Peace Project Water Use Plan

WAC Bennet Dam Entrainment

Implementation Year 2021

Reference: GMSMON-4

Hydroacoustic Monitoring at the W.A.C Bennett Dam Spillway

Study Period: June 2021 - July 2021

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November 04, 2022

REPORT

GMSMON-4 WAC Bennett Dam Entrainment Monitoring

Implementation Year 4 (2021) Report

Submitted to:
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04 November 2022

Executive Summary

In accordance with the objectives of the GMSMON-4 Bennett Dam Entrainment Monitoring Program created under the Peace River Water Use Plan, this study was designed to evaluate fish entrainment at W.A.C. Bennett Dam spillway during the 2021 spill occurring between 29 June to 7 July. The monitoring approach was consistent with previous monitoring at this location to characterize and enumerate fish entrainment through the use of standard gill (index) netting methods for sampling fish in the forebay reservoir combined with hydroacoustic methods for monitoring fish targets at the spill gates. Hydroacoustic methods followed those used in 2012 and 2020 to the extent required to provide results that could be compared and contrasted across 2012, 2020, and 2021. Mobile hydroacoustics using boat-mounted transducers were also deployed in 2021 for scanning the water column in the forebay to estimate the abundance and distribution of fish, providing context around the relative effect of entrainment on local populations.

The Williston Reservoir has been previously characterized as a dynamic fishery subject to changes in species composition and abundance over time. The results from this study when compared to previous historical work also suggest continued shifts in community composition, for example, fewer Kokanee were captured in 2021 and 2020, versus 2012 netting efforts. Recent netting efforts in 2021 also yielded different results than 2020. Peamouth Chub was the dominant fish species in the catch for 2021, and the relative abundance of Peamouth Chub was measurably higher than that recorded in 2020 when Longnose Sucker and Lake Whitefish were the dominant species. Whether species community shifts are real and reflect larger ecosystem processes is unknown. Differences in species compositions in the fish catch may be explained, in part, by sampling biases related to sampling dates, gear, and locations. The effects of which can be exacerbated by the challenges of capturing schooling fish in the reservoir such as Kokanee over a relatively short duration sampling program.

Results from the mobile hydroacoustic surveys also identified changes in fish densities relative to previous mobile surveys, which could be attributed to various factors, including those discussed above for species composition shifts. For all transects combined, the average fish density in 2021 was 22.70 fish/ha, 73% lower than the 85 fish per hectare in 2008 and 82% lower than the 128 fish/ha in 2012. Across the forebay, the average density for each transect increased from west to east, with transects closest to the dam having higher densities.

The duration of the spill event in 2021 was within a 7-day period (or 168 hours), with gates open for 106 hours in total from the first hour the gates were open to when they were closed for the remainder of the season. The spill rate remained relatively constant when gates were open (568 to 602 m^3/s). Hydroacoustic data were recorded over the entire spill period by both vertical and horizontal transducers mounted on the upstream pier of the center spill gate, and a vertical transducer mounted on the upstream pier of the East Gate. Total cumulative entrainment at all gates was estimated at 217,500 fish, with a variance (i.e., relative percent difference) estimate of 167,258 to 267,743 fish. The East Gate recorded the highest entrainment, which was statistically higher than the Central Gate. It could not be determined if the higher entrainment rates at the East Gate were driven by high numbers of fish travelling along the shorelines of the reservoir or due to higher fish densities east of the spill gate. As both scenarios were equally probable, entrainment at the West Gate was estimated by incorporating the variability in entrainment rate observed across the east and central gates such that the total cumulative entrainment estimate was considered a conservative estimate (i.e., potentially overestimated).

Based on track size analyses of the hydroacoustic data it was determined that most of the fish entrained during the 2021 spill period (92%) were small-bodied fish less than 75 mm in length. This small size class was assumed to represent a mix of age 0+ Kokanee and Lake Whitefish, Pygmy Whitefish, Redside Shiner and Peamouth Chub (up to age 2) based on historical catch data for the reservoir. The species composition of entrained fish less than 75 mm in length remains a key source of uncertainty in estimating species-specific entrainment.

Based on the findings from 2020 entrainment monitoring on peak entrainment during the early morning hours surrounding sunrise (Golder 2021), BC Hydro applied intermittent gate closure mitigation for these hours for the 2021 spill to reduce entrainment numbers. It was also proposed that intermittent gate closures have 'additional benefits' with the potential to reduce the hourly entrainment rates through behavioural mechanisms, for example, avoidance of the disturbance created by the movement or noise of the gates. Similarly, the intermittent closure of the gates may eliminate the potential for any attraction to the forebay once the gates are open and water is flowing. A comparison of hourly data summarized for the Central Gate in 2020 and 2021 show varying trends between years, with consistently low entrainment rates during the two-hour interval following gate opening in the morning in 2021. Statistical trends in hourly entrainment in 2021 were also quantified using a mixed-effects model, demonstrating that time since gates opened had a non-linear significant effect on entrainment (but only for the vertical beam data). After accounting for the influence of covariates in the model developed for the vertical beam data, entrainment rates increased as time elapsed since the gates opened.

The present study suggests that the benefits of gate closure mitigation include a reduction in entrainment by a minimum of 127,236 fish and up to 224,102 fish. The lower estimate conservatively applied uniform hourly entrainment rates across the day to rates that would have been observed if the gates were open during the night-time hours when mitigation was applied. The upper estimate was based on differences in fish densities throughout the day using the daily proportion of fish entrained between midnight at each of 09:00, 10:00, 11:00, 12:00, 13:00, and 14:00, for days with 24 h of entrainment data.

Interpretation of annual trends of entrainment rates and the benefits of mitigation closure on reducing entrainment are challenging, recognizing annual differences in the timing of the spill, environmental conditions, and the fish community composition in the forebay at the time of the spill. Continued investigations into fish responses to intermittent gate closure spills are warranted to confirm the benefits of the mitigation on overall entrainment.

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1.0 INTRODUCTION

Williston Reservoir (the reservoir) is located in north-central British Columbia (BC), approximately 200 km north of Prince George, BC (Figure 1) and is part of the Mackenzie River drainage system. In 1967, the W.A.C. Bennett Dam was built across the Peace River, resulting in creation of the reservoir and flooding of the Parsnip River, Finlay River, and the Peace River. The reservoir surface area ranges from 1,647 to 1,800 km^2, depending on reservoir pool elevation. The reservoir and upper Peace watershed and the aquatic resources they support are important to local Indigenous communities and provide recreation use for fishing and boating for nearby population centres of Prince George, Mackenzie, Fort St. John, Dawson Creek, and Chetwynd (Blackman 1992).

In response to concerns that fish were being entrained through the W.A.C. Bennett Dam (the dam) spillway during spill events, the Peace River Water Use Plan Committee recommended the creation of the GMSMON-4 Bennett Dam Entrainment Monitoring Program (BC Hydro 2008). The monitoring program included plans to assess the impacts of flood pulse events and related spills on the reservoir fish population. The main objectives of the monitoring program include the following:

- Estimate species composition and abundance of fish in the forebay that may be vulnerable to entrainment
- Estimate fish entrainment through the spillway, including species and size composition
- Quantify the relationship between spill discharge rate and the number of fish entrained
- Evaluate diel and spatial variability in the number of fish entrained

Four previous studies have attempted to quantify fish entrainment during a spill event at the dam over the past three decades. The first study, in 1996, used mark-recapture methods combined with a stationary hydroacoustic assessment that was conducted during the final five days of a spill that occurred over a two-month period (Ebel 1996). This study used single-beam data and estimated approximately 15,000 fish were entrained per day, with higher entrainment rates during twilight and evening hours. However, this study could not provide size class information due to equipment limitations. A study in 2002 focused on estimating mortality associated with the spill using only a mark-recapture program (BC Hydro 2002). More recently, a 2012 study used hydroacoustic surveys and gill netting to estimate fish entrainment (BioSonics 2012; LGL 2012). This study incorporated split-beam technology that allowed for the size of a target to be estimated based on its position in the beam and the intensity of acoustic energy that is reflected back towards the transducer. A range of different spill rates were also observed during this study allowing the development of a preliminary equation describing the relationship between spill discharge rate and fish entrainment. In 2012, it was estimated that 17,500 fish were being entrained per day.

To provide additional insight into the relative impact of these spill events on reservoir fish populations four mobile hydroacoustic studies have been conducted to gain information on the composition, distribution, and abundance of fish in the pelagic area of the Peace Reach of Williston Reservoir, within the vicinity of the dam. The first study, in 1988, included three separate surveys (July, September, and October) as well as day-time and night-time surveys to evaluate differences in the distribution and abundance of fish related to survey timing, concluding night surveys conducted from summer to early fall provide the most robust estimate of fish abundance. This study estimated an average fish density of 49 fish/ha in the Peace Reach and 48 fish/ha in the forebay above the W.A.C Bennett Dam. The total population in 1988 was estimated at 1.6 million in the Peace Reach and 338,565 in the forebay (Johnson and Yesaki 1989). A 2000 study was conducted at the end of August over a period of six nights and consisted of a combination of hydroacoustics, trawl surveys, and gill netting. This study estimated higher average fish densities than the 1988 study, with average fish density estimated at 70 fish/ha in the Peace Reach and 57 fish/ha in the forebay. The total population was estimated at 1.4 million in the Peace Reach (Sebastian et al. 2003). An additional four night-time surveys were conducted in 2008 at the end of July and early August. Estimates from these surveys were higher than in previous years, with average fish densities estimated at 141 fish/ha across the Peace Reach and 85 fish/ha in the forebay. The fish population was estimated at 582,343 in the forebay and 3.2 million in the Peace Reach (Sebastian et al. 2008). Mobile hydroacoustic surveys conducted in July 2012 focused on the habitat zones within the forebay and directly adjacent to the spillway gates (zones 31 and 32). Fish densities in the forebay in 2012 were the highest of all previous monitoring years, at 128 fish/ha. In 2012, fish population estimates were 3.7 million in the Peace Reach and over 1 million in the forebay (LGL 2012).

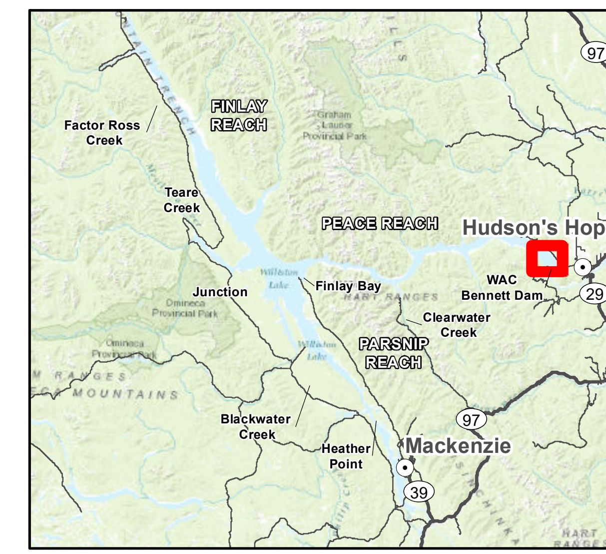
In 2020, Golder Associates Ltd (Golder) was contracted by BC Hydro to continue the monitoring program using similar methods to those used in 2012 (Golder 2021). Entrainment monitoring took place between 22 July and 2 September and focused on monitoring fish entrainment rates across the central spill. In addition to the installation of a vertically oriented split-beam transducer used in previous monitoring programs this study also incorporated a horizontally oriented split-beam transducer to better detect fish within the upper water column (0 to 5 m), allowing for a more robust estimate of entrainment rates in the spillway. As in the 2012 study, index netting was used to collect data on fish sizes and species relative abundance in the reservoir. In 2020, it was estimated that an average of 28,745 fish were being entrained daily, although there was a large amount of variation between daily estimates. As all available hydroacoustic equipment was dedicated to monitoring entrainment, no mobile survey was conducted during the 2020 monitoring program.

Golder continued the monitoring program in the reservoir in 2021, utilizing both mobile and stationary hydroacoustics to evaluate fish abundance in the forebay and quantify the impact of fish entrainment during the 2021 spill that occurred from 29 June to 6 July. Mobile hydroacoustic surveys were conducted prior to the start of the spill, occurring overnight on 23 June and 25 June. The survey design focused on the same three transects completed during the 2012 survey (transect 31.5, 32, and 32.5; Figure 1), to provide directly comparable data, and included two additional transects to increase survey coverage in regions closer to the spill gates (transect 31.75 and 32.75; Figure 1). A single replicate of each transect was conducted each night and the data was pooled to evaluate the abundance of fish in the Peace Reach of Williston Reservoir. Entrainment monitoring followed the 2020 study design with the addition of a second vertically oriented split-beam transducer at the East Gate to evaluate differences in entrainment rates across gates. As in previous years, fish community sampling (index netting and minnow trapping) was used to complement hydroacoustic data and provide relative abundance and length class information, which are required data to provide species specific abundance and entrainment estimates.

The primary report objectives are to address the questions and objectives proposed for the GMSMON-4 Bennett Dam Entrainment Monitoring Program and include the calculation of fish abundance and distribution in the forebay and provide estimates of entrainment rates (including species specific entrainment results) using data collected from hydroacoustic monitoring and fish community sampling methods. This report also includes the objective of evaluating the benefits of intermittent gate closure mitigation on entrainment rates. Details are provided further below on the monitoring program methods for hydroacoustic monitoring (including equipment set up, data acquisition, and analysis), and fish sampling methods used to provide species-specific statistics. The provided information is intended to supplement previous monitoring results and guide future decision making related to spill risk and flood pulse strategies to minimize impacts on Williston Reservoir fish populations.

LEGEND

- HYDROACUSTIC SURVEY 2 TRANSECTS (20210625)
- HYDROACUSTIC SURVEY 1 TRANSECT (20210623)
- ROAD
- WATERCOURSE
- WATERBODY
- WAC BENNETT DAM SPILL GATE
- HISTORICAL WAYPOINT



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COORDINATE SYSTEM: NAD 1983 CSRS UTM ZONE 10N

CLIENT
BC HYDRO

PROJECT
2021 HYDRO MONITORING -W.A.C BENNETT DAM

TITLE
2021 MOBILE HYDROACUSTIC SURVEY TRANSECTS

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-02-15
DESIGNED	MT
PREPARED	JP
REVIEWED	
APPROVED	

PROJECT NO.	CONTROL	REV.	FIGURE
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1.1 Fisheries Setting

The construction of the W.A.C. Bennett Dam on the Peace River has changed the fish community structure as the system transitioned from a lotic to a lentic ecosystem. Stockner et al. (2005) described the initial biological productivity in the reservoir as “boom and bust” with a 10-year boom period followed by a subsequent decline in production as the system gradually transitioned to its current oligotrophic state. Following impoundment, the Williston Reservoir was classified as a moderately productive ecosystem but progressively lost nutrients through sedimentation and outflow. Combined with the scarcity of littoral carbon production associated with severe fluctuations in water level (drawdown) and winter ice-scouring, the system has gradually lost biological productive capacity to sustain high level of fish production (Stockner et al. 2005).

Initial assessments of the fish community in the Williston Reservoir by Barret and Halsey (1985) and Blackman (1992) documented 12 different species including: Arctic Grayling (*Thymallus arcticus*), Bull Trout (*Salvelinus confluentus*), Burbot (*Lota lota*), Kokanee (*Oncorhynchus nerka*), Lake Trout (*Salvelinus namaycush*), Lake Whitefish (*Coregonus clupeaformis*), Largescale Sucker (*Catostomus macrocheilus*), Longnose Sucker (*Catostomus catostomus*), Mountain Whitefish (*Prosopium williamsoni*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Peamouth Chub (*Mylocheilus caurinus*), Rainbow Trout (*Oncorhynchus mykiss*), Redside Shiner (*Richardsonius balteatus*), and White Sucker (*Catostomus commersonii*). Five additional species were identified as being present in in the Reservoir from 1977 to 2018 based on a query of the British Columbia Ministry of Environment Fish Inventory Data (MOE 2020) for a grand total of nineteen species. These species include: Dolly Varden (*Salvelinus malma*), Lake Chub (*Couesius plumbeus*), Prickly Sculpin (*Cottus asper*), Pygmy Whitefish (*Prosopium coulterii*), and Slimy Sculpin (*Cottus cognatus*) (Table 1).

