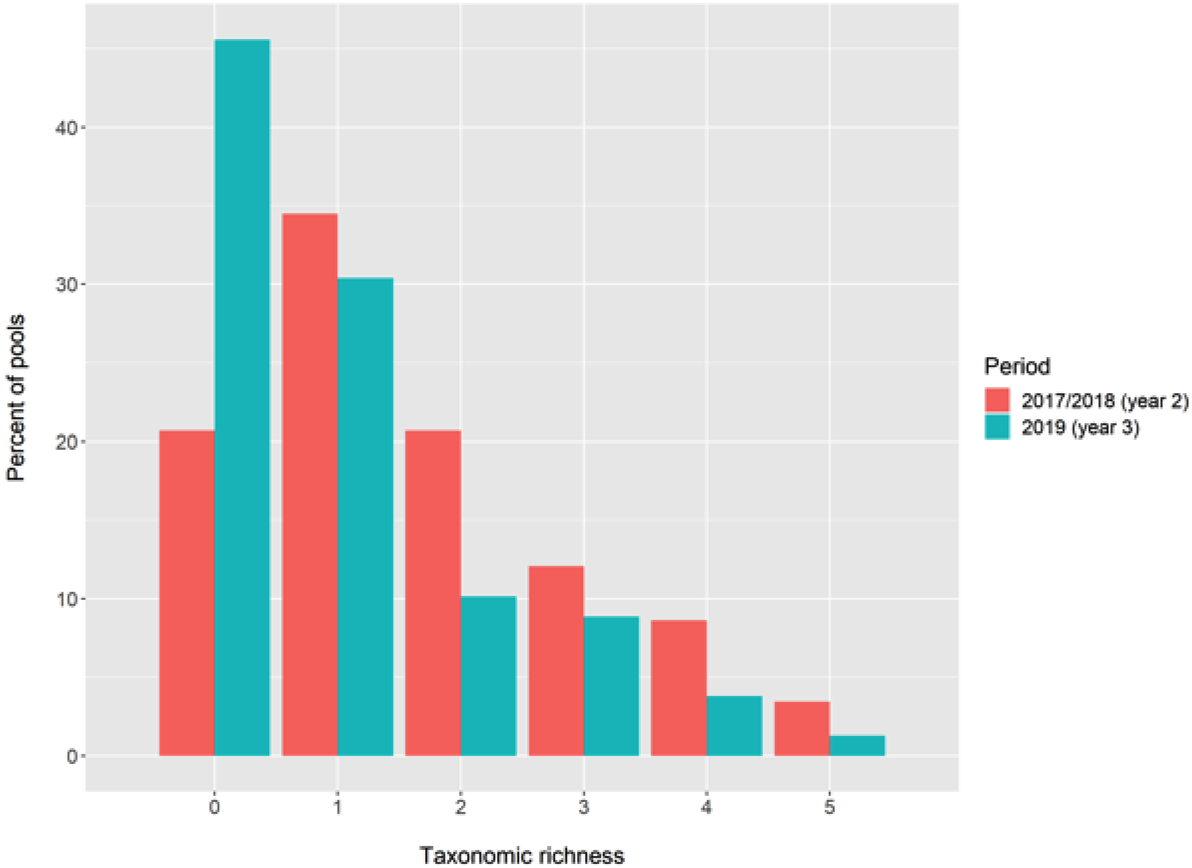


Figure 9. Taxonomic richness in all isolated pools (Year 2: n = 64 and Year 3: n = 79) sampled along the drawdown zone of Kinbasket Reservoir. Sampling effort was not standardized between years (varying annual reservoir elevation) or between many pools (due to varying combination of fishing methods conducted between pools as dictated by pool characteristics [see 3.3 Pool Sampling and 3.4 Fish Survey Data]), therefore, direct comparison cannot be made.

Over 50% of sampling effort and discrete pools sampled occurred below 730 mASL of which 54% of those pools contained fish (Table 17). Nearly all species observed occurred below 735 mASL in both years sampled (Figure 10). Bull Trout (n=1) and Kokanee (n=2) were only observed (albeit very small presence) above 735 mASL. Species that were common above 735 mASL include Longnose Sucker, Lake Chub, Redside Shiner, and Prickly Sculpin. Nearly all dead fish were observed below 735 mASL (Figure 11).