Of the species listed above, Bull Trout (specifically the Western Arctic Population) are the only species with a status of special concern under the *Species at Risk Act* (SARA) and Committee on the Status of Endangered Wildlife in Canada (COSEWIC, Government of Canada 2020) and are also listed provincially as special concern (Government of British Columbia 2020). Four of the species, including Arctic Grayling, Lake Trout, and Burbot are provincially designated as ‘apparently secure, with some cause for concern’ (Government of British Columbia 2020). Kokanee and Peamouth Chub have no provincial status and their status has not yet been assessed due to insufficient data. The remaining 12 species are Provincially designated as ‘demonstrably widespread, abundant, and secure’ (Government of British Columbia 2020).

Historical data (1974 to 2012) has suggested the species composition in the Peace Reach has shifted from a Lake Whitefish dominated fish assemblage to one dominated by Kokanee and Peamouth Chub. Over the same period, previously abundant species such as Rainbow Trout, Longnose Sucker, and Arctic Grayling appeared to have decreased to very low numbers. More recently, index netting in the forebay in 2020 captured few Kokanee and the catch was dominated by Longnose Sucker and Lake Whitefish, which made up nearly 75% of the catch and Lake Trout were captured in the forebay for the first time in 2020. Differences in the fish catch may be explained by sampling biases related to timing, sampling gear and location, particularly the addition of near shore net sets in 2020. These effects can be exacerbated by the challenges of capturing schooling fish in the pelagic zones of a reservoir, such as Kokanee (i.e., you either catch a lot in a net or none), over a relatively short duration sampling program.

Table 1: Fish Species Documented in Williston Reservoir and their Provincial and Federal Conservation Status

Common Name	Scientific Name	Code	BC Provincial Status and List[(a)]	SARA Status[(b)]
Arctic Grayling	*Thymallus arcticus*	GR	Apparently secure, with some cause for concern	-
Bull Trout	*Salvelinus confluentus*	BT	Special Concern	Special Concern
Burbot	*Lota lota*	BB	Apparently secure, with some cause for concern	-
Kokanee	*Oncorhynchus nerka*	KO	No status (unknown)	-
Lake Chub	*Couesius plumbeus*	LKC	Secure	-
Lake Trout	*Salvelinus Namaycush*	LT	Apparently secure, with some cause for concern	-
Lake Whitefish	*Coregonus clupeaformis*	LW	Secure	-
Largescale Sucker	*Catostomus macrocheilus*	CSU	Secure	-
Longnose Sucker	*Catostomus catostomus*	LSU	Secure	-
Mountain Whitefish	*Prosopium williamsoni*	MW	Secure	-
Northern Pikeminnow	*Ptychocheilus oregonensis*	NSC	Secure	-
Peamouth Chub	*Mylocheilus caurinus*	PCC	No status (unknown)	-
Prickly Sculpin	*Cottus asper*	CAS	Secure	-
Pygmy Whitefish	*Prosopium coulterii*	PW	Secure	-
Rainbow Trout	*Oncorhynchus mykiss*	RB	Secure	-
Redside Shiner	*Richardsonius balteatus*	RSC	Secure	-
Slimy Sculpin	*Cottus cognatus*	CCG	Secure	-
White Sucker	*Catostomus commersonii*	WSU	Secure	-

a) Government of British Columbia (2020); [(b)] Government of Canada (2020); '-' no status

2.0 METHODS

2.1 Fish Community Sampling

The species composition in the forebay of the Peace Reach of the Williston Reservoir, specifically in the vicinity of W.A.C. Bennet Dam (the dam), was determined from gill net and minnow trap data collected between 29 June and 6 July 2021. Netting locations were chosen to evaluate the spatial distribution of fish near the spill gates in the upper 15 m of the water column where fish were more likely to be entrained through the spillway. All sampling was completed in accordance with the British Columbia, Ministry of Forest, Lands and Natural Resource Operations and Rural Develop (FLNRO) Fish Collection Permit (permit number: FJ21-612928).

The index netting was conducted using three different nets (Table 2). All nets were set perpendicular to shore and were set at depths of either 5, 10, or 15 m with slightly more effort directed towards the 5 m stratum (i.e., 149 hours of the 254 hours total), as this stratum has historically had the highest catch per unit effort. Nets had an average soak time of 14.9 hours.

Table 2: Gill Net Dimensions for 2021 Sampling

Net	Net Length (m)	Net Width (m)	Stretched Mesh Size (mm)			
			Panel 1	Panel 2	Panel 3	Panel 4
1	61	1.8	19	38	64	89
3	45.7	1.8	25	19	38	-
4	45.7	1.8	19	38	89	-

'-' = not applicable

In addition to gill nets, two clusters of three minnow traps were set along the shoreline at a depth of 1.5 m, just upstream from the spillway to target small-bodied species moving towards the gates. Minnow trap soaking time was 118.5 hours. Traps were checked twice a day for the duration of the sampling program.

To provide a direct comparison to previous survey years, four nets were set in the vicinity of Gillnet Station 1 (Figure 2), which was used in previous studies (Sebastian et al. 2008, and Plate et al. 2012). Similar to the 2020 sampling program a series of three nets were set just outside the log-stop surrounding the spillway to apportion the fish species composition in areas directly adjacent to the spill gates. However, due to low capture rates in both these areas no additional netting occurred at these locations and the remaining nets were deployed along the west bank of the forebay where higher densities of fish were detected during mobile hydroacoustic surveys. The UTM coordinates of each net were recorded and the proximity to the spill gates were later calculated in GIS.

All captured individuals were identified to species, fork lengths (±1 mm) and weights (±1 g) were measured, and representative photographs were taken before releasing the fish back into the reservoir. Length data were used to determine the length distribution of each species for use in evaluating species-specific entrainment rates. Data for species with low capture rates, such as Redside Shiner and Rainbow Trout, were supplemented by data collected during previous netting programs on the reservoir in an effort to better establish the length distribution of these species (Sebastian et al. 2008, Sebastian et al. 2012, Golder 2021).

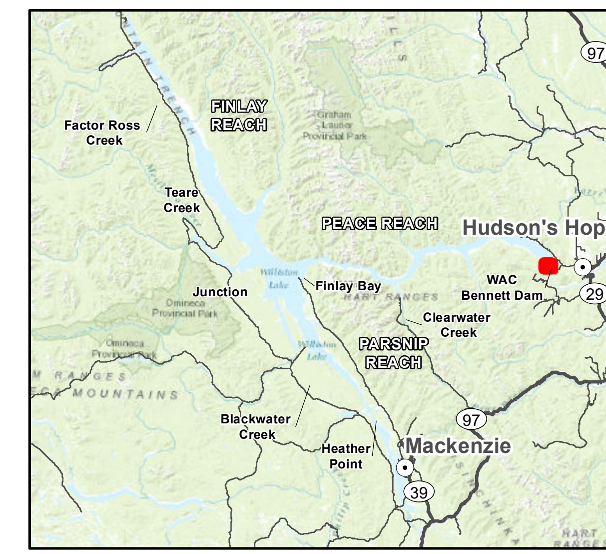
Catch per unit effort (CPUE) was calculated for each net as the total number of individuals captured per 100 m^2 of net per hour of effort. The total CPUE for each species and depth stratum was reported as the average CPUE across all applicable net sets.

LEGEND

- WAC BENNETT DAM SPILL GATE
- GILL NET STATION 1
- MINNOW TRAP LOCATION
- ROAD
- WATERCOURSE

5m CPUE	10m CPUE	15m CPUE
0.0	0.0	0.0
0.1	0.1	0.1
0.2 - 0.3	0.2 - 0.3	0.2 - 0.3
0.3 - 0.5	0.3 - 0.5	0.3 - 0.5
0.6 - 1.0	0.6 - 1.0	0.6 - 1.0
1.1 - 2.0	1.1 - 2.0	1.1 - 2.0
2.1 - 5.0	2.1 - 5.0	2.1 - 5.0
5.1 - 12.0	5.1 - 12.0	5.1 - 12.0

CPUE = CATCH PER UNIT EFFORT (PER 100 M2 OF NET PER HOUR)



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COORDINATE SYSTEM: NAD 1983 CSRS UTM ZONE 10N

CLIENT
BC HYDRO

PROJECT
2021 HYDRO MONITORING -W.A.C BENNETT DAM

TITLE
2021 FISHING LOCATIONS AND CATCH PER UNIT EFFORT IN THE FOREBAY

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-02-15
DESIGNED	MT
PREPARED	JP
REVIEWED	
APPROVED	

PROJECT NO.	CONTROL	REV.	FIGURE
21460846	3000	A	2

2.2 Hydroacoustic Monitoring

2.2.1 Calibration and Data Acquisition

Prior to the start of data collection, a field calibration was performed for all hydroacoustic instrumentation using a standard-sized tungsten-carbide sphere with a known theoretical target strength to ensure the accuracy of target strength measurements for calculating fish size. The calibration sphere was positioned approximately 7 m below the transducer and target strength information was collected for a minimum of 3,000 pings, with approximately 500 to 700 pings per beam quadrant and a minimum of 500 pings within ± 3 degrees from the centre of the beam. Target strength data were analyzed in Echoview® 11.0 (Echoview) and the difference between the measured and theoretical value was applied as a correction for all target strength data during post-processing to offset equipment drift from factory settings and environmental factors, increasing the accuracy of target strength measurements.

In addition, a water quality profile was conducted on 1 July to establish a temperature profile for calculating the speed of sound in water and subsequently the range of each fish track from the transducer. This data was also used to provide insight into potential environmental gradients that may influence the spatial distribution of fish in the water column.

All data above a -130 decibel (dB) threshold were collected by the BioSonics® echosounder and recorded on a Panasonic Toughbook computer running BioSonics® Visual Acquisition™ Program 6.4.1. Each transducer was set to achieve a ping rate of approximately 5 pings per second and each ping had a pulse duration of 0.2 milliseconds (ms). Hydroacoustic data files were saved in 30-minute increments to prevent the loss of large portions of data due to power failure or equipment damage by floating debris.

2.2.2 Hydroacoustic Data Analysis

Hydroacoustic data was managed and analyzed in Echoview following the standard operating procedures for fisheries acoustic studies outlined by Parker Stetter et al. (2009). Fish passing through the acoustic beam were identified using single echo detection followed by fish tracking analysis methods which identifies targets in the water as fish based on specified echo characteristics (Table 3). This method calculates the three-dimensional position of each target in a ping and utilizes corresponding target strength and range information from successive pings to group single echoes into a fish track. For this study, a minimum of three single targets, with a maximum gap of three pings, was required for a fish track to be considered valid. Further analysis of each single target in a track was used to map the path of the fish through the acoustic beam (i.e., direction of travel) and used to estimate the approximate fish size.

Minimum detection thresholds were applied to data from each transducer, based on their specific frequency, removing targets less than 27 mm in length, consistent with previous monitoring (Golder 2021).
While hydroacoustics has the capacity to detect juvenile fish smaller than the 27 mm threshold length, the inclusion of smaller targets would introduce uncertainty into the analysis through the incidental detection of large zooplankton and floating organic debris resembling small fish. Prior to exporting results, all target echoes in close proximity to the bottom and in areas of high background noise were visually inspected and verified as fish targets based on the shape of the echo, its position in the water column and the signal to noise ratio in the adjacent water (Simmonds and MacLennan 2005).

Table 3: Single Echo Detection and Fish Track Settings

Single Target Detection	
Compensated TS threshold (dB)	-60
Pulse length determination level (dB)	6
Minimum normalized pulse length	0.6
Maximum normalized pulse length	1.5
Beam compensation model	BioSonics
Maximum beam compensation (dB)	6
Minor axis angles (degrees) standard deviation	1.2
Major axis angles (degrees) standard deviation	1.2
Fish Track Acceptance Criteria	
Minimum number of single targets in a track	3
Minimum number of pings in track (pings)	3
Maximum gap between single targets (pings)	3

The approximate size of each fish track detected was calculated from its target strength using Love's (1977) all-aspect equation adjusted for the frequency of the specific transducer (Equation 1). Love's equation was based on data from variety of different species of teleostean fishes and was developed for frequencies ranging from 15 to 1,000 kHz. Although this equation was not developed specifically for the species present in Williston Reservoir, it provides a consistent bias for scaling fish length from its target strength. It is the most widely applied equation of its kind, and has been applied in numerous studies including the 2012 entrainment study conducted by BioSonics Inc.

Love's (1977) all-aspect equation accounts for the potential for fish to be insonified in any position (i.e., any amount of rolling, pitching, or yawing; Equation 1) and uses empirically derived constants *a* and *b* to adjust the equation to account for the fish orientations to be considered. For the horizontal beam data all possible angles were considered as fish, particularly small fish, could be theoretically oriented in any direction, with no predictable dominant orientation (*a* = 0.021, *b* = 1.87). Alternatively, the equation was adjusted for the vertical beam data to reflect fish only being insonified at angles up to a maximum of ±90º from the standard upright position (*a* = 0.021, *b* = 1.87). This range was deemed more appropriate for vertical data as fish are considered to be primarily insonified in the dorsal aspect. Each equation was adjusted for the specific frequency of transducer and are outlined below.

Equation 1 - Love's All-Aspect Equation for Fish Length.

$$L = \sqrt[b]{\frac{10^{(TS \div 10)} \times 4\pi}{\lambda^2 \times a}} \times \lambda$$

Where *TS* denotes target strength, λ is the acoustic wavelength (based on the transducer frequency), *a* and *b* are empirically determined constants specific to aspect of fish to be considered.

2.3 Mobile Hydroacoustic Survey

2.3.1 Survey Design

To quantify the abundance of fish that utilize the Peace Reach of Williston Reservoir, a mobile hydroacoustic survey was conducted overnight on 23 June and 25 June. No data was collected overnight on 24 June due to poor weather conditions and wind speeds exceeding 20 km per hour. Surveys were initiated approximately one hour after sunset to limit the amount of light encountered during surveys to reduce the potential for light avoidance reactions and schooling behaviours, subsequently increasing the effectiveness of hydroacoustic methods (e.g., Yule 2000). Surveys took approximately 6 hours to complete and were conducted between 23:00 and 05:10. Weather conditions during each survey where similar with an average wind speed of 9 km per hour and an average air temperature of 12.6ºC on 23 June and 19.4ºC overnight on 25 June.

Hydroacoustic equipment was mounted on the port side of the vessel and transducers were positioned approximately 0.5 m below the surface of the water (Figure 3). Previous mobile hydroacoustic surveys on Williston Reservoir utilized only a vertically oriented transducer, however, the narrow beam angle and the cone shape of the acoustic beam results in smaller volumes of water being insonified with decreasing range from the face of the transducer, resulting in the upper portion of the water column being under sampled. This bias combined with the impact of vessel avoidance behaviours of fish contributes to lower estimated fish densities in the upper water column when deploying only a vertically oriented transducer. Therefore, each survey in 2021 included a 213 kHz and a 201 kHz split-beam transducer positioned vertically and horizontally in the water column, respectively, to better quantify the density of fish in the upper 5 m of the water column (Kubecka and Wittingerov 1998; Gangl and Whaley 2004). Another advantage of the implementation of a second transducer oriented horizontally in the water column is the ability to cover littoral habitat near shorelines without having to navigate closer to the shoreline, providing coverage up to a distance of 60 m from the boat.

The boat was operated at a speed of approximately 1.25 m/s during data collection, which was slower than previous surveys, to improve data quality and compensate for the relatively low ping rate associated with collecting data to a range of 60 m from the transducer. An average ping rate of 4.4 pings per second was consistent across both surveys and was greater than the ping rate recorded for all previous monitoring programs with the exception of the 2012 survey by Plate et al (2012). However, the recorded ping rate of 10 pings per second during the 2012 survey was unlikely to be an accurate reflection of the true value given data was recorded to a depth of 60 m. Although it is possible to set the ping rate to 10 pings per second, the echosounder will not initiate a subsequent ping until the previous ping has returned from the maximum depth of data collection (i.e., 60 m). Data collected during this monitoring program indicated the maximum attainable ping rate under these collection parameters was 4.4 pings per second. For comparison, a summary of the data collection parameters for all previous monitoring programs and the parameters for this program are summarized in Table 4. In short, the slower boat speed and the faster ping rate relative to Sebastian et al (2003 and 2008) would improve fish detection in the reservoir.