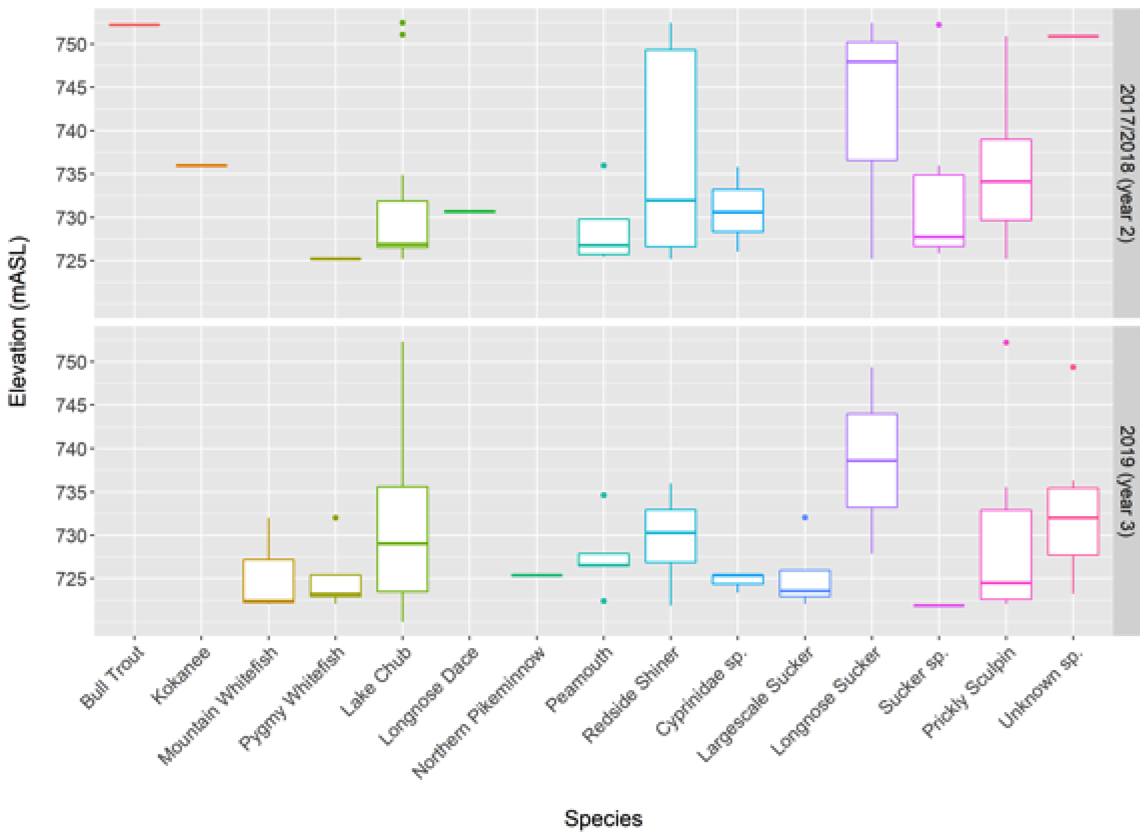


Figure 10. **Elevational distribution of fish taxa observed alive in pools sampled along the drawdown zone of Kinbasket Reservoir in Year 2 and Year 3.** Reservoir water level reached low pool on 23 April 2018 at an elevation of 719.35 mASL in Year 2 and on 13 April 2019 at an elevation of 714.92 mASL in Year 3. Pools were sampled between 724 and 753 mASL in Year 2 and between 720 and 753 mASL. Sampling effort was not standardized between years (varying annual reservoir elevation) or between many pools (due to varying combination of fishing methods conducted between pools as dictated by pool characteristics [see 3.3 Pool Sampling and 3.4 Fish Survey Data]), therefore, direct comparison cannot be made. Species arranged by taxonomic relationship.

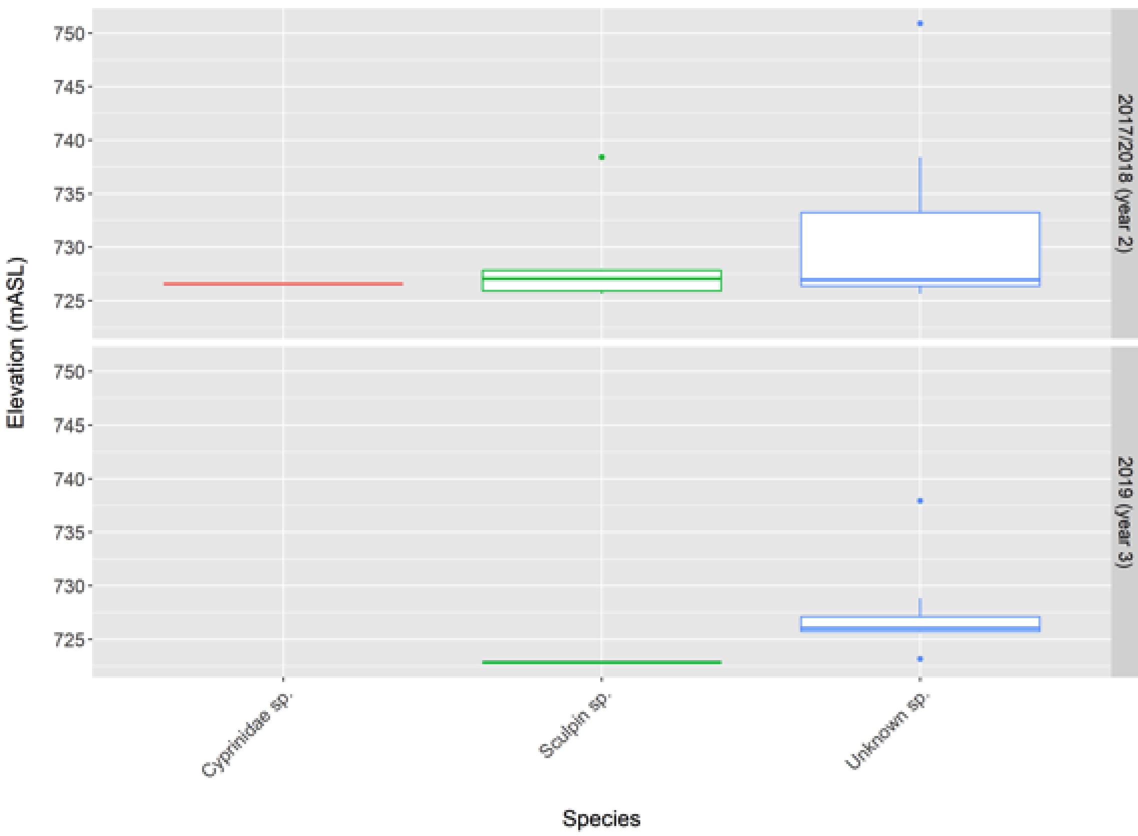


Figure 11. Elevational distribution of fish taxa observed dead in pools sampled along the drawdown zone of Kinbasket Reservoir in Year 2 and Year 3. Reservoir water level reached low pool on 23 April 2018, at an elevation of 719.35 mASL in Year 2 and on 13 April 2019, at an elevation of 714.92 mASL in Year 3. Pools were sampled between 724 and 753 mASL in Year 2 and between 720 and 753 mASL.

Table 17. Number of isolated pools sampled in the drawdown zone of Kinbasket Reservoir across an elevational range of 715 mASL to 755 mASL. In Year 2, pools were sampled from 724 to 753 mASL and pools in Year 3 were sampled from 719 to 753 mASL. Reservoir reached low pool of 719.33 mASL on 24 April 2018 in Year 2 and 714.92 mASL on April 13 in Year 3. A discrete pool is an isolated pool unique in position but may vary in volume and surface area of standing water during isolation between each sampling event.

Elevation (mASL)	Year 2 (2017/2018)	Year 3 (2019)	Discrete pools	Discrete pools containing fish
715−720	0	1	1	1
720−725	0	17	17	10
725−730	24	31	32	26
730−735	9	11	18	13
735−740	10	13	13	9
740−745	0	1	1	0
745−750	5	2	5	4
750−755	10	3	10	5
Total	**58**	**79**	**97**	**68**

Fork length measurements (total length for sculpins due to rounded caudal fin) were performed on 939 fishes (Year 2 − 467, Year 3 − 472) across 13 taxa (Figure 12). The single length-measured Bull Trout, Longnose Dace, and two Kokanee were all juvenile. The length measurements indicated that fishes stranded in pools in the DDZ were primarily juvenile (87%) across both years combined and were the dominant life stage in all taxa sampled. Adults were considerably less encountered and observed in cyprinids (i.e., minnows), suckers, and sculpins.