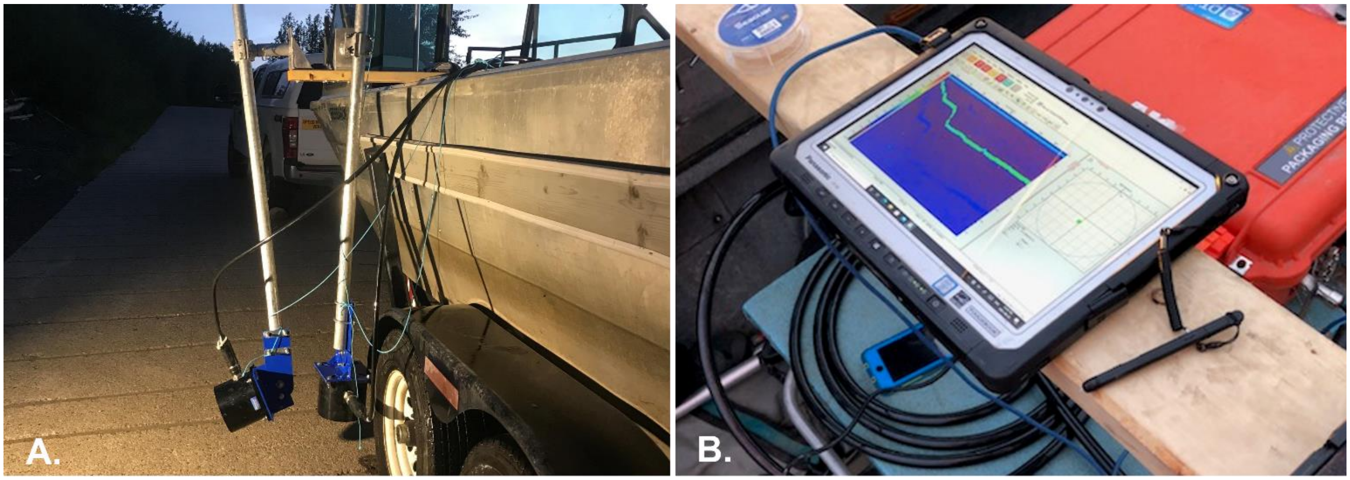


Figure 3: Mobile Hydroacoustic Survey Set-Up Including (A) Transducer Orientation off the Port Side of the Survey Vessel and (B) the Panasonic ToughBook Running BioSonics Visual Acquisition Software

Table 4: Comparison of Technical Parameters for Mobile Hydroacoustic Surveys on Williston Reservoir between 1988 and 2021

Source	Johnson & Yesaki 1989	Sebastian et al. 2003	Sebastian et al. 2008	Plate et al. 2012	Golder 2022
Year	1988	2000	2008	2012	2021
Reach	Peace	Peace	Peace	Peace / Forebay	Peace / Forebay
Make and Model	Biosonics	Simrad EY 500	Simrad EY 500	Biosonics DTX	Biosonics DTX
Frequency (kHz)	420	120	120	200	201/213
Depth of Face (m)	1	1.5	1	0.5	0.5
Pings/ Second	3.25	2	3	10	4.4
Pulse Width (ms)	0.4	0.3	1	0.2	0.2
Boat Speed (m/s)	2	2	2	1.7	1.25
Sampling Threshold (-dB)		70	70	75	130
Processing Threshold (dB)		65	70	60	60
Beam Width Nominal (°)	6	6	6	6	6.8 / 11.8
Beam Width Effective (°)	10	10	10	12	10 / 20
Minimum Fish Detection Range (m)	7	10	8	3	2

Hydroacoustic surveys focused on the detection of pelagic fish greater than 27 mm in length and the general survey design was developed based on previous monitoring programs and consisted of five transects across the forebay. Three of these transects (31.5, 32, and 32.5) utilized the same transect endpoints as previous surveys (Sebastian et al. 2003 and 2008, Plate et al. 2012) but transects lines were extended closer to the shoreline to add additional coverage (Figure 1). The first of the remaining two transects was positioned between 31.5 and 32 and the other to the east of transect 32.5 and these transects were numbered 31.75 and 32.75, respectively.

Transects 31.5, 31.75 and 32 were separated by approximately 2 km while the spacing between 32, 32.5 and 32.75 was reduced to 1.5 km to increase coverage in the area directly adjacent to the spill gates.

Data collection continued while travelling from the end of one transect to the start of the next to evaluate fish density in near shore regions of the reservoir which were not sampled during previous mobile surveys. These near-shore transects were on average 200 m from the shoreline and the average water depth along these transects was 20 m (Figure 1).

The survey was replicated each night and followed the same alignment and orientation during each survey, providing duplicates of each transect. All data were georeferenced using a Garmin GPS connected to the echosounder. The start and end coordinates of each transect as well as transect length and the direction of travel is provided in Table 5.

Table 5: Mobile Hydroacoustic Survey Design Including Transect Coordinates, Length, and Direction of Travel on the Peace Reach of Williston Reservoir

Transect	Start Coordinates		End Coordinates		Transect Length	Direction of Travel
	Easting	Northing	Easting	Northing		
31.5	0547131.1	6215964.0	0544033.2	6212851.5	4.50	SW
31.75	0545658.7	6211424.1	0548856.0	6214732.5	4.50	NE
32	0550391.1	6213047.0	0547192.9	6209834.0	4.50	SW
32.5	0548488.3	6209112.7	0551384.9	6211989.7	4.00	NE
32.75	0551457.9	6209945.0	0549829.4	6208371.0	4.25	SW

2.3.2 Total Abundance Estimation

Historical methods were used to calculate the abundance of fish in the Peace Reach of the Williston Reservoir. The Areal Density method was consistent with historical methods and provide a direct comparison to the results of previous monitoring programs. Fish densities were extrapolated to a total population estimate for the forebay and the entire Peace Reach following the methods outlined in Sebastian et al. (2008).

To calculate fish populations in the Peace Reach of the Williston Reservoir, the average hydroacoustic density across transects was multiplied by the total area of the corresponding zone. Calculations for the total area of Zone 31 (3,532 ha), Zone 32 (3,451 ha) and the entire Peace Reach (31,345 ha) are provided by Sebastian et al. (2003). For Zone 31 and Zone 32, the average fish density was calculated using only the data collected in those specific zones (e.g., average fish density for transect 31.5 and 31.75 was used to calculate the total abundance of fish for Zone 31). The total abundance for the entire Peace Reach used the average from all five transects and the error in abundance estimates for each zone reflected the variability in fish density observed for all transects completed in that zone.

For the areal fish density method, fish densities were calculated by assigning each fish detected a weighting factor relating the diameter of the acoustic beam relative to the distance (or range) of the track from the transducer. Fish density was then calculated as sum of all weights, standardized to 1 meter, divided by the transect length (Equation 2). This same general methodology was also used in entrainment calculations and a more detailed description of the method can be found in Section 2.4.2.2.

Equation 2 – Areal Fish Density.

$$D_i = \frac{\sum_j 1/b}{l_i}$$

Where D_i is the fish density (fish/m^2) for transect *i*, the summation of all fish observed in transect *i*, b equals the weighting factor (beam diameter (m) at range of fish j), and l_i is the length (m) of transect *i*.

2.4 Fish Entrainment

Fish entrainment monitoring occurred for the duration of the spill in summer 2021. The spillway gates were open continuously from 14:00 on 29 June for approximately 37 hours until 1 July, at which point the gates were closed daily during early morning hours surrounding sunrise when historical rates of entrainment were previously recorded to be highest (Golder 2021). During the monitoring period the spill rate remained relatively constant when gates were open, ranging from 543 to 594 cubic metres per second (m^3/s). Through most of the spilling period, the gates were open daily between the hours of 09:00 and 00:00. In total the spill event occurred over a seven-day period for a total of 106 hours. A complete record of the spill period and flow rates can be found in Table 6.

Table 6: Spill Period and Flow Rates at W.A.C. Bennett Dam, 29 June to 6 July 2021

Start Date/Time		End Date/Time		Mean Flow (m^3/s)
29-Jun-21	14:00	01-Jul-21	03:00	594
01-Jul-21	03:00	01-Jul-21	14:00	0
01-Jul-21	14:00	02-Jul-21	00:00	589
02-Jul-21	00:00	02-Jul-21	09:00	0
02-Jul-21	09:00	03-Jul-21	00:00	571
03-Jul-21	00:00	03-Jul-21	12:00	0
03-Jul-21	12:00	04-Jul-21	00:00	569
04-Jul-21	00:00	04-Jul-21	11:00	0
04-Jul-21	11:00	05-Jul-21	00:00	566
05-Jul-21	00:00	05-Jul-21	10:00	0
05-Jul-21	10:00	06-Jul-21	00:00	569
06-Jul-21	00:00	06-Jul-21	09:00	0
06-Jul-21	09:00	06-Jul-21	14:00	543
06-Jul-21	14:00	06-Jul-21	23:00	0

2.4.1 Equipment and Set-Up

The hydroacoustic monitoring approach at the spillway gates was consistent with previous monitoring programs and incorporated the use of three BioSonics split-beam transducers to continuously monitor fish targets moving through the east and central spill gates (Figure 4). Transducers were connected to a BioSonics® DTX echosounder located in the wheelhouse and the installation of hydroacoustic equipment at the Central Gate was identical to the 2020 set-up and included a horizontal and a vertically oriented transducer (Golder 2021). The only difference was the frequency of the horizontal beam was changed from 418 kHz to 201 kHz and the beam angle of the vertical transducer was increased from 6.8 to 11.8 degrees. The lower frequency reduces background noise for smaller particles in the water such as bubbles, zooplankton and floating debris while the larger beam angle increases the area of the gate covered by the acoustic beam.

As previously discussed, the cone shape of the acoustic beam results in an increase in the volume of water being scanned with range from the transducer, resulting in a smaller proportion of the upper water column being scanned compared to lower water column depths. To account for this, the second transducer (201 kHz) on the Central Gate was oriented horizontally to gain a better understanding of the spatial distribution and entrainment rates of fish in the upper part of the water column (i.e., regions less than approximately 4 m in depth), an area largely missed by a vertically oriented transducer beam. This transducer was set up with a beam angle of 11.8, rather than the 6.8-degree angle used in 2021, in order to increase the area of the gate covered by the acoustic beam. A third transducer (202 kHz) was installed at the East Gate with the 6.8-degree beam oriented vertically in the water column. The two-gate study design was implemented to evaluate whether the entrainment of fish was uniform across the spillway gates and to help describe any variance in entrainment estimation between gates.

Each transducer was secured to the mounting equipment provided by BC Hydro and lowered into place along the stoplog track on the upstream piers and angled towards the gate (Figure 4). The echosounder and computer were located in the spillway galley and installation was completed with the assistance of BC Hydro personal. Transducers were tilted towards the spill gate in such a way that the acoustic beam covered the area as close to the spill gate as possible, to improve accuracy of entrainment numbers and reduce interference from structures. The installation depth of each transducer was set at approximately 1.25 m from the surface of the water to protect the equipment from floating debris and account for a potential drop in reservoir elevation.

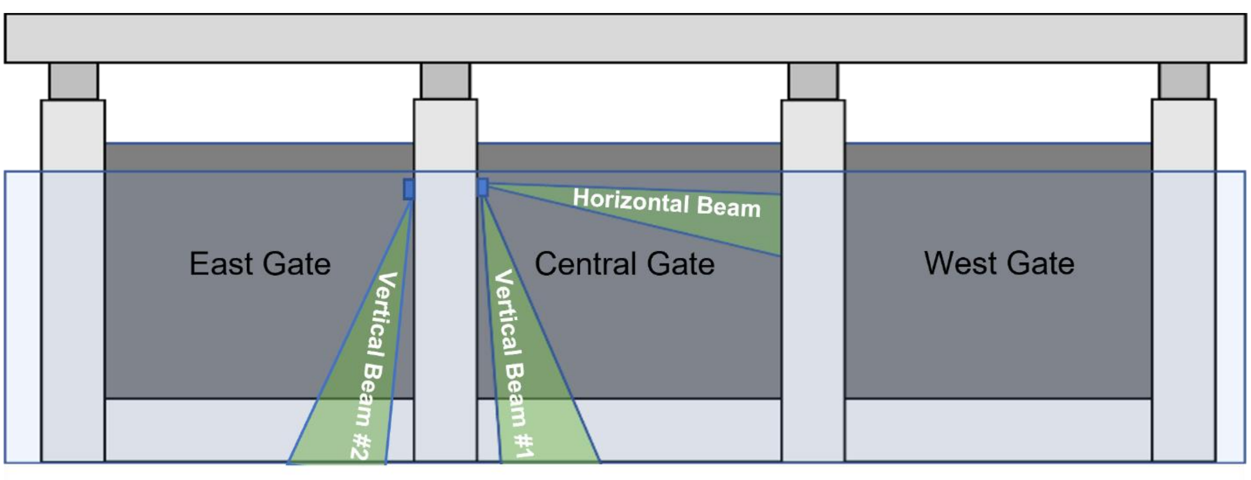


Figure 4: Conceptual Hydroacoustic Equipment Set Up at The Spillway Gates, Including Two Transducers Installed at the Central Gate and One Transducer at the East Gate

2.4.2 Entrainment Calculation

The methods implemented in 2021 to evaluate total entrainment, including size class and species-specific estimates were identical to the methods implemented in the previous monitoring program in 2020 (Golder 2021). The exact methods used are highlighted below for reference.

2.4.2.1 Direction of Travel

The split-beam technology used in this study allows for the direction of travel of each fish track to be determined and incorporated into estimates of fish entrainment. Each of the four quadrants of a split-beam transducer has a dedicated acoustic receiver that measures the arrival time of the acoustic pressure wave. The differences in the arrival time at each of the quadrants is used to calculate the position of the target within the beam and allows for the direction of travel to be calculated based on data from successive pings. This is also essential in the accurate evaluation of an objects target strength as the same object will have a higher target strength in the center of the beam compared to regions further away from the axis. A calculation of an object’s position in the beam therefore allows for the target strength of the object to be corrected based on its distance from the center of the beam, providing a more accurate evaluation of fish length. In contrast, the single-beam units utilized prior to 2012 can only detect direction of travel when a change in range is involved (e.g., fish moving up or down in the water column) and cannot directly measure fish target strength as their position in the beam cannot be determined.

The estimated direction of travel was incorporated into total entrainment estimates and used to evaluate the ability of fish to swim against the flow and escape entrainment. For the purpose of estimating entrainment, a direction of travel towards the spill gate was set to 0º with 180º indicating travel away from the spill gate. Only fish with a direction of travel within 90º of 0º were considered to be entrained.

2.4.2.2 Total Fish Entrainment

As the acoustic beam is narrower than the width of the spill gate, all detections were extrapolated into unsampled areas by calculating a weighting factor for each identified fish track, following the methods outlined in BioSonics (2012). This process of spatial extrapolation required calculating the effective beam width for each target, which represents the approximate width of the acoustic beam at the specified target depth, taking into account the targets size (target strength) and the transducers beam pattern. Each target was than assigned a weighting factor based on the ratio of the gate width to the effective beam width which was used to calculate the theoretical number of fish that would have been detected if the entire width of the spill bay were sampled. For reference, an example of the full beam pattern of transducers can be found in Appendix A.

The first step in the calculation of effective beam width was determining the maximum angle from the beam axis each fish track could be detected. This was accomplished by applying the difference in the mean target strength of each fish track and the selected detection threshold (-60 dB) against the appropriate transducer directivity function (Figure 5). This function accounts for a transducer’s beam pattern when calculating the effective angle, or more specifically, accounts for acoustic intensity peaks along the beams axis and decreases towards its edges. In these lower intensity regions, a larger target is required to reflect the necessary acoustic energy to surpass the minimum threshold to be considered a fish track, compared to an area directly under the beam axis. Therefore, as the difference between the mean target strength and the applied threshold increases, the effective angle also increases (i.e., a larger fish can be detected further away from the beam axis than a smaller fish). Using standard trigonometry this angle was converted to an effective beam width using the range (m) of the target from the face of the transducer (Equation 3).

Equation 3 – Effective beam width

$$Effective\ Beam\ Width\ (m) = 2 \times Range\ (m) \times \tan\ (Half\ Angle)$$

Each track was assigned a weight based on the ratio between the width of the area it is being extrapolated to and the effective beam width for that track. Data from the horizontal transducer was extrapolated to the upper 4 m of the water column while total entrainment in the regions below this depth was based on the vertical beam data. Fish entrainment at a gate was calculated per hour as the sum of weights over the corresponding interval. Furthermore, a small number of tracks were observed moving away from the spill gate during active spilling periods. Therefore, entrainment was based off the net difference in the number of fish heading upstream versus downstream.

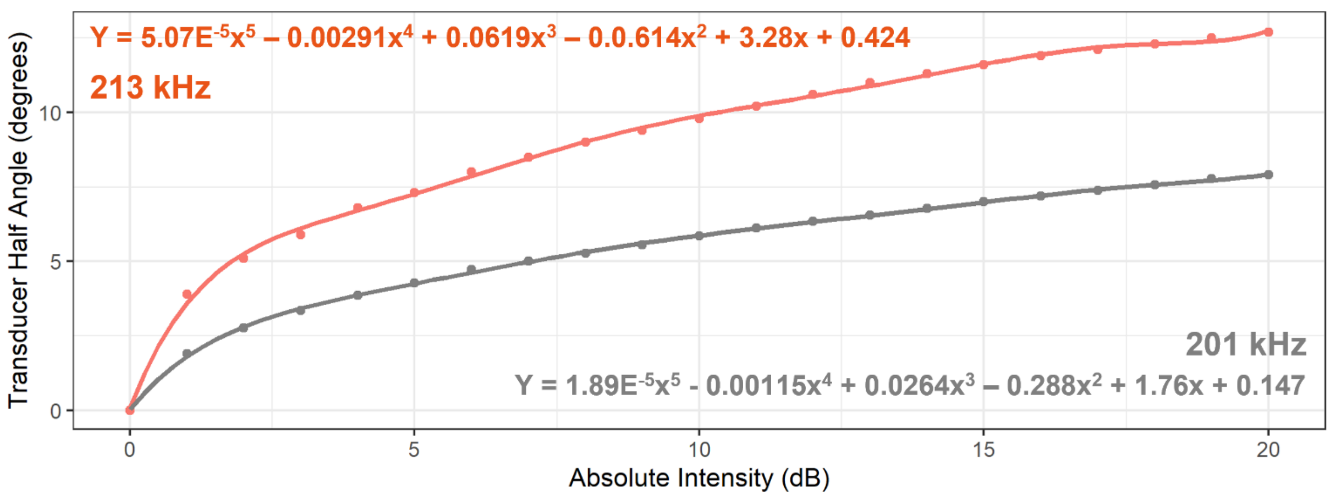


Figure 5: Transducer Beam Pattern Directivity Function

2.4.2.3 Entrainment Error

In 2020, only the Central Gate was monitored, and total entrainment estimates assumed a uniform distribution of fish across all gates, based on the findings by BioSonics (2012). Total entrainment was calculated by multiplying the results from the Central Gate by a factor of three to account for the two gates that were not monitored. The variability in the total entrainment estimate for the spill period was based on the reported 8.8% coefficient of variation in Biosonics (2012), to account for the potential minor differences in entrainment rates across gates.

A preliminary comparison of vertical transducer data from the 2021 entrainment monitoring showed a difference in the rate of entrainment between the Central and East gates. The difference in entrainment between gates was then assessed using a generalized mixed effect model and was constructed to assess the difference in entrainment (using vertical beam data) between the Central and East gates. The fixed effects included gate, hour of the day, water temperature, and the length of time since the gate opened; each gate opening event was treated as a random intercept. The model was fitted using the R package glmmTMB. As for the overall analysis of entrainment, the effects of hours since gate opening, hour of the day, and water temperature was modelled as a spline, to account for nonlinearity. Statistical significance was accepted at an alpha of 0.05.

As the West Gate was not monitored, two difference scenarios were proposed to estimate entrainment at this gate and explain the variance in total entrainment, recognizing the uncertainty in entrainment at the West Gate. The first scenario assumed that entrainment rates across the gates adjacent to the shoreline (i.e., East and West gates) will be similar, and therefore, entrainment rates at the West Gate will be equivalent to those observed at the East Gate. This scenario reflected the large number of Peamouth Chub captured and observed directly along shorelines and assumes that fish behaviour (e.g., spawning behaviour) was responsible, in part, for the higher entrainment rate observed at the gate closest to the shoreline (i.e., the East Gate). An alternative scenario reflected the mobile hydroacoustic survey data, which suggested higher densities of fish east of the spill gates. This spatial distribution of fish could have contributed to the higher entrainment rates observed at the East Gate. Under this second scenario, it was assumed that the east-west gradient of fish densities in the forebay was responsible for difference in entrainment rates between gates. Therefore, this second scenario applied the entrainment rates at the Central Gate to estimate those at the West Gate.

The variability in entrainment estimates was calculated as the relative percent difference (i.e., RPD) in entrainment between scenarios. The variability derived from the vertical transducer was assumed to be similar for the horizontal transducer, such that the magnitude of difference in entrainment estimates between the Central and East gates for the vertical data (i.e., lower water column) was used to solve entrainment estimates for the horizontal data (i.e., upper water column) for the East Gate.

2.4.2.4 Mitigation Analysis

Total entrainment without gate closure mitigation was estimated two ways. First, the calculated mean hourly entrainment rate was multiplied by the spilling period duration (total hours). In other words, this calculation applied uniform hourly entrainment rates (e.g., during the day) to the rates what would have been observed if the gates were open during the night-time hours when mitigation was applied. A second approach was also taken to calculate the extent of mitigation in 2021 by accounting for differences in fish densities throughout the day. Specifically, the daily proportion of fish entrained between midnight at each of 09:00, 10:00, 11:00, 12:00, 13:00, and 14:00 was calculated, for days with 24 h of entrainment data. These hours were chosen since in 2021, gate closures occurred between midnight at 09:00 (on 02 July and 06 July), 10:00 (0n 05 July), 11:00 (04 July), 12:00 (03 July), and 14:00 (29 June and 01 July). These entrainment proportions were then used to calculate for each day in 2021, how many fish would have been entrained, if the gates remained open throughout the morning hours.

To better understand the potential influence of gate closure mitigation on entrainment rates, rates were examined throughout the day and relative to when the gates were opened using mean hourly data plots and mixed effects modelling. It was proposed that the noise associated with opening the gates displaces fish from the area immediately surround the spillway (or alternatively, that the spillway gates are an attractant to fish the longer they are open). If this was the case, then it was predicted that entrainment rates would be lowest immediately gates were opened. The effects of hour of day and time since the gates opened on total entrainment rates were quantified using a generalized mixed-effect model, where each gate opening event was treated as a random intercept, using the R package glmmTMB. Using data collected under the GSMON-11 monitoring program, water temperature was included as a covariate in the model as a potential confounding influence on fish behaviour.

All three fixed effects were modelled as splines, to account for nonlinearity. Statistical significance was accepted at an alpha of 0.05.

Differences in entrainment between 2020 and 2021 were assessed visually. A statistical analysis could not be performed, due to multiple confounding variables – sampling in 2020 took place in late summer (22 July to 01 September) with gates mostly open throughout the period, while sampling in 2021 took place earlier in the summer, between 29 June and 06 July, with frequent gate closures. Therefore, seasonal differences in fish size and species composition, in addition to differences in gate management, would confound any attempts to assess whether 2020 entrainment differed from 2021 values. Instead, 2020 and 2021 entrainment data were used to plot mean hourly entrainment values for visual comparison, and 2020 data (without gate closures) were used to estimate the extent of mitigation in 2021.

2.5 Species Specific Estimates

The approximate species composition of fish was estimated using the length class and relative species composition collected during concurrent index netting upstream of the dam. For consistency, total abundance estimates were reported using the same size classifications used in previous reports (i.e., <75 mm, 75 to 465 mm, and >465 mm), which was designed to differentiate fry versus non-fry, and to identify large-bodied predators. The species composition classification in this report provides four categories or classes where the mid-size length class was divided into two bins (75 to 245 mm, and 245 to 465 mm), while keeping the previously defined fry size and large predator size categories. Gear limitations resulted in small sized fish not being captured during 2021 fish community sampling, or in the previous three sampling events (Sebastian et al. 2008, Plate et al. 2012, Golder 2021). Therefore, determining the species composition of fish <75 mm in length was not possible. The 75 to 245 mm length bin was incorporated to isolate catchable small-bodied species, and the 245 mm upper boundary was based on the maximum expected size of Kokanee and Peamouth Chub. Only seven Kokanee were captured in 2021, and therefore, the maximum expected size was based on the upper length range of spawning Kokanee from the Germansen, Pelly and Russel tributaries to Williston Reservoir which ranged from 240 to 244 mm (Wilson 2021). A 235 mm Peamouth Chub was captured in the forebay during the 2012 monitoring program (Plate et al. 2012) and have been reported to reach lengths of 247 mm (Scott and Crossman 1998). This size class included Kokanee, Peamouth Chub, Pygmy Whitefish, and Redside Shiner as well as Lake Whitefish and Mountain Whitefish up to age 2 years. Juvenile Lake Trout up to age 1 year, Longnose Sucker up to age 3 years were also included in the 75 to 245 mm length bin, while only one Rainbow Trout in this size class was captured which is consistent with the expectation that juvenile Bull Trout and Rainbow Trout would likely still be in the tributaries in which they were spawned (Scott and Crossman 1998). The next size length category (245 to 465 mm) focused on the isolation of the remaining age groups for Lake Whitefish, Mountain Whitefish and Longnose Sucker. The largest length class (>465 mm) was consistent with the previous classification for large predators and focused on large adult Lake Trout and Bull Trout from other large bodied species that typically do not exceed this length.

3.0 RESULTS AND DISCUSSION

3.1 Fish Community Sampling

A total of 15 species were captured during fish community sampling in 2021 with a cumulative total of 432 fish captured in the forebay above the W.A.C Bennett Dam. Peamouth Chub made up the majority of the total catch (78.9%), which was considerably greater than in 2021 (12.1%) (Golder 2021). Longnose Sucker was the next most abundant species at 8.1% of the catch, followed by Redside Shiner (5.1%), Lake Whitefish (1.9%), Lake Trout (1.6%), and Kokanee (1.6%). Burbot, Pygmy Whitefish, Mountain Whitefish, Bull Trout, Northern Pikeminnow, Rainbow Trout, and three Sculpin species (Slimy Sculpin, Prickly Sculpin, and Torrent Sculpin) made up the remainder of the catch (Figure 6). While previously documented in other areas of Williston Reservoir, Pygmy Whitefish, Mountain Whitefish, Northern Pikeminnow, Slimy Sculpin, and Prickly Sculpin have not been captured in the forebay during prior to this year. This was the first time that Torrent Sculpin was documented in the reservoir.

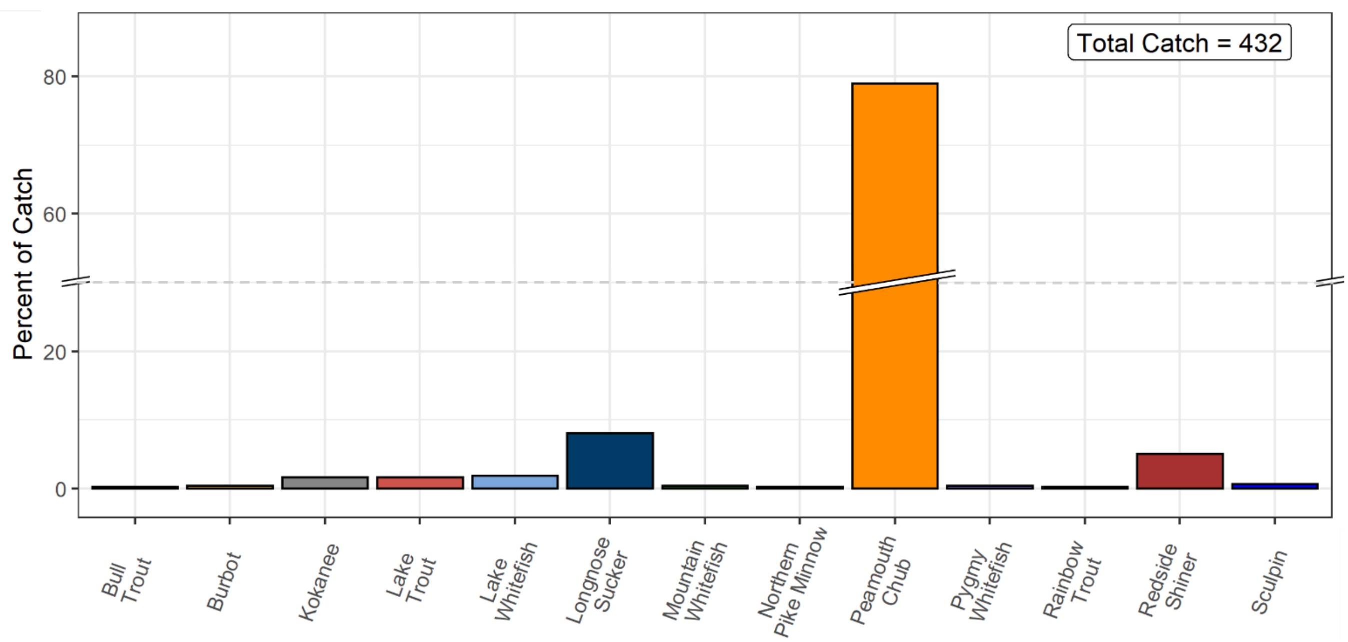


Figure 6: Relative Species Composition in Gill Net and Minnow Trap Catch, Forebay of W.A.C. Bennett Dam, Williston Reservoir, June – July 2021

3.1.1 CPUE by Location

During fish community sampling in 2021, 91% of fish were captured in nets set at a depth of 5 m, 4.6% were caught at 10 m, 1.4% were caught at 15 m, and the remaining 3.0% were caught in minnow traps. Although this trend may reflect a bias in effort towards the 5-m stratum (149 of the total 254 hours; Table 7), when corrected for effort, the 5-m stratum also had the highest total CPUE (0.337 fish/100 m^2/hr) with all fish species except Sculpins being captured at this depth. Total CPUE was lowest in the 10-m sets, at 0.053 fish/100 m^2/hr. Only three nets were set at a depth of 15 m, for a total of 38 hours of effort. These nets captured a total of six fish, generating a CPUE of 0.064 fish/100 m^2/hr. The CPUE for minnow traps was 0.010 fish/trap/hr.

Kokanee and Lake Trout were the only species that had a higher CPUE at depths below 5 meters, with the greatest CPUE at 10 m depths (Figure 7). Although the capture rate of Kokanee and Lake Trout was low in 2021, these results demonstrate that these species are utilizing a range of depths in the forebay, likely reflecting vertical trends in water temperature and the species' preferred thermal ranges (i.e., 10ºC to 15ºC for Kokanee and 10ºC for Lake Trout; Scott and Crossman 1998). Peamouth Chub were captured in nets at all depths and were the only species caught in the 15-m sets, with the highest CPUE in 5-m sets (Figure 7). Longnose Sucker and Lake Whitefish were the only other species caught at depths below 5 m. Overall, the data suggests that the majority of species typically inhabit the upper 5 m of the water column while Kokanee, Lake Trout, and Peamouth Chub occupy a wider range of depths.

Kokanee were the only species caught in pelagic net sets. Gill nets 16 and 17 were set as close to the shore as possible and caught 10 different species and 91.8% of the Peamouth Chub captured, as well as the majority of Longnose Sucker and Lake Whitefish. Peamouth Chub were caught primarily in nearshore net sets and were captured in 7 out of the 10 nets set along the west bank, suggesting they are the most abundant species in the area and are widely distributed along the littoral zones surrounding the spill gate. Peamouth Chub that were captured and examined for maturity were observed to be ready to spawn (i.e., were ripe with milt release upon handling) and several large schools of adult-sized Peamouth Chub were observed traversing the shoreline directly adjacent to the spillway gates in the days preceding the spill. Most of the fish captured (97%) were of a length between 75 and 465 mm. All Sculpin species and just under half of the Redside Shiner caught were captured in minnow traps.