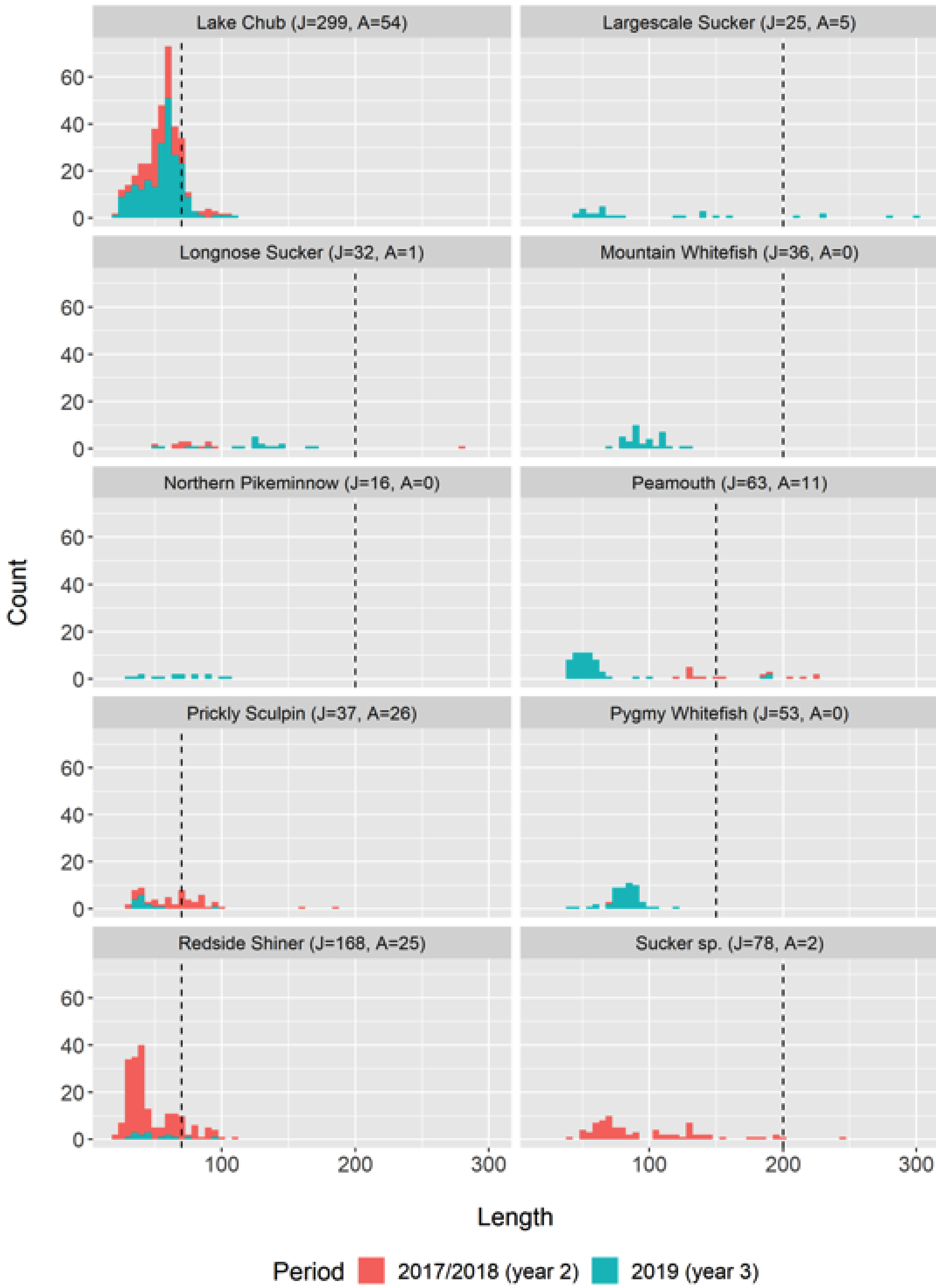


Figure 12. **Length (mm) frequencies of fishes (n > 10 measured fish) sampled in isolated pools in Year 2 and Year 3 combined along the drawdown zone of Kinbasket Reservoir** between elevation 724 and 753 mASL (Year 2) and 719 and 753 mASL (Year 3). The dotted vertical line in each graph represents the approximate juvenile to adult length thresholds. Measurements above (to the right) the dotted line represents adult life history stage. Fishes arranged in alphabetical order.

Discussion

Stranded fishes occurred in both years and were common across all high risk fish-stranding areas identified in Year 1. Fish species of concern identified by BC Hydro (Bull Trout, Rainbow Trout, Kokanee, and Burbot) were not at high risk of stranding (at least down to 720 mASL), as only three fish (one Bull Trout and two Kokanee) were observed of the 4,035 fish sampled. Although a direct comparison between annual fish stranding could not be assessed due to annual variation in reservoir level during sampling and varied combination of fish sampling methods conducted on each pool (method limitations dictated by pool characteristics), Lake Chub, Redside Shiner and Prickly Sculpin were consistently abundant and widespread across the DDZ in both years. Most fishes observed were below 735 mASL, this was likely be due to the unequal distribution of pools across the DDZ elevation (Figure 13). More than 60% of pools were found at a relatively narrow elevation range of 10 m between 725 and 735 mASL.

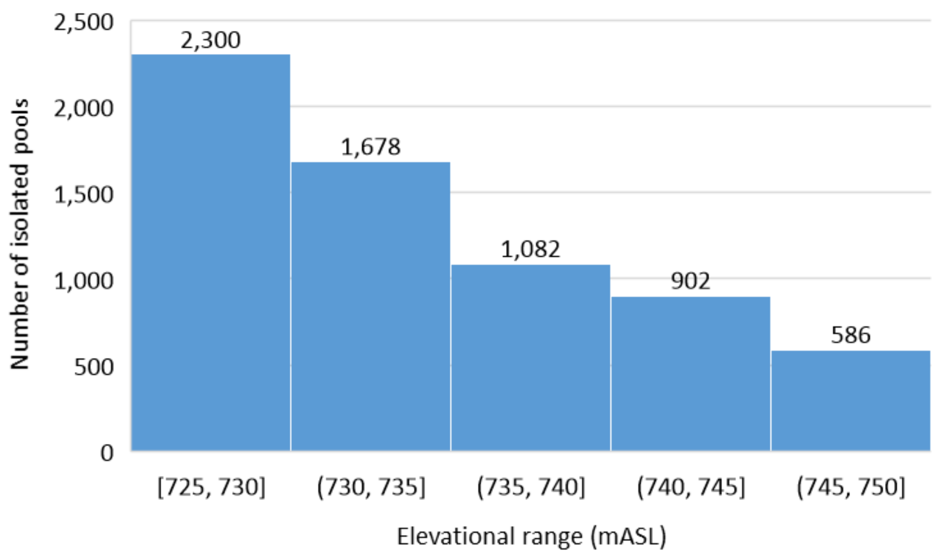


Figure 13. **Number of isolated pools by elevational range located in the DDZ of Kinbasket Reservoir as identified from DEM in Year 1.** DEM was based on 2002 aerial photography, flown at an elevation of 714 mASL. A total of 6,548 pools were identified between elevation 754 and 725 mASL along slopes less than six percent.

While dead fishes were also widespread, the extent of mortality cannot be inferred from the available data as predators/scavengers and decomposition are likely important factors in obscuring causes of mortality (Appendix 6). As most identifiable dead fishes were sculpins (and most likely are the unidentifiable fishes), it does not seem that drawing of the reservoir is having a major impact on the populations of these fishes, as they appeared to be a common group observed alive in the two years of field sampling. Stranded sculpins are most at risk of mortality due to their benthic ecology (e.g., often bury in soft substrate, underneath rocks and woody debris) and more likely, than other species, to occupy shallower depressions, which dry out faster than deeper pools when exposed (McPhail 2007). Juvenile age classes were the most affected by stranding for all taxa observed, however, adult cyprinids, particularly Lake Chub, Redside Shiner, and sculpins, also appeared to be common.

The fish sampling techniques used in this study were effective in documenting the presence of fishes stranded in isolated pools along the DDZ, however unequal treatment of fishing gear per pool prevented a direct comparison of fishing effort between pools, study areas and years (see section 4.0 Datasets). As it is now well understood that fishes are being stranded in the DDZ of Kinbasket Reservoir, additional years of sampling are recommended for the following reasons:

Appendix 5. Over-winter Fish Survival

Introduction

See 4.4 Dataset 04. Prior to CLBMON-4, information about fish stranding in the DDZ of Kinbasket Reservoir was mostly unknown aside from anecdotal evidence. We sampled isolated pools in the DDZ to determine fish presence before and after winter and deployed dissolved oxygen (DO)/temperature data loggers into high elevation isolated pools (747−753 mASL) to assess over-winter fish survival. The results of this study were used to assist in answering MQ7 (MQ7: Are operational or non-operational changes recommended to mitigate or to reduce the risk of fish stranding?).

Methods

Fish Sampling

Fish sampling was conducted on six high elevation isolated pools (747−753 mASL) in the DDZ of Kinbasket Reservoir along Bush Arm (near Bush River causeway) and the shore north of Bear Island (KM88 along Bush Arm FSR) in October 2017 (Table 18). Fish sampling techniques included dip netting and minnow traps (three traps per pool soaked for 24hr period) baited with canned cat food. Repeat sampling was executed in May 2018, after ice melt to re-assess fish presence.

Data Loggers

See Methods section 3.5 Data Loggers. Data loggers were deployed in pools that were observed to contain fish during the fall field survey for CLBMON-4 (Table 19), or in pools reported anecdotally to contain fish during summer 2017 field surveys for CLBMON-58 (Table 1). Six data loggers were mounted horizontally, each on on 2 m length rebar, and placed fully submerged under water and their sensor raised a minimum of 5 cm off the pool floor to approximately mid-water column height (20 to 55 cm depth). The horizontal positioning of the loggers prevented buildup of bubbles on the sensor. DO concentration (mg/L), temperature (°C) and time (24 hr) were programmed to record data every 10 minutes and data were downloaded using the manufacture's software (PME miniDOT software). Three data loggers were retrieved on 05 May 2018, from LGL staff working on CLBMON-58, while the remaining three loggers were retrieved on 11 May 2018, by crew working on CLBMON-4.

Dataset

See 4.4 Dataset 04. All fishes captured from both sampling periods were used in the analyses. Every captured fish was counted and identified to species, and length was measured from a subsample of approximately 30 fish per species. All live fish were then released back into their respective pools during both surveys. Dead fishes, if present were also documented (i.e., identified and enumerated) but not released back into the pools. Dead fishes observed from subsequent trips were assumed to have died between sampling events. Data loggers were calibrated prior to deployment and their data were uploaded to a computer following deployment.

Analyses

Fish data were summarized in table format. Winter fish survival of isolated pools was assessed by the presence and condition of fishes between sampling periods. Fishes that were observed alive in isolated pool during the spring field session (spring 2018) suggested that a pool supported over-winter fish survival. Daily average DO and temperature data were plotted on line graphs for each data logger/pool.

Results

Six pools sampled in fall 2017 containing fish were resampled in spring 2018 during reservoir filling and after ice melt (Table 18). Live fishes were present in four pools after repeat sampling in the spring. Lake Chub and Redside Shiner were present in both sampling periods, but did not differ in size between sampling periods (Figure 14). Bull Trout, Prickly Sculpin and Longnose Sucker were not detected during the spring sampling. A single dead fish was observed during the spring session in pool 22, the same pool where four Prickly Sculpin were observed in the fall session. This finding suggested that the unidentifiable fish was likely the same species and that fishes did not survive over winter in this shallow pool. No fishes were observed in pool 24 during the spring sampling period. Since this pool was not completely isolated during the fall sampling period, it is possible that fishes escaped from this pool before it became isolated.

Table 18. High elevation pools (747−752 mASL) in the drawdown zone of Kinbasket Reservoir with fish observed in October 2017 and re-sampled in May 2018. Provincial freshwater fish codes used from Appendix 9 A of the Fisheries Information Summary System (FISS): BT − Bull Trout, CAS − Prickly Sculpin, LKC − Lake Chub, LSU − Longnose Sucker, RSC − Redside Shiner, SU − Sucker sp., UNK − unknown fish. Pool depth and area based on wetted measurements collected during the fall 2017 survey. Pool area was approximated by multiplying the maximum wetted length by the maximum wetted width using field-collected measurements. Values inside brackets next to each fish species represents total count sampled.

Location	Pool label	Elevation (mASL)	Pool Area (m^2)	Max. pool depth (cm)	Fish 24 Oct 2017	Fish 11 May 2018
Bear Island	19	752.47	600	100	LKC (7), LSU (2)	LKC (9), RSC (4)
Bear Island	20	751.01	450	100	RSC (9)	LKC (1)
Bear Island	22	750.66	40	60	CAS (4)	UNK (dead - 1)
Bear Island	23	749.35	60	20	RSC (12)	RSC (6)
Bear Island[a]	24	747.89	2,349	100	LSU (1), CAS (2), RSC (12)	None
Bush Arm	59	752.20	525	30	BT (1)	RSC (11), SU (1)

[a] Reservoir water elevation was standing at 748.45 mASL during the fall data logger deployment (24−25 October 2017). Pool 24 was still inundated until 04 November 2017 (water levels provided by BC Hydro) when the reservoir water level declined to 747.61 mASL.