Table 7: Location of Nets on the Peace Reach of Williston Reservoir between 27 June and 2 July 2021

Set	Net ID	Net Depth (m)	Start		End		Effort (hr)	UTM (Zone U10)		Distance from Spill Gate (m)
			Date	Time	Date	Time		Easting	Northing	
GN1	3	5	27-Jun-21	10:22	27-Jun-21	14:25	4.05	548588	6209078	534
GN2	1	10	27-Jun-21	11:50	27-Jun-21	16:06	4.27	548516	6209130	605
GN3	4	15	27-Jun-21	14:18	27-Jun-21	18:03	3.75	548605	6209071	523
GN4	3	5	27-Jun-21	14:36	28-Jun-21	12:33	21.95	548434	6209067	582
GN5	1	10	27-Jun-21	17:23	28-Jun-21	13:07	19.73	548449	6210109	1,572
GN6	4	15	27-Jun-21	18:20	28-Jun-21	12:56	18.60	548503	6210098	1,553
GN7	1	10	29-Jun-21	17:12	30-Jun-21	08:17	15.08	548885	6208997	466
GN8	4	15	29-Jun-21	17:41	30-Jun-21	09:00	15.32	548983	6208936	458
GN9	3	5	29-Jun-21	18:00	30-Jun-21	16:10	22.17	548947	6208754	298
GN10	1	10	30-Jun-21	08:53	01-Jul-21	09:15	24.37	548966	6209980	1,441
GN11	4	5	30-Jun-21	15:00	01-Jul-21	10:01	19.02	548956	6209976	1,435
GN12	3	5	30-Jun-21	17:10	01-Jul-21	11:15	18.08	548231	6209227	827
GN13	4	5	01-Jul-21	10:35	01-Jul-21	14:15	3.67	547507	6209816	1,746
GN14	1	10	01-Jul-21	11:00	01-Jul-21	14:45	3.75	547896	6209578	1,310
GN15	3	5	01-Jul-21	13:59	02-Jul-21	08:20	18.35	548537	6209049	521
GN16	4	5	01-Jul-21	14:26	02-Jul-21	14:20	23.90	547417	6209794	1,795
GN17	1	5	01-Jul-21	15:02	02-Jul-21	09:05	18.05	548125	6209274	929
MT		1	27-Jun-21	17:50	02-Jul-21	16:19	118.48	548503	6209002	492

Note: GN = gill net; MT = Minnow Trap

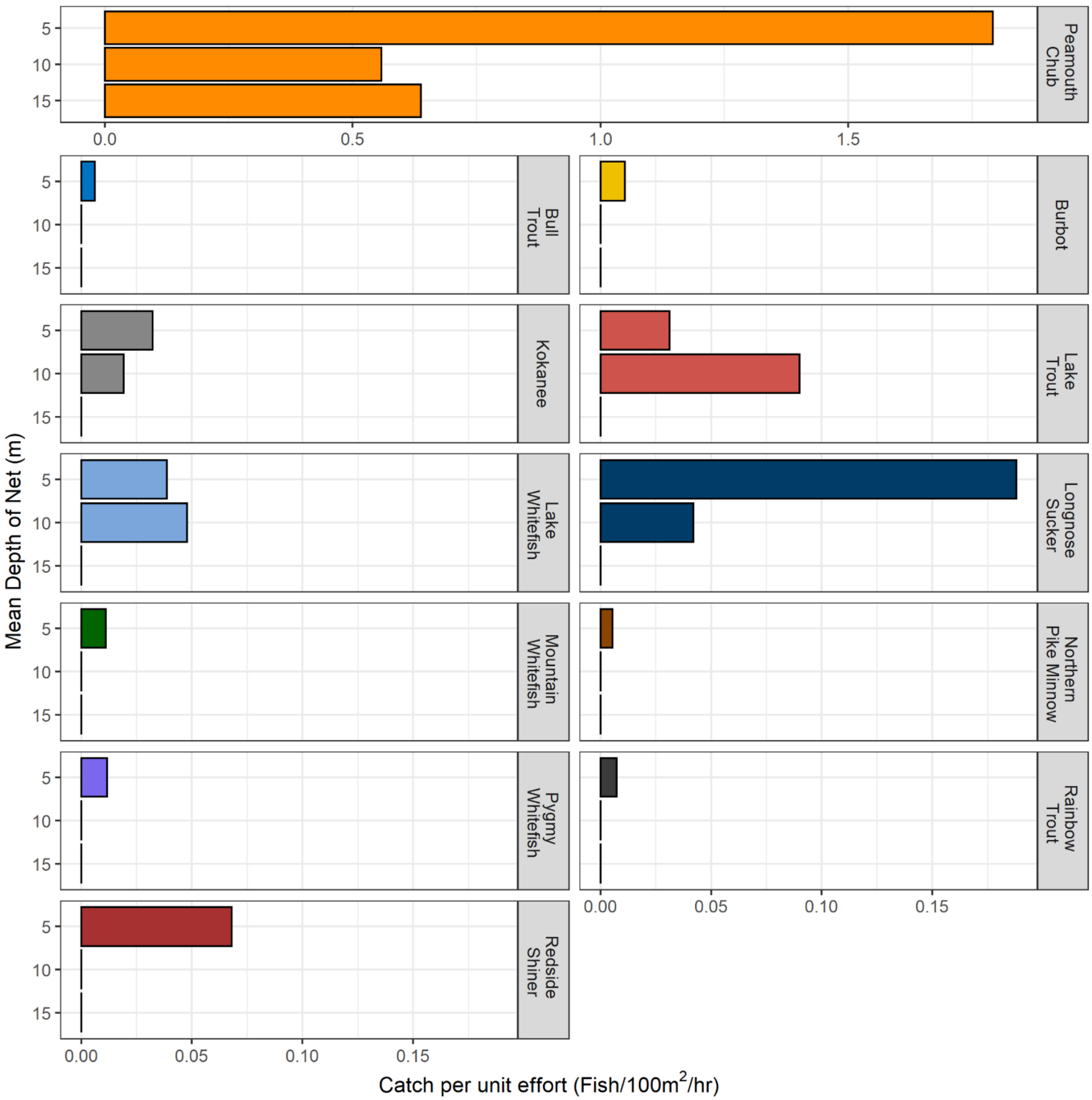


Figure 7: Gill Net Catch per Unit Effort (Fish/100 m²/Hr) by Species and Depth Strata, Forebay of W.A.C. Bennett Dam, Williston Reservoir, June to July 2021

Over half (10 out of the 17 nets) were set in nearshore areas adjacent to the littoral zone, along the west bank of the forebay, and in general, the CPUE per net was highly variable across the reservoir ranging from 0 to 10.81 fish/100 m²/hr (Figure 2). CPUE for the four nets set in the pelagic area was low, with two nets catching no fish and the other two nets catching a total of three fish.

In an effort to better characterize the fish community in the areas directly adjacent to the spill gate the remaining nets (three in total) were set just outside of the log-stop surrounding the gate. These net sets were located within 500 m of the spill gate and the CPUE observed at these sites was considerably lower than in other nearshore areas, with only one net catching any fish. The results suggest larger fish were actively avoiding areas closer to the spill gates.

3.1.2 Catch Trends Across Monitoring Years

Catch rates have been highly variable across monitoring years (1974 to 2021) (Figure 8). This may be partly due to variability in timing of sampling and capture methods. A comparison of gill net catch up to, and including data collected in 2012 suggested that the pelagic community in the Peace Reach of the Williston Reservoir was in the process of shifting from a Lake Whitefish and Peamouth Chub dominated community to one dominated by Kokanee (Sebastian et al. 2008, Plate et al. 2012). Although sampling efforts in the forebay and as part of entrainment monitoring for the spillway do not necessarily provide the power to track population-level trends in the reservoir, the results from recent sampling efforts also indicate that shifts in the fish community are on-going. The 2020 results suggest a potential decline in the relative abundance and CPUE for Kokanee and Peamouth Chub and a potential increase in Lake Whitefish and Longnose Sucker CPUE (Golder 2021). Results from 2021 show a potential increase in overall fish diversity, the highest Peamouth Chub CPUE across all monitoring years, and a decrease in both Kokanee and Lake Whitefish catch rates. Both Lake Trout and Redside Shiner were caught in the forebay for the second year in a row and were not caught prior to 2020.

Variation in catch trends across years may be due to different sampling methods, including focusing on different areas of the forebay or setting nets at different depths. In 1988, sampling mainly consisted of nets in littoral regions, and did not capture significant numbers of fish in pelagic nets (Johnson and Yesaki 1989). Sampling in 2000 and 2008 focused on pelagic nets set exclusively in the top few meters of the water column, resulting in a high abundance of Peamouth Chub and Kokanee (Sebastian et al. 2003, 2008). Plate et al. (2012) expanded on this sampling plan by incorporating additional net sets at depths of 5 m and 10 m in an attempt to better evaluate the vertical distribution of fish in the water column to support entrainment estimates. Sampling in 2020 from 25 to 29 July included nearshore net sets, leading to the capture of a variety of other species including Longnose Sucker that had not previously been caught in the pelagic zone. Nets were also set in deeper locations in 2020 to catch larger bodied individuals to better characterize the large targets observed during hydroacoustic entrainment monitoring at the spill gate.

Sampling in 2021 included similar methods to those used in 2020, incorporating both pelagic and nearshore net sets, nets set at a range of depths, and introduced the use of minnow traps. Sampling in 2021 occurred about 1 month earlier in the season and a portion of the sampling occurred during the 2021 heat dome event, which started in the Peace approximately 21 June and continued to 30 June. This variety in capture methods could account for the greater diversity of species caught in 2021 compared to previous years. Setting minnow traps allowed for the capture of Sculpin species and a higher number of Redside Shiner than seen in 2020 (Figure 8). Kokanee CPUE has ranged from 0.001 fish/100 m^2/hr (2020) to 0.14 fish/100 m^2/hr (2012), with relatively low variation in CPUE across all years. In 2021, Lake Whitefish had a CPUE of 0.035 fish/100 m^2/hr, which was the second lowest CPUE across monitoring years and 25 times lower than in 2020. Peamouth Chub catch rates were the highest of all years in 2021, at 1.23 fish/100 m^2/hr. Rainbow Trout and Bull Trout catch rates appear to be declining across monitoring years, but it is unclear to what extent those trends are influenced by differences in gear types, sampling locations, and sampling dates.

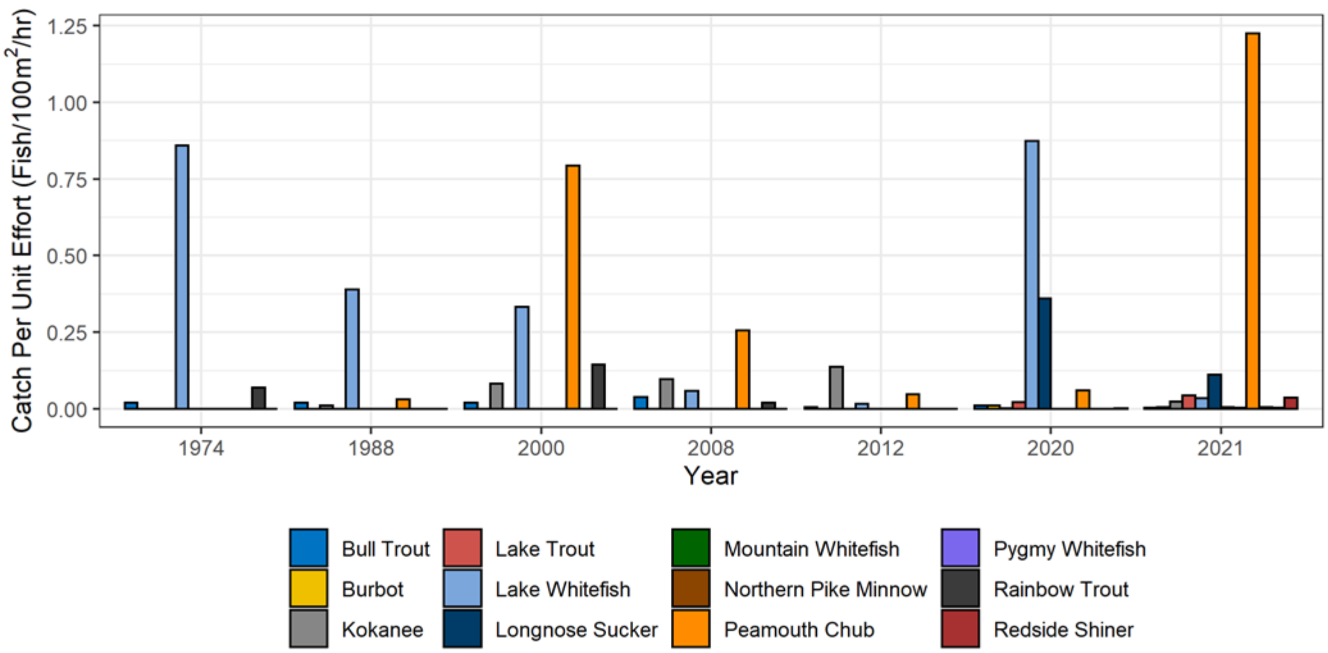


Figure 8: Historical Catch per Unit Effort (Fish/100 m^2/hr), Peace Reach of Williston Reservoir, 1974–2021; Note: Timing of Sampling and Capture Methodologies Varied Between Years

Sources: 1974 data from Barrett and Halsey 1975; 1988 data from Blackman 1992; 2000 and 2008 data from Sebastian et al. 2003 and 2008; 2012 data from Plate et al. 2012; 2020 from Golder 2021.

3.2 Hydroacoustics

3.2.1 Environmental Parameters

The water column profile measurements on July 1, 2021 showed that surface water temperature was 24.9ºC during sampling, considerably higher than the 2020 surface temperature of 17.8ºC, beyond the limit for many cold water fish species, and substantially higher than normal for this time of year (Stockner et al. 2005). A marked decline in temperature was observed over the first 6 m of the water column, dropping by over 11°C over this range (Figure 9). Temperatures continued to decline with depth reaching 7.3ºC at a depth of 30 m with an average water temperature of approximately 12.2°C across the 30 m profile. Water temperatures at 6 m were nearly identical to the temperature observed in 2020 at this depth and the higher temperatures in the upper 5 m was attributed to the abnormally high air temperatures during the sampling period (average maximum daily temperature of 32.8°C in Fort St John, BC between June 21 to June 30, 2021, reaching 38.1°C on June 29; Government of Canada 2021). The average speed of sound in water in the area surrounding the spill gate was estimated at 1,455 m/s, which was subsequently used to calculate the range of each target from the transducer.

Dissolved oxygen surface readings indicated a dissolved oxygen concentration of 8.3 mg/L. Dissolved oxygen concentrations increased most rapidly for the first 6 m, increasing by 2.0 mg/L relative to surface readings (Figure 9). Dissolved oxygen concentrations continued to increase with depth, reaching 11.5 mg/L at 30 m depth and an average concentration of 10.5 mg/L. This trend differs with the data collected in 2020, in which concentrations declined with depth below 7 m.