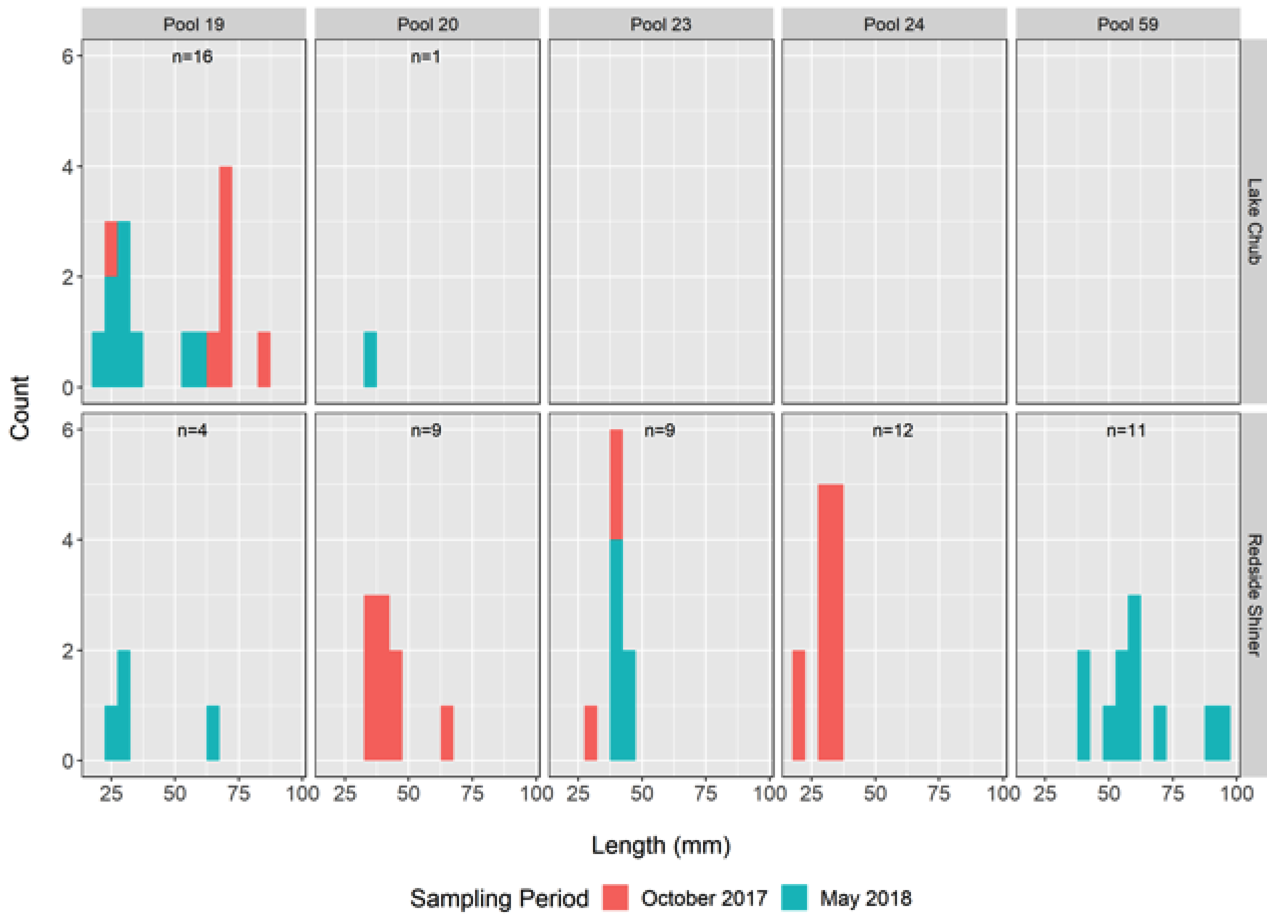


Figure 14. **Stacked bar graph illustrating the length distribution of Lake Chub and Redside Shiner sampled in five high elevation (>745 mASL) isolated pools along the DDZ of Bush Arm and Bear Island, Kinbasket Reservoir in Year 2 for CLBMON-4.**Sampling was conducted in October 2017 prior to winter freezing then repeated in May 2018 after snow melt to assess if stranded fishes survive overwinter in isolated pools. Not all fish were measured for length, and only these two species were plotted due to their re-occurrence between sampling periods (Lake Chub) and relatively higher abundance (Redside Shiner).

Table 19. **Locations of dissolved oxygen (DO) and temperature data loggers** deployed in October 2017 in high elevation pools (between 747 and 752 mASL) in the drawdown zone of Bush Arm and shoreline north of Bear Island (west of Bush Arm on KM88 of Bush Arm FSR) of Kinbasket Reservoir. Provincial freshwater fish codes used from Appendix 9 A of the Fisheries Information Summary System (FISS): CAS – Prickly Sculpin, LKC – Lake Chub, LSU – Longnose Sucker, RSC – Redside Shiner. Data loggers in pools 28 and 61 were removed by LGL wildlife crew and fish sampling was not conducted. Pool area was approximated by multiplying the maximum wetted length by the maximum wetted width using field measurements collected during the data logger deployment date. Values inside brackets next to each fish species represents total count sampled.

Location	Pool Label	Deployment date	Retrieval date	Elevation (mASL)	Pool Area (m^2)	Pool depth (cm)	Sensor depth (cm)	Fish Oct 2017	Fish May 2018
Bear Island	19	24-Oct-17	11-May-18	752.47	600	100	30	LKC (7), LSU (2)	LKC (9), RSC (4)
Bear Island	20	24-Oct-17	11-May-18	751.01	450	100	35	RSC (9)	LKC (1)
Bear Island	22	25-Oct-17	11-May-18	750.66	40	60	36	CAS (4)	UNK (dead - 1)
Bear Island[a]	24	24-Oct-17	05-May-18	747.89	2,349	100	55	LSU (1), CAS (2), RSC (12)	None
Bush Arm	28	24-Oct-17	05-May-18	751.51	504	30	25	None	N/A
Bush Arm	61	25-Oct-17	05-May-18	751.10	19,240	50	20	None	N/A

[a] Reservoir water elevation was standing at 748.45 mASL during the fall data logger deployment (24−25 October 2017). Pool 24 was still inundated until 04 November 2017 (water levels provided by BC Hydro) when the reservoir water level declined to 747.61 mASL.