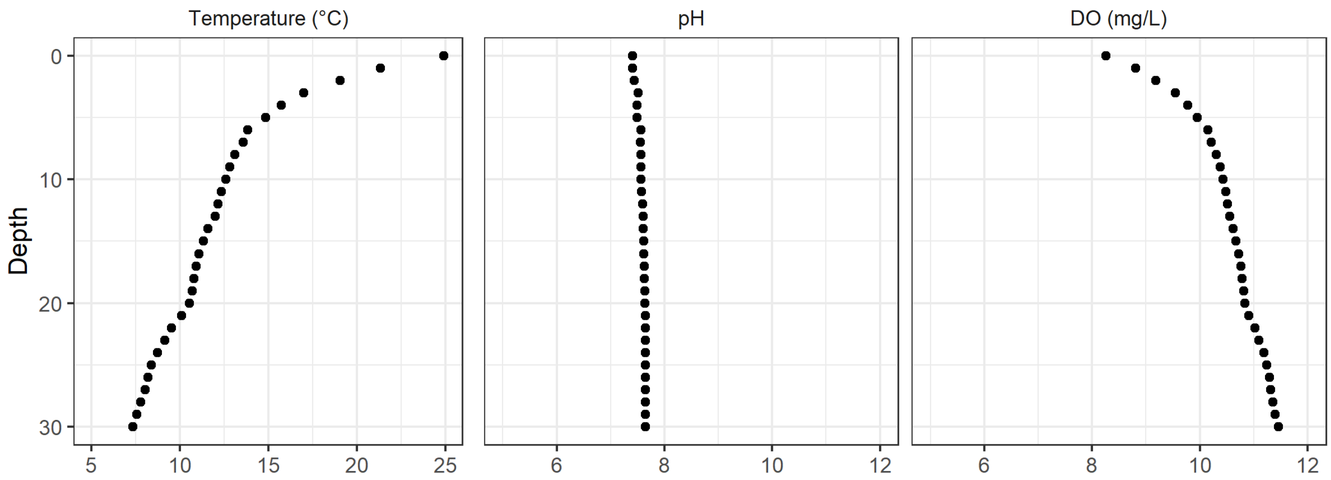


Figure 9: Water Quality Profile at Depth (m), Forebay of W.A.C. Bennett Dam, July 2021

3.2.2 Mobile Surveys

Mobile hydroacoustic surveys were conducted between the hours of 23:00 and 05:10 on 23 and 25 June 2021, lasting an average of 5.8 hours per survey (Table 8). The mean volume of water insonified by the horizontal beam (0 to 5 m depth) averaged 4.05 x 10^6 m^3 during the survey. The mean volume of water insonified by the vertical beam (greater than 5 m depth) averaged 6.12 x 10^6 m^3 during the survey. There was a slight difference in the volume of insonified water between survey replicates (4.9% difference in horizontal beam volume and 2.6% difference in vertical beam volume). As the results from each survey are standardized by depth and variability is low, the difference in the volume of insonified water between surveys was not anticipated to have any measurable impact on calculated fish densities or abundance.

Survey conditions were similar between nights with wind speeds averaging 9 km/h during both surveys and cloud cover was less than 20%. No precipitation occurred during either of the surveys and the average air temperature was 12.6°C for survey 1 and 19.4ºC for survey 2. Therefore, the environmental conditions during each survey were not expected to drive differences in fish densities observed during surveys.

Table 8: Mobile Hydroacoustic Survey Summary of the Forebay for 2021

	Survey 1	Survey 2
Date	23-Jun	25-Jun
Start-End Time	23:00-5:10	23:20-4:45
Average Wind Speed (km/hr)	9	9
Average Air Temperature (ºC)	12.6	19.4
Horizontal Beam Volume (1.0 x 10^6 m^3)	4.15	3.95
Vertical Beam Volume (1.0 x 10^6 m^3)	6.12	6.28
Horizontal Calibration Offset (dB)	2.01	
Vertical Calibration Offset (dB)	1.82	

A combined total of 881 fish tracks were detected by both transducers during the two surveys, with 72% of tracks being detected during the first survey (Table 9). The horizontal transducer (0 to 5 m depth stratum) detected a total of 540 tracks (61% of the total) during the two surveys, with the mean length of fish detected being 87 mm ± 91 SD. The vertical beam (greater than 5 m depth stratum) detected 341 tracks with a mean length of 145 mm ± 169 SD. The combined mean length of tracks detected during both surveys was 109 mm ± 130 SD; the mean length during survey 1 was 106 mm, slightly shorter than the mean length from survey 2 (118 mm).

Table 9: Mobile Hydroacoustic Survey Fish Tracking Results

	Horizontal Beam		Vertical Beam		Combined	
	# Tracks	Mean Length (mm)	# Tracks	Mean Length (mm)	# Tracks	Mean Length (mm)
Survey 1	399	86 ± 86 SD	236	139 ± 160 SD	635	106 ± 122 SD
Survey 2	141	88 ± 105 SD	105	157 ± 188 SD	246	118 ± 150 SD
Combined	540	87 ± 91 SD	341	145 ± 169 SD	881	109 ± 130 SD

Mobile surveys in 2021 detected the main fish layer extending to a depth of about 35 m (Figure 10), which is similar to the results of the 2008 survey (Sebastian et al. 2008). In contrast, the 2012 surveys indicated a distinct layer of fish just below the thermocline (between 5 and 18 m depth) with relatively few fish detected at depths greater than 20 m (Plate et al. 2012).

Mobile surveys in 2021 also detected large numbers of fish in the upper stratum of the water column (0 to 5 m depth) by the horizontal beam (Figure 10). The upper stratum contains a large portion of the fish community based on 2021 mobile survey results and the fish community sampling results. These fish targets in the upper stratum were largely absent from both the 2008 and 2012 surveys, reflecting biases of relying entirely on vertical beaming transducers for fish detection.

In 2021, large fish (i.e., greater than 460 mm) were detected from the surface to depths of 50 m (Figure 10). There were more large fish detected in 2021 compared to in 2008 and 2012, which both saw relatively few large fish detected.

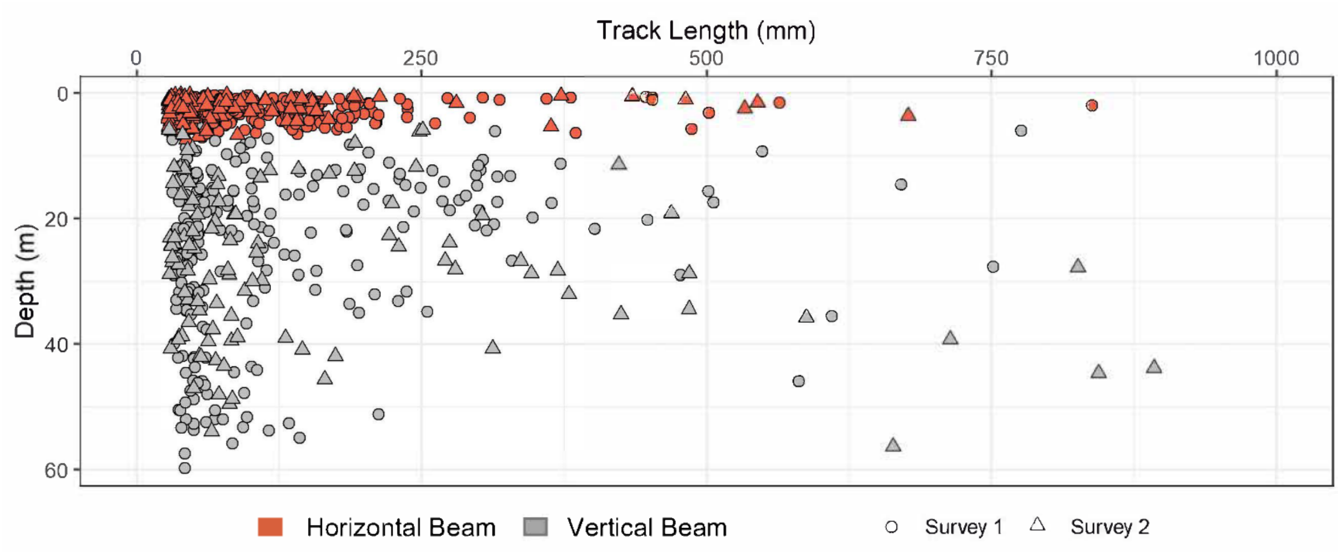


Figure 10: Distribution of Individual Fish by Length and Depth Detected during Mobile, June 2021 Hydroacoustic Surveys

3.2.2.1 *Areal Density*

The results in this section were calculated following the same method used in previous monitoring reports (Sebastian et al. 2003 and 2008, Plate et al. 2012) to provide directly comparable results, and therefore, only used data from the vertically oriented transducer. The only difference in methods was the addition of transect 31.75 and 32.75 (Figure 1), which were not used in previous studies. All transects were surveyed once each night resulting in two replicates of each transect and the mean fish density and standard deviations are shown in Figure 11 along with transect densities from 2008 (Sebastian et al. 2008) and 2012 (Plate et al 2012) for comparison. Of note, each transect was sampled only once in 2008, and therefore, reported fish densities do not include error estimates.

Overall, the density of fish observed across each transect in 2021 was lower than previous monitoring programs and the average density for each transect increased from west to east, with transects closest to the dam having higher overall fish densities. This pattern was in contrast to the results of the 2008 and 2012 surveys where fish densities increased with distance from the dam Figure 11. Transect 31.5, which is the farthest from the dam, had the lowest average fish density during the 2021 surveys (6.09 fish/ha ± 2.01 SD) and showed the largest relative decline compared to previous monitoring years, declining by approximately 97% relative to 2012 and 95% to 2008. Observed densities increased to 13.05 fish/ha ± 9.07 SD for transect 31.75 and 9.56 fish/ha ± 0.67 SD for transect 32. Fish density for transect 32.5 (38.98 fish/ha ± 37.26 SD) was the within range of estimates from 2008 (47.00 fish/ha). Although densities along this transect were 58% lower than the 92.39 fish/ha ± 32.99 SD detected in 2012, the standard deviations based on transect replicates did overlap. The highest fish density detected in 2021 was along transect 32.75 at 45.80 fish/ha ± 29.14 SD. When data from all transects were combined, the average fish density detected in 2021 was 22.70 fish/ha ± 23.58 SD, which was 73% lower than the 85 fish per hectare in 2008 and 82% lower than the 127.61 fish/ha ± 70.69 SD in 2012 (Figure 11).

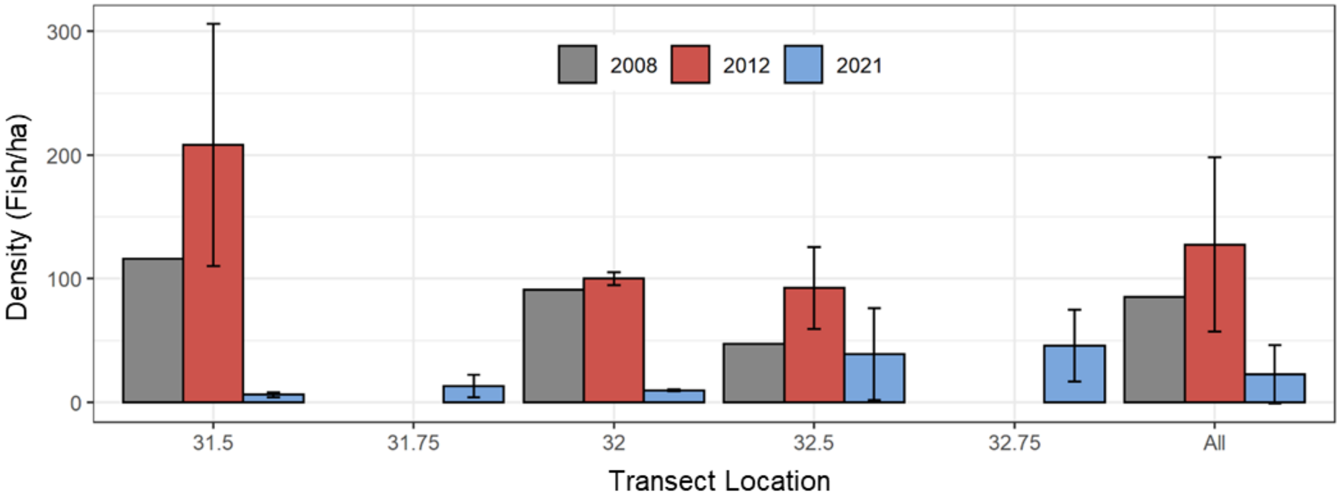
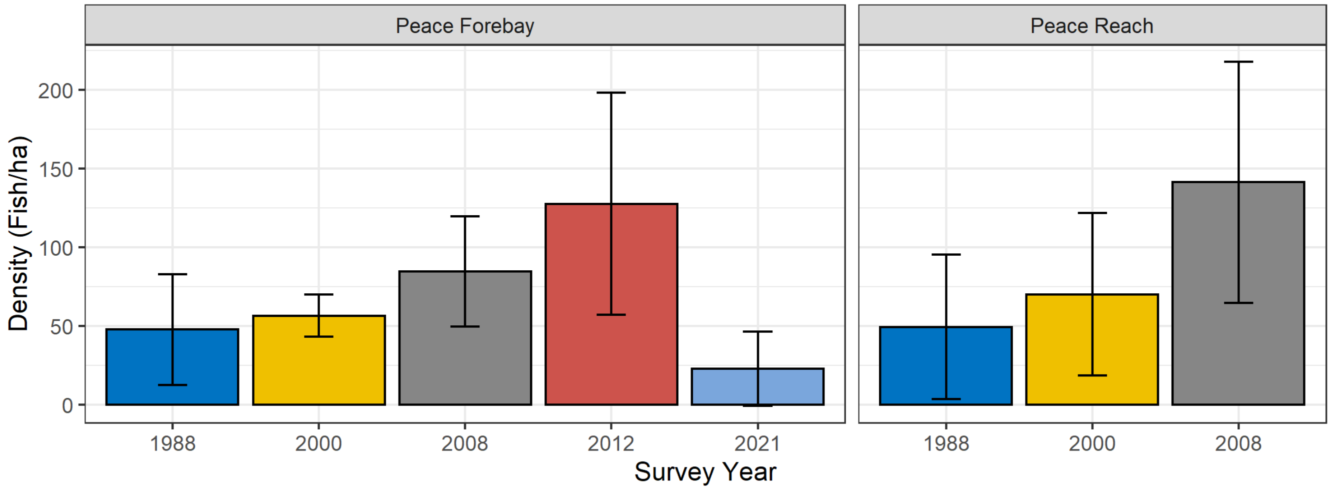


Figure 11*:* Fish Density by Transect ± SD (West to South) from Mobile Hydroacoustic Surveys Conducted in the Peace Reach of Williston Reservoir, 2008 – 2021

The results from the 1988 and 2000 mobile surveys were not included in the above comparison due to differences in the survey design. The 1988 survey by Johnson and Yesaki (1989) was conducted in the same general area but followed a different set of transects entirely while transect 32 was the only transect completed in 2000 by Sebastian et al. (2003) that was consistent with subsequent monitoring programs. Although a direct comparison between transects could not be made to these historical monitoring programs, the average fish density observed in the forebay of the Peace Reach appears to have increased steadily from 47.65 fish/ha ± 32.10 SD in 1988 (Johnson and Yesaki 1989) to 127.62 fish/ha ± 70.69 SD in 2012 (Plate et al. 2012) before declining to 22.70 fish/ha ± 23.58 SD in 2021 (Figure 12).

Fish densities further upstream in the Peace Reach appear to have shown a similar temporal pattern to the forebay increasing from 49.28 fish/ha ± 45.96 SD in 1988 (Johnson and Yesaki 1989) to 141.31 fish/ha ± 76.54 SD in 2008 (Sebastian et al. 2008) (Figure 12). In 2012 and 2021, all transects were located within the forebay and density estimates were restricted to this zone.



Note that All 2012 and 2021 Transects were in the Forebay of W.A.C. Bennett Dam, Williston Reservoir

Figure 12*:* Mean Areal Fish Density ± SD by Zone from Mobile Hydroacoustic Surveys, 1988 - 2021.

The decline in fish densities relative to previous mobile surveys could be attributed to various factors, including the timing of the survey in relation to a spill event, a change in the spatial distribution of fish in the reservoir related to survey timing, and natural successional changes in the fish community related to temporal fluctuations in reservoir productivity. The preceding spill event in 2020 may have contributed to the decreased fish densities in the forebay in 2021. In 2020, spillway gates were open for 841 hours between 22 July and 1 September, resulting in an estimated entrainment of 1,057,278 (+/- 1 SD = 93,232) fish. In contrast, previous mobile surveys were tracking populations that were not subject to spilling events the year prior to monitoring. Surveys were conducted while the spill was in progress in 2012 and no spilling occurred during surveys in 2008 and the year prior to surveys in 2008.