Dissolved oxygen (DO) levels varied substantially between isolated pools (from the data loggers deployed in the six pools from October 2017 to May 2018) (Figure 15). A relationship was not observed between this variation in DO levels and the presence of live or dead fishes (Table 19). This suggests that DO levels are not likely related to fish survival in isolated pools. The instantaneous minimum threshold of dissolved oxygen for fish survival is 5 mg/L (BC MOE 2018). Only pool 20 containing live fish before and after data logger deployment had a steady DO reading above this value (Figure 15). While pool label 24 showed a similar trend in DO levels (except for a few days of hypoxia in April), no fishes were observed in the spring. This pool was still inundated during the fall survey and it is possible that fishes emigrated before the pool became exposed and isolated. Pool 22 was the only pool to contain dead fish in the spring. DO levels in this pool fell below 5 mg/L before the pool started to freeze, suggesting that reduced DO levels may have resulted in fish death. In the case of pool 19 where DO levels declined to hypoxic levels immediately after installation, live fishes were still observed in the spring.

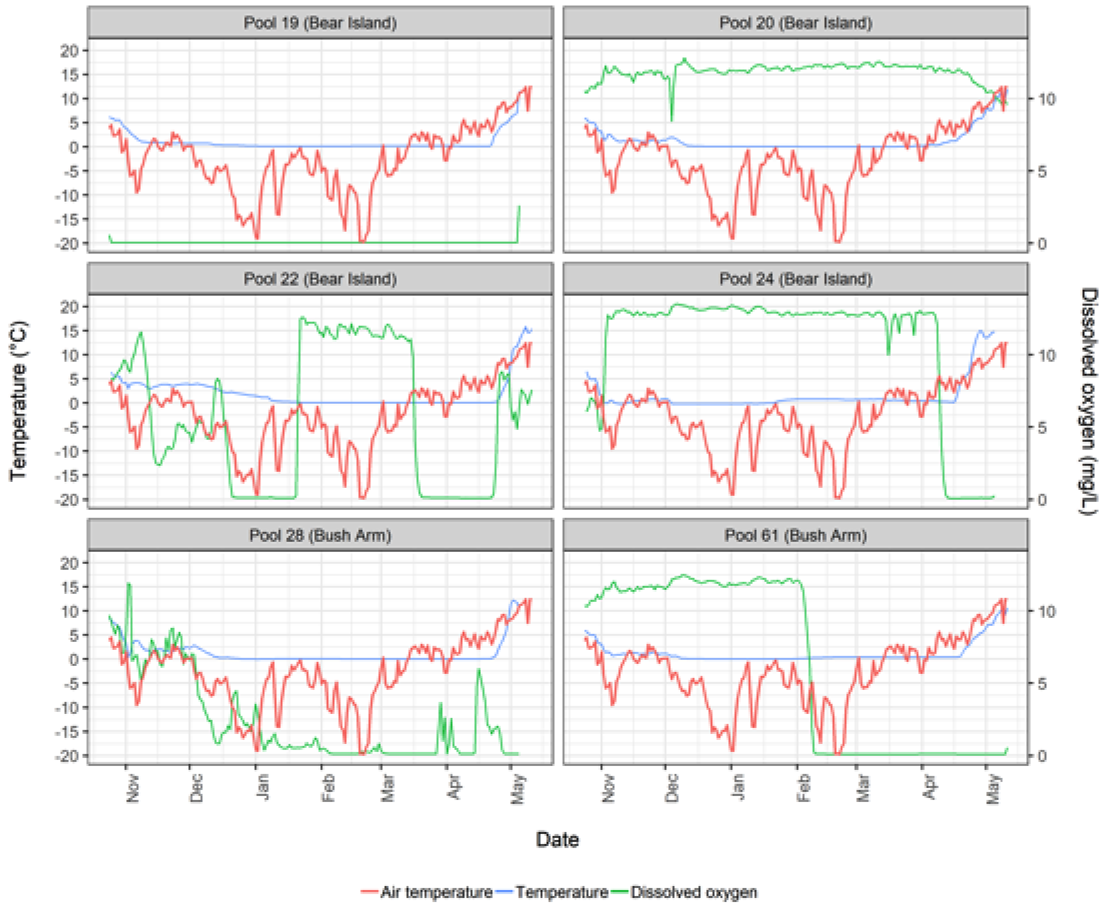


Figure 15. **Daily variation in dissolved oxygen (DO; mg/L) (green line) and water temperature (°C) (blue line) relative to air temperature (°C)** (measured at Mica Dam: https://pacificclimate.org/data/bc-station-data) at six high elevation pools (between 753 and 747 mASL) located along the DDZ of Bush Arm and Bear Island of Kinbasket Reservoir. Data loggers were set at a depth between 25 and 55 cm below the surface when first installed. Data loggers were deployed in October 2017 and retrieved in May 2018.

Discussion

Four of the six pools sampled in fall containing live fish had live fish during the spring sampling session. Species composition did however change considerably between sampling periods (Table 18). The difference in species occurrence between surveys may be due to detection failure (i.e., unlikely to catch all fish in a pool during a single sampling event), or migration via hydrologic channels connecting to the reservoir or to another pool.

Based on the DEM produced in Year 1 and on recent 20-year air temperature and reservoir elevation data for Kinbasket Reservoir, 522 pools (6.99 ha) between an approximate elevational range of 750 mASL and 745 mASL became isolated prior to winter freezing (Figure 16). According to the elevational distribution of observed fishes in Appendix 4 and the results from this study, only a single dead fish was observed in that elevational range while live fishes (n = 215) were observed in six pools sampled in spring of 2018 and 2019 combined, indicating that fishes survive over winter in high elevation pools.

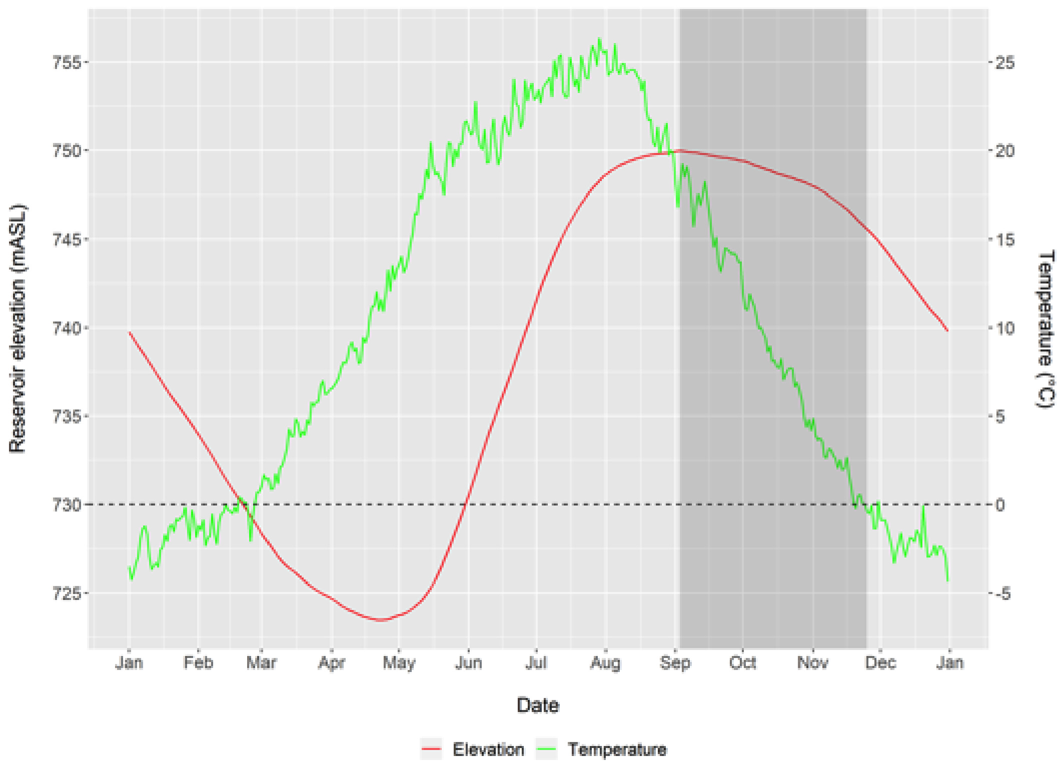


Figure 16. **Kinbasket Reservoir elevation (mASL, red line) and air temperature (°C, green line)** based on a 20-year average from 2000 to 2019. Temperature values recorded for Mica Dam and obtained online from www.climate.weather.gc.ca. The shaded area represents the 20-year average time frame between date of highest average pool elevation (left edge – 03 Sep, 749.98 mASL) and the date at which the average temperature is consistent below zero degrees Celsius (right edge – 25 Nov, 745.57 mASL) that estimates start of reservoir freezing.

Although DO levels reached hypoxic levels in most pools, data loggers only detected environmental conditions in immediate proximity to the sensor, therefore it is possible whether DO levels in these pools exhibited stratification across the water column and if fishes distributed themselves accordingly. It is also likely that DO levels were sometimes measured when the loggers were frozen in ice, leading to possible erroneous readings. Other factors that may contribute to over-winter fish mortality include pool dewatering and complete pool freezing (see Methods 3.5 Data Loggers).

Appendix 6. Environmental Data and Incidental Wildlife Observations

Introduction

In addition to fish sampling, physicochemical measurements, and cover (i.e., riparian vegetation, substrate, and woody debris) data were collected at each isolated pool to assess fish habitat quality. Incidental wildlife observations (e.g., visual encounter, tracks) were also documented to provide information on potential fish predation.

Methods

The following environmental data were collected at each sampled isolated pool to assess fish habitat quality and potential signs of predation from wildlife:

- Turbidity via a Triton Turbidity Wedge© in fall 2017 survey and a LaMotte 2020 we/wi turbidity meter in spring 2018 survey.
- Physicochemistry – DO (mg/L), temperature (°C) from a YSI Pro2030 handheld dissolved oxygen meter, and pH from a Hanna HI 98129 combo pen.
- Visual assessment of pool riparian and in-pool vegetation cover and large woody debris using the Reconnaissance Fish and Fish Habitat Inventory methods (RIC 2001).
- Incidental wildlife or wildlife sign observations (potential fish predators).

Dataset

Physicochemical conditions were collected at 12 of 14 pools in October 2017, 45 of 50 pools in May 2018, and 65 of 79 pools in May 2018. Water was not present or too shallow (less than 10 cm) for the remaining pools to be measured. Pool cover was recorded for all pools sampled. Only dominant cover is summarized in tabular format. Wildlife signs were recorded incidentally and summarized in tabular format.

Analyses

Physicochemical measurements were compared to the water quality guidelines for aquatic wildlife developed by the Canadian Aquatic Biomonitoring Network (CABIN 2012). Water quality measurements that fell outside of these guidelines were highlighted in the results.

Raw data for dominant pool cover and incidental wildlife sign for all pools sampled were summarized in a table. No further interpretation was conducted.

Results

The results of the physicochemical measurements collected at sampled isolated pools are summarized in Table 20.

Table 20. **Physicochemical variables collected at isolated pools sampled in Year 2 and Year 3 along the drawdown zone of Kinbasket Reservoir.** Definitions and justifications for the measured parameters were compiled from the Canadian Aquatic Biomonitoring Network (CABIN 2012), Guidelines for Interpreting Water Quality Data (RISC 1998), and Key Ecological Temperature Metrics for Canadian Freshwater Fishes (Hasnain et al. 2010).

Parameter	Mean ± SD	Typical limits and discussion
Dissolved oxygen (mg/L)		Maximum solubility of oxygen is ~15 mg/L at 0°C. Fishes require an instantaneous minimum DO of 5 mg/L for all life stages other than buried embryos and alevins.
Fall 2017 (n = 12)	8.44 ± 2.86	DO values were above the minimum level for fish survival for all except two pools sampled. One pool measured 1.10 mg/L in fall 2017, and another measured 2.98 in spring 2019. Fishes were not observed in these pools.DO ranged between 5.10 and 19.90 mg/L for the remaining pools measured.
Spring 2018 (n = 45)	8.89 ± 8.12	
Spring 2019 (n = 65)	9.27 ± 1.47	
pH		Natural fresh waters have a pH ranging from 4.0 to 10.0. Most lakes in B.C. have pH of 7.0 or greater. Lethal effects of aquatic life occur below pH 4.5 and above pH 9.50, with optimal levels being between pH 6.50 and 9.00.
Fall 2017 (n = 12)	7.50 ± 0.32	All recorded values except for one pool sampled in spring 2018 fell within the range that aquatic life can tolerate. All pH measurements ranged between 7.10 and 9.67. No fish were observed in the single isolated pool sampled in spring 2018 with a pH of 9.67.
Spring 2018 (n = 45)	8.52 ± 0.47	
Spring 2019 (n = 65)	8.30 ± 0.45	
Water temperature (˚C)		Temperature naturally varies in water bodies from 0° to 40°C (hot springs). The maximum weekly average for adult and juvenile salmonids is 18−19°C. The mean critical thermal maxima for catostomidae (suckers) and cyprinidae (minnows) in Canada are 32.7°C and 32.6°C, respectively. Long term maximum temperature should be maintained below 25°C for all freshwater fishes.
Fall 2017 (n = 12)	6.74 ±. 1.36	All temperature measurements fell between 3.7 and 29.3°C. Live fishes were observed in pools with temperatures recorded above 25°C. Suckers, Redside Shiner, Lake Chub, and Peamouth were the predominant fishes in these warm pools, followed by a couple of dead sculpins.
Spring 2018 (n = 45)	19.98 ± 4.21	
Spring 2019 (n = 65)	20.22 ± 4.23	