The 2012 and 2021 mobile surveys were also conducted mid-July and late June respectively compared to the 2008 survey which was conducted at the end of August. The difference in timing of these surveys, specifically in relation to the 2008 survey, could explain some of the observed difference in fish density estimates. For example, Johnson and Yesaki (1989) detected higher fish densities in late summer/early fall compared to surveys conducted in June.

Using the areal densities described above, the total abundance of fish in each habitat zone (31 and 32) and the Peace Reach as a whole were calculated as the product of the fish density for that zone and the total surface area of that zone calculated by Sebastian et al (2003). The average fish density in zone 31 (included transects 31.5 and 31.75) was 9.57 fish/ha and extrapolating that density to the 3,532 ha of total area in that zone resulted in an estimated abundance of 33,800 fish (Table 10). Zone 32, which is closest to the spill gates, had an estimated surface area of 3,451 ha resulting in an estimated population of 108,532 fish based on the mean density of 31.45 fish/ha (Table 10). As previously discussed, all transects completed in 2021 were located within the forebay of the dam (zones 31 and 32) and in an effort to calculate the total abundance of fish in the entire Peace Reach, the average fish density across all transects (22.70 fish/ha) was used to represent fish densities for the Peace Reach. Given a surface area of 31,345 hectares, the estimated population for the Peace Reach was 711,453 fish.

The large variances in the abundance estimates (see Table 10) was a reflection of the patchy distribution of fish observed during transects and the associated high degree of variability across transects.

Table 10: Fish Abundance by Habitat Zone from Mobile Hydroacoustic Surveys using Historical Methods (Areal Density), June 2021

Habitat Zone	Transects	Average Density (Fish/ha)	SD	Zone Area (ha)	Abundance	SD
31	31.5, 31.75	9.57	6.70	3,532	33,800	23,667
32	32, 32.5, 32.75	31.45	27.28	3,451	108,532	94,152
Peace Reach	31.5 - 32.75	22.70	23.58	31,345	711,453	739,198

3.2.3 Entrainment Monitoring

Stationary hydroacoustic methods were used to monitor fish entrainment at the W.A.C. Bennett Dam spillway during the 2021 spill event that occurred between 29 June and 6 July 2021. The spillway gates were open continuously from 14:00 on 29 June for approximately 37 hours until 1 July, at which point the gates were closed daily during early morning hours surrounding sunrise when historical rates of entrainment were highest (Golder 2021). Of the 106 hours the gates were open approximately 88.7% of that occurred between the hours of 09:00 and 00:00 and hydroacoustic monitoring occurred for the entire duration of the spill.

To calculate the net number of fish entrained during the spill, the direction of travel of each target was examined to evaluate the proportion of fish that were able to swim against the flow and escape entrainment. It was estimated that 3,032 of the 3,715 tracks (81.6%) detected by the vertical beam, and 3,022 of the 4,174 tracks (72.4%) detected in the horizontal beam were moving towards the gate at risk of entrainment. Figure 13 shows the estimated cumulative entrainment rates for each day of the spill.

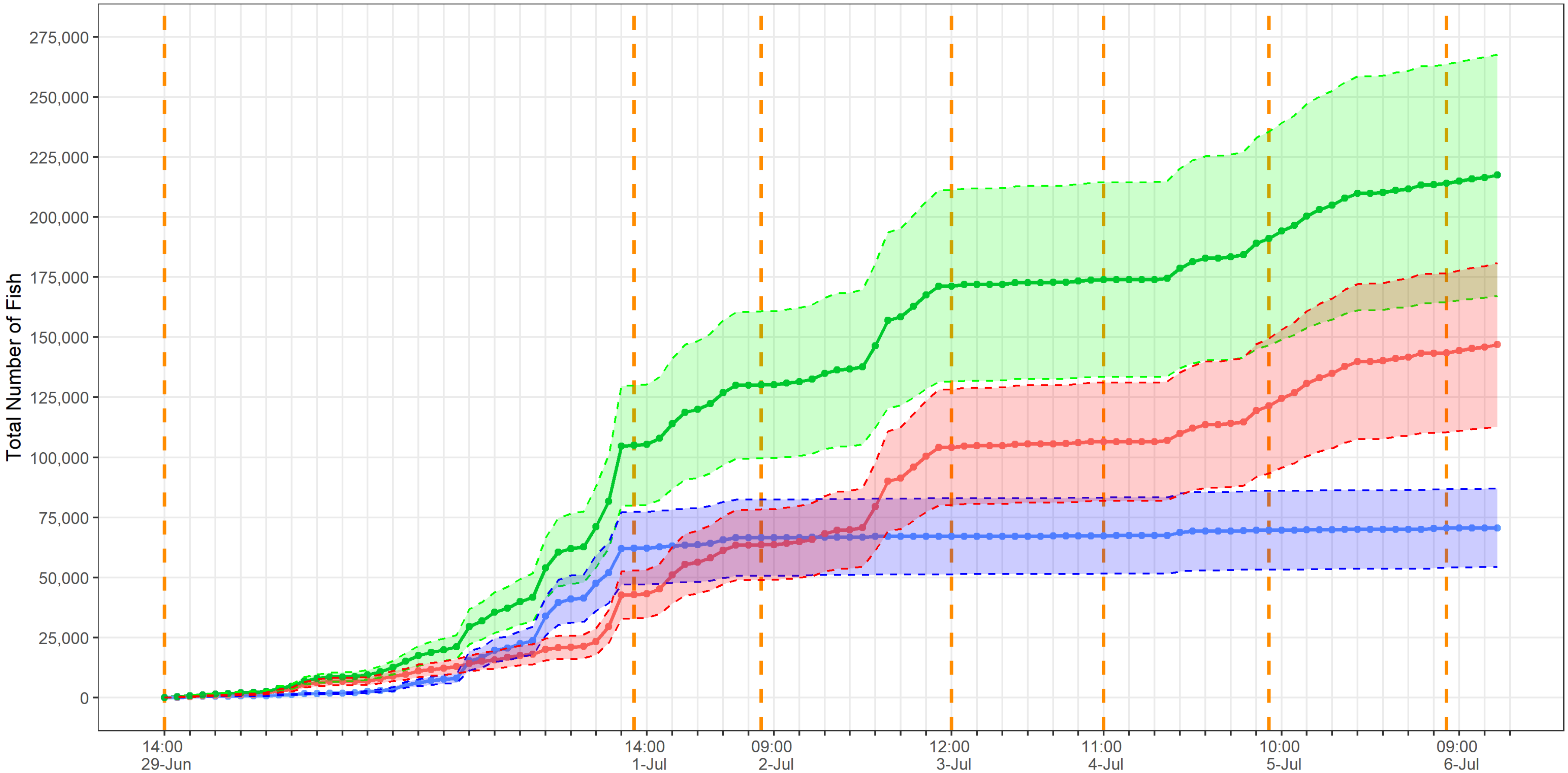


Figure 13: Cumulative Entrainment ± Relative Percent Difference for 29 June to 6 July 2021 for Vertical Transducer (Blue), Horizontal Transducer (Red), and Combined (Green); Vertical Dashed Orange Lines Identify Spill Gate Opening After Closure with Time Stamp for Reopening

Entrainment rates across multiple gates were not evaluated for the 2020 monitoring program, in part, because Biosonics (2012) previously reported no significant difference in entrainment rates across gates, but also because of limitations in equipment availability. Differences in entrainment (using vertical beam data) between gates were assessed using 2021 data. A generalized mixed effect model was constructed to assess the difference in entrainment between the Central and East gates. The fixed effects included gate, hour of the day, water temperature, and the length of time since the gate opened; each gate opening event was treated as a random intercept. The effect of gate was found to be significant ($p < 0.001$), as was the effect of hours since the gate opened ($p < 0.001$); neither water temperature nor hour of day were significant (Figure 14). Therefore, the variability in entrainment rates between gates was thought to be the primary source of error when estimating total entrainment for 2021 when extrapolating estimates to include entrainment at the West Gate.

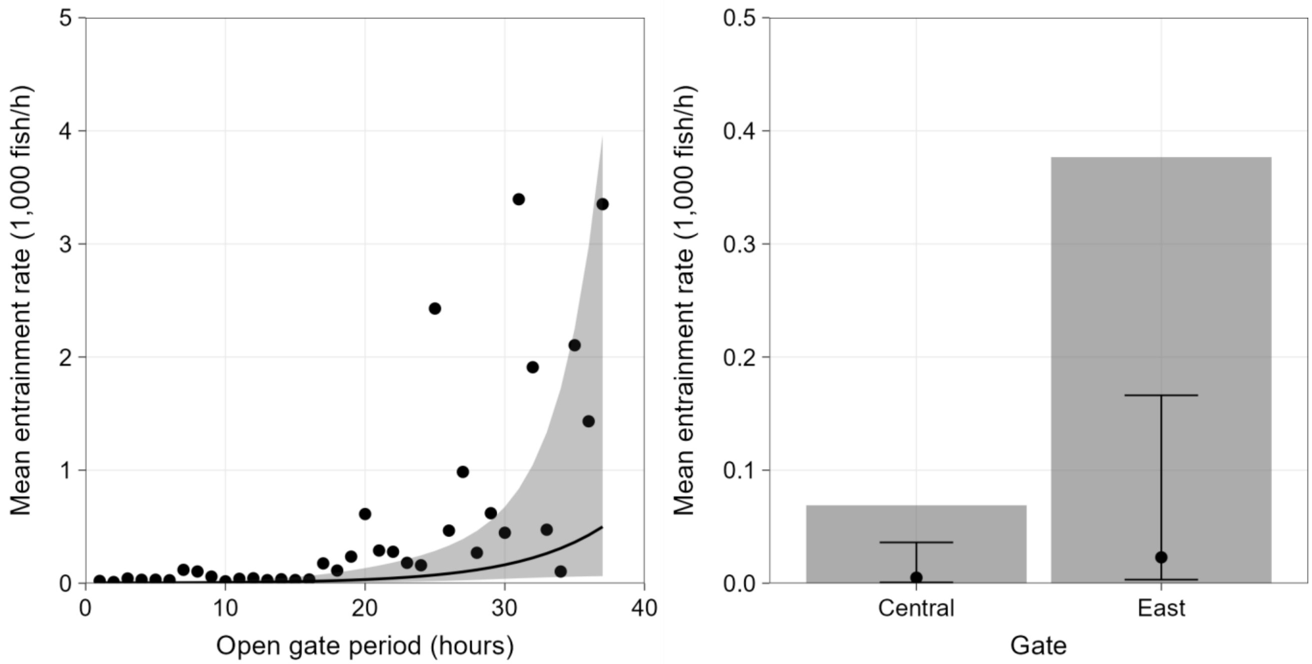


Figure 14: Predictions for Mean Entrainment Rates (Using Vertical Beam Data) at the Central and East Gates, While Holding the Other Variables Constant; Shaded Area (for Curve) and Error Bars (for Points) Represent 95% Confidence Interval

Total cumulative entrainment was estimated at 217,500 fish, with a relative percent difference (RPD) of ±46% around the estimate (167,258 to 267,743 fish). It could not be determined if the higher entrainment rates at the East Gate was driven by high numbers of fish travelling along the shoreline or due to the higher density of fish east of the spill gate (observed during mobile surveys). As both scenarios were considered equally probable, entrainment at the West Gate was estimated by incorporating the variability in entrainment rate observed across the east and central gates. The total cumulative entrainment estimate and variability around the estimate were based on the following:

- Cumulative entrainment measured by the vertical transducer was 39,846 fish at the East Gate and 7,226 fish at the central gate, with a mean entrainment of 23,536 fish for the two gates.
- Predicted cumulative entrainment for the lower water column for the West Gate was 23,536 fish using the mean estimates of the other two gates that were monitored.
- Cumulative entrainment for the horizontal transducer at the Central Gate was 15,032 fish, where entrainment was 1.93 times higher in the upper 5 m of the water column versus the lower water column.
- Predicted cumulative entrainment for the upper water column at the East Gate was 82,896 fish (if applying the 5.51 times difference between east and central gates for the vertical transducer results)
- Predicted cumulative entrainment for the upper water column for the West Gate was 48,964 fish using the mean estimate from the other two gates.

Over the 106 hours, entrainment through the spillway gates averaged 2,052 fish per hour (Figure 13). This rate of entrainment is approximately 1.6-times the rate of entrainment calculated for 2020 (for the 841-hour spilling duration), reflecting the elevated rates of entrainment at the East Gate. However, if comparisons are restricted to the first 106 hours of hydroacoustic monitoring, entrainments were similar between years, with slightly reduced rates in 2021 compared to 2020 (2,160 fish per hour). Consistent with 2020, most entrained fish were small-sized fish. A total of 92.3% of entrained fish in 2021 were less than 75 mm in length, representing a mix of age 0+ Kokanee and Lake Whitefish, Pygmy Whitefish, Redside Shiner, and Peamouth Chub (up to age 2) based on historical catch data for the reservoir. Medium sized targets (75 to 465 mm) accounted for an additional 6.1% and large targets (>465 mm) made up less than 0.01% of entrained fish.

Almost twice the number of fish were entrained from the upper water column (as estimated by the horizontal transducer beam data) compared to the number of fish in the lower water column (vertical transducer beam data). This result was consistent with the index netting results, but was in contrast to the distribution of fish observed in 2020 when entrainment estimates were similar for the upper and lower strata.

Despite a relatively consistent spill rate (568 to 602 m^3/s) a moderate degree of variability in hourly entrainment was observed throughout the monitoring period, ranging from 0 to approximately 22,000 fish over a one-hour interval. Similar to the patterns observed in 2020, spikes in entrainment were associated with the detection of a large number of small fish passing through the acoustic beam over a relatively short duration. In fact, the cumulative number of fish entrained from four separate one-hour intervals accounted for greater than 25% of all fish entrained.

3.2.3.1 Effects of Intermittent Gate Closures

The results of the 2020 entrainment study indicated the highest rates of entrainment were observed in the hours surrounding sunrise which occurred between 04:49 and 06:10 in 2020 (Figure 15). These findings were consistent with Ebel (1996), who noted higher rates of entrainment during twilight hours. Therefore, after the first 37 hours, the majority of the spill in 2021 was conducted between the hours of 09:00 and 00:00 to avoid those times with historically higher entrainment rates in an effort to reduce entrainment and the impact to Williston Reservoir fish populations.

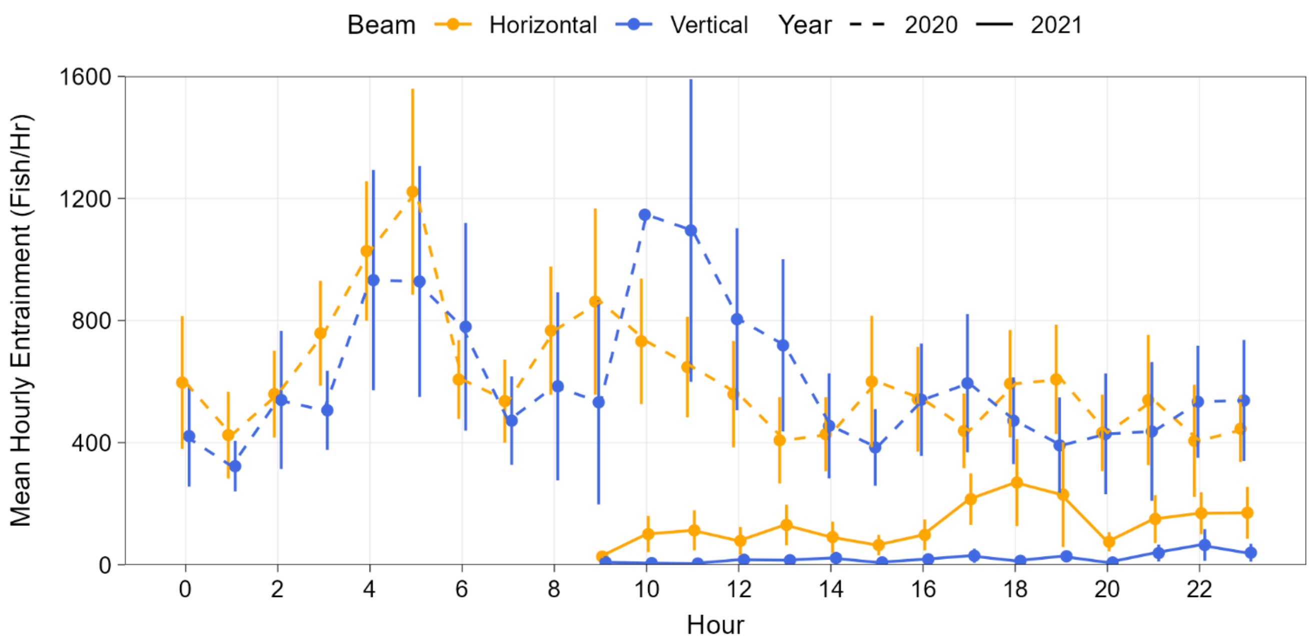


Figure 15: Mean Diel (Hourly) Entrainment Rates for Vertical and Horizontal Beam Data (with standard error bars) from the Central Gate at W.A.C Bennett Dam spillway, 2020 (dashed lines) and 2021 (solid lines); Note: 2021 Entrainment Rates are Restricted to Periods Following Intermittent Gate Closures

To evaluate the effects of intermittent gate closures on the rate of fish entrainment, data from the Central Gate was summarized as it provided the most complete data set, including data from both a horizontally and vertically oriented transducer. Focusing specifically on the Central Gate also allowed for a direct comparison to the 2020 results. Over the duration of the 2021 spill an estimated 22,258 fish were entrained through the central spill gate, with approximately twice as many fish entrained from the upper 4 m of the water column. The first 37 hours of the spill that occurred uninterrupted accounted for approximately 45% of all fish entrained through this gate (9,997 fish), a rate of 270 fish per hour. Following the daily gate closures that started on 1 July, total entrainment began to plateau as the number of fish entrained at the Central Gate decreased to 178 per hour over the final 69 hours of the spill.