Parameter	Mean ± SD	Typical limits and discussion
Turbidity (NTU)		Pure distilled water has a turbidity of 0 Nephelometric Turbidity Units (NTU). High levels of turbidity reduce light penetration and therefore plant growth and can thereby suppress fish productivity. Turbid waters become warmer as suspended particles absorb heat from sunlight, causing oxygen levels to fall. Suspended solids in turbid water can clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. Drinking water has a turbidity limit of 1 NTU for health, and 5 NTU for aesthetics. The recommended turbidity limit for aquatic life is 50 NTU.
Fall 2017 (n = 12)	<50 all pools	Turbidity measured greater than 50 NTU for five pools sampled in spring of 2019 (50.10−91.86 NTU). Fish were observed in one of these pool with only two dead sculpins recorded. Elevation of these pools ranged from 722 to 744 mASL.
Spring 2018 (n = 45)	11.56 ± 9.18	Turbidity measurements fell below 50 NTU for the remaining pools sampled across all years and ranged between 0.34 and 42.9 NTU.
Spring 2019 (n = 65)	29.04 ± 45.35	

Pool habitat was assessed for all pools sampled in the field program of CLBMON-4. Most pools were homogenous and provided little to no vegetation cover (Table 21). Vegetation cover only occurred in isolated pools above elevation 747 mASL. Large woody debris occurred in 71% of pools but most often in very small quantities.

Table 21. Presence of habitat cover from discrete isolated pools sampled in Year 2 (n = 58) and Year 3 (n = 79) along the drawdown zone of Kinbasket Reservoir. Habitat data collection followed the Reconnaissance Fish and Fish Habitat Inventory methods (RIC 2001).

Habitat	Year 2	Year 3
Riparian vegetation		
Grass	13	5
None	45	74
In-pool vegetation		
Algae	7	0
Vascular plants	14	5
None	37	74
Large woody debris		
Present	49	52
None	9	27
Dominant bed material		
Fines	57	77
Organic	1	2

No signs of wildlife were observed during the fall 2017 survey. Signs of wildlife were observed on 58% (n = 29) of pools in spring 2018 and 63% (n = 50) of pools in spring 2019 comprising of 14 mammal, seven bird taxa and one amphibian (Table 22, Photo 8). Mammal tracks (62%) were the dominant form of evidence belonging primarily to bears, grey wolf and mustelids. Corvid (crows and ravens), tracks comprised 41% of all bird observations. Two old beaver ponds located at Bear Island were well known from previous studies (e.g., CLBMON-58) and are not currently maintained by any beavers. No direct evidence of fish predation or signs of physical damage to fish were observed; however, an Osprey was hovering over pool 95 along the DDZ of Columbia Reach.

Table 22. Number of isolated pools sampled along the drawdown zone of Kinbasket Reservoir with incidental wildlife observations from Year 2 and Year 3 surveys for CLBMON 4. No signs of wildlife were detected during the October 2017 survey. Evidence of wildlife were observed at 29 pools in May 2018 and 50 pools in May 2019.

Wildlife taxa	**Evidence**						**Total**
	Sighting		**Tracks**		**Dam**		
	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3	
Mammal							
American Mink (*Neovison vison*)				1			**1**
Bear sp. (*Ursus* sp.)		3	5	15			**23**
Black Bear (*Ursus americanus*)			1				**1**
Coyote (*Canis latrans*)			1				**1**
Deer sp. (*Odocoileus* sp.)				1			**1**
Grey Wolf (*Canis lupus*)			2	18			**20**
Muskrat (*Ondatra zibethicus*)			1	5			**6**
Mustelid sp. (Mustelidae)			7	3			**10**
North American Beaver (*Castor canadensis*)					2		**2**
Raccoon (*Procyon lotor*)				7			**7**
Red Fox (*Vulpes vulpes*)			1				**1**
River Otter (*Lontra canadensis)*				5			**5**
Wild Cat (Felidae)			1	1			**2**
Wolverine (*Gulo gulo*)				4			**4**
Bird							
Bird sp. (Aves)				5			**5**
Bird of Prey (Owls, Hawks, and Falcons)			1				**1**
Corvid (Corvidae)			5	12			**17**

Wildlife taxa	Evidence						Total
	Sighting		Tracks		Dam		
	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3	
Goose (Anserinae)		1	1	4			**6**
Gulls (Laridae)	1		2				**3**
Osprey (*Pandion haliaetus*)	1						**1**
Small Passerine (Passeriformes)			8				**8**
Amphibian							
Western Toad (*Anaxyrus boreas*)	1	1					**2**

Discussion

While most isolated pools sampled had water quality readings well within those recommended for fish and other aquatic life, these measurements can only be interpreted for the time frame during which the pools were sampled. It does not appear that water quality was a significant concern on the survival of stranded fishes in isolated pools as most fishes observed during the two-year field program were alive across the DDZ. Due to the dynamic nature of Kinbasket Reservoir (i.e., steadily fluctuating water levels and the shifting of pools – see Appendix 2) and the low elevation (below 745 mASL) of most isolated pools in the DDZ, it is unlikely for cover, such as aquatic vegetation and woody debris, to establish in these pools and provide habitat for fishes. Although direct predation of wildlife on stranded fishes was not observed, it cannot be concluded that predation does not have an impact on stranded fishes. Nearly all incidental wildlife observations are of potential fish predators, and it can only be suspected that these animals feed on stranded fishes during their exposure to isolated pools. No further recommendations are needed to improve these methods or add further information to answer the current management questions; however, these methods could be adapted to answer any new objectives or management questions that may arise.