Overall, intermittent gate closures appeared to have a positive effect on reducing the overall entrainment rate with the lowest entrainment rates consistently observed during the two-hour interval following the opening of the gates (Figure 15). During this two-hour period the average entrainment rate was 63 fish ± 86 SD, which typically occurred between 09:00 and 11:00. In contrast, this period of day showed a spike in entrainment rates in 2020 when gates were continuously left open (Figure 15). This pattern supports the hypothesis that the noise associated with opening the gates displaces fish from the area immediately surround the spillway (or alternatively, that the spillway gates are an attractant to fish the longer they are open). Furthermore, the rate of entrainment increased as the number of hours the gate was open increased. This was evident in the horizontal transducer data where entrainment numbers gradually increased, reaching rates that were comparable to the average hourly entrainment observed in 2020 (Golder 2021; Figure 15). Vertical entrainment rates followed a similar pattern but remained below the 2020 entrainment rates for all hour intervals.

Of note, any differences relative to 2020 could be attributed to a difference in the abundance of fish in the forebay of the dam prior to the spill event. However, as a mobile survey of the forebay was not completed in 2020 due to equipment limitations, the effect of differences in fish abundance could not be evaluated.

The effects of hour of day and time since the gates opened on total entrainment rates in 2021 were quantified using a mixed-effect model. Using data collected under the GSMON-11 monitoring program, water temperature was included as a covariate in the model as a potential confounding influence on fish behaviour. For the horizontal beam data, none of the selected variables were statistically correlated with entrainment rates, although water temperature had a non-significant influence on entrainment ($p = 0.056$). After accounting for influences of covariates in the model developed for horizontal beam data, cooler water temperatures of approximately 13 to 14.5ºC were associated with peak entrainment rates (Figure 16). For the vertical beam data, hour of day and water temperature were not statistically correlated with entrainment rates, whereas time since gates opened had a non-linear effect on entrainment ($p < 0.001$). After accounting for the influence of covariates in the model developed for the vertical beam data, entrainment rates exponentially increased as time elapsed since the gates opened (Figure 17).

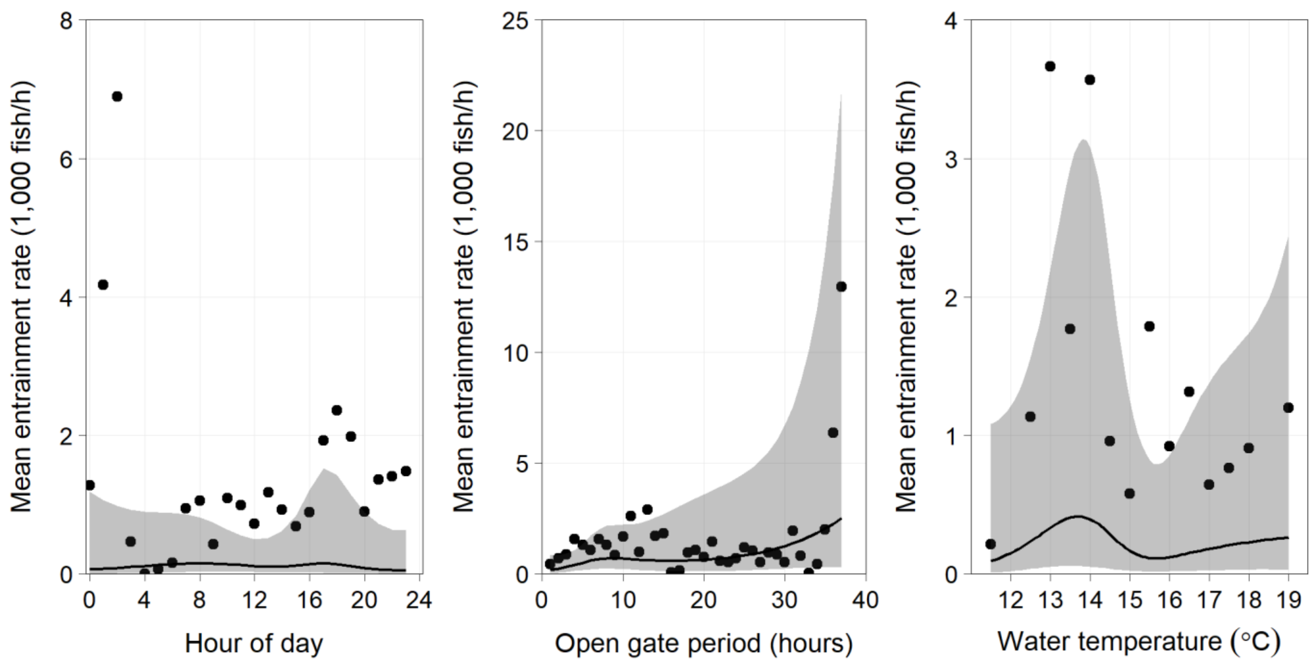


Figure 16: Prediction Curves for Mean Entrainment Rates Using Horizontal Beam Data While Holding the Remaining Two Variables Constant; Shaded Area Represents 95% Confidence Interval

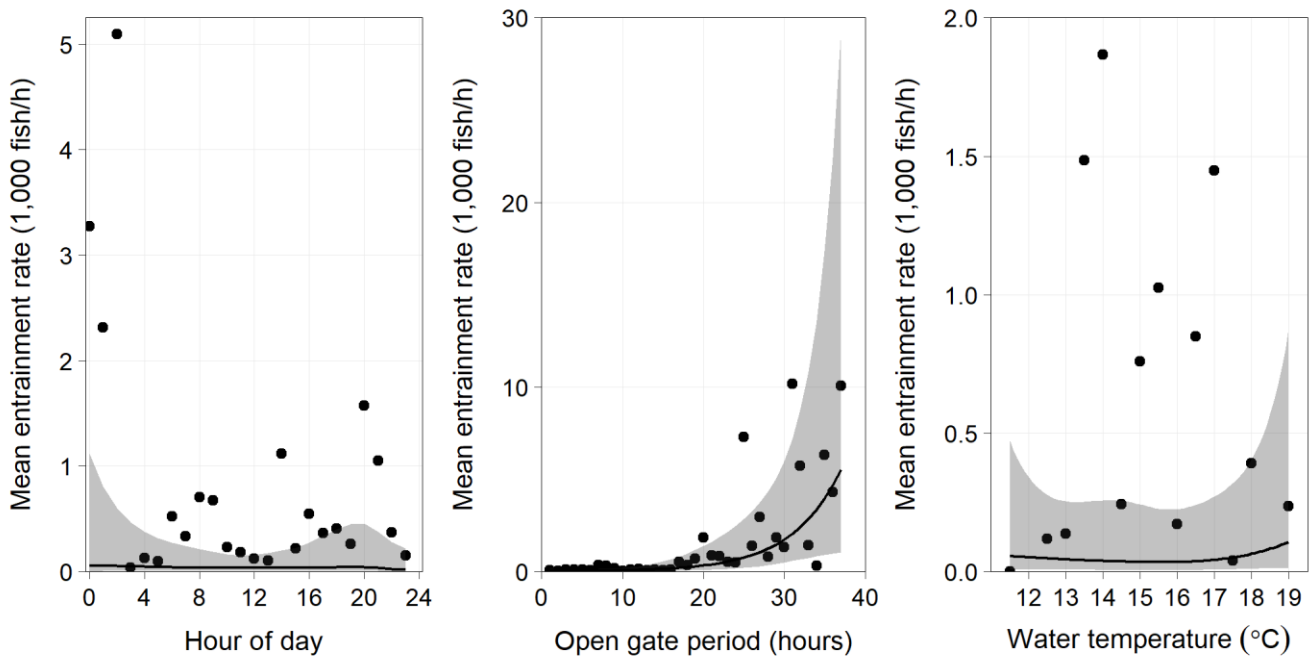


Figure 17: Prediction Curves for Mean Entrainment Rates Using Vertical Beam Data While Holding the Remaining Two Variables Constant; Shaded Area Represents 95% Confidence Interval

To calculate the benefits of mitigation in 2021, two approaches were taken – one assumed a uniform temporal distribution of fish across the day, while the other accounted for differences in fish densities throughout the day. For the assumption of a uniform temporal distribution of fish, the mean hourly fish entrainment was calculated. Over a 7-day (168-hour) period, the gates were open for 106 hours or 63.1% of the 7-day period, resulting in the entrainment of 217,500 fish or 2,052 fish per hour. To estimate total entrainment without gate closure mitigation, the calculated mean hourly entrainment rate of 2,052 fish per hour was multiplied by 168 hours, resulting in the entrainment of 344,736 fish. Therefore, the gate closure mitigation applied during the 2021 spilling period potentially reduced entrainment numbers by 127,236 fish.

To estimate the benefits of mitigation while accounting for temporal differences in fish entrainment during the day, the daily proportion of fish entrained between midnight at each of 09:00, 10:00, 11:00, 12:00, 13:00, and 14:00 was calculated, for days with 24 h of entrainment data. These hours were chosen since in 2021, gate closures occurred between midnight at 09:00 (on 02 July and 06 July), 10:00 (0n 05 July), 11:00 (04 July), 12:00 (03 July), and 14:00 (29 June and 01 July). These entrainment proportions were then used to calculate for each day in 2021, how many fish would have been entrained, if the gates remained open throughout the morning hours.

Note that these estimates are based the combined vertical and horizontal data at the Central Gate only (since no sampling was performed at the East Gate in 2020). The proportions were then applied to 2021 data collected at both Central and East gates, on entrainment values collected using only the vertical beam (since no horizontal beam data were available for the East Gate).

Based on 2020 data, an average of 41%, 48%, 53%, 59%, 63%, and 67% of the total daily entrainment occurred between midnight and 09:00, 10:00, 11:00, 12:00, 13:00, and 14:00, respectively. Daily variability in proportion of entrainment was high (Figure 18). The respective entrainment proportion, calculated using the combined horizontal and vertical beam data at the Central Gate, on the single 2021 sampling day without gate closure, was low, suggesting differences in fish abundance between the two sampling years.

Applied to 2021 data (from the combined Central, East, and West gates), the proportion of entrainment that would have occurred in 2021 between midnight and each day's gate opening was calculated using the mean value of 2020 cumulative entrainment for that hour. Based on this calculation, the gate closure mitigation applied during the 2021 spilling period potentially reduced entrainment numbers by 224,102 fish.

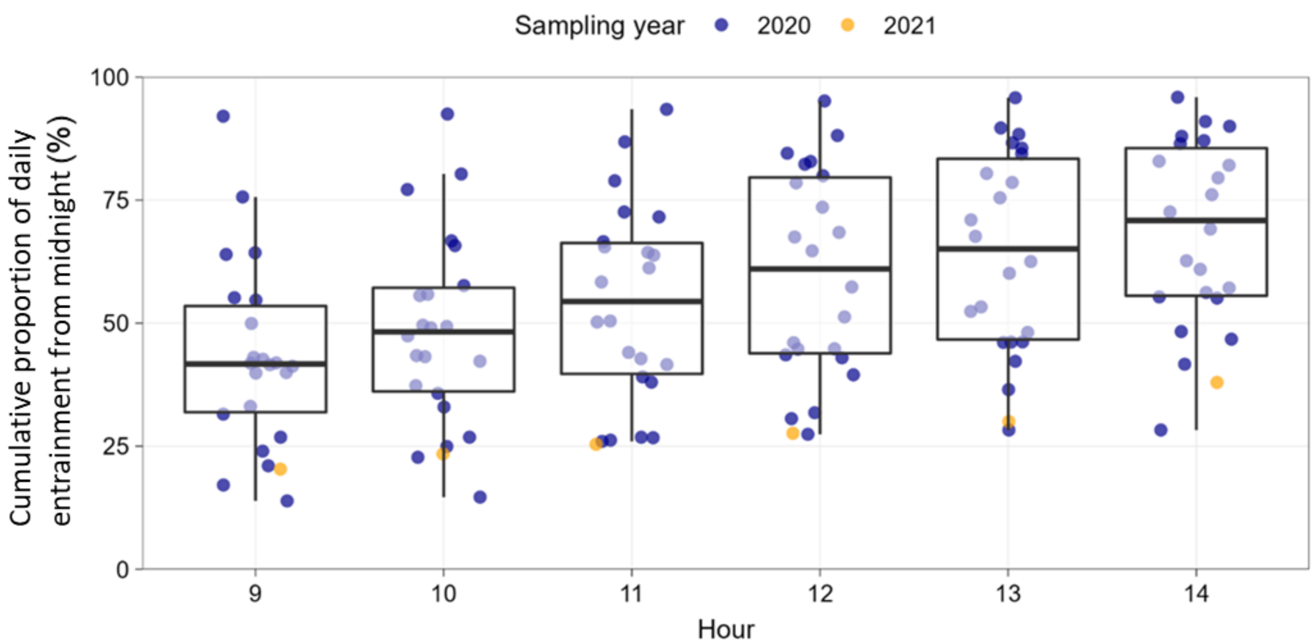


Figure 18: Entrainment at the Central Gate (Vertical Beam Only), Calculated between Midnight at Each of 09:00, 10:00, 11:00, 12:00, 13:00, and 14:00, for Days with 24 h of Entrainment Data. Boxplots were Drawn Using only 2020 Data.

3.3 Species-Specific Estimates

Relative species abundance of fish was broken down into three size classes (Figure 19). Of species captured in the smallest size range (75 to 245 mm), 76.7% were Peamouth Chub, 11.9% Redside Shiner, 3.8% Kokanee, 2.7% Lake Whitefish, 1.6% Longnose Sucker, 1.1% Pygmy Whitefish, with Lake Trout, Mountain Whitefish, Northern Pike Minnow and Rainbow Trout each account for approximately 0.5%. Peamouth Chub dominance in the fish community in 2021 is contrast to the dominance by Longnose Sucker and Lake Whitefish in 2020 (combining for 74.3% of the total catch in 2020).

Only four species were captured with individual lengths greater than 245 to 465 mm, dominated by Longnose Sucker (79.5%). Lake Trout accounted for 10.3% of this size class with Lake Whitefish and Mountain Whitefish making up 7.7% and 2.6%, respectively. The largest size class (>465 mm) was made up of 50% Lake Trout, with Bull Trout and Longnose Sucker each accounting for 25% of this size class. Burbot and Sculpin species were not included in either the abundance or entrainment estimates as demersal behaviours (Scott and Crossman 1998) were thought to reduce their probability of entrainment and made them less likely to be detected during mobile hydroacoustic surveys.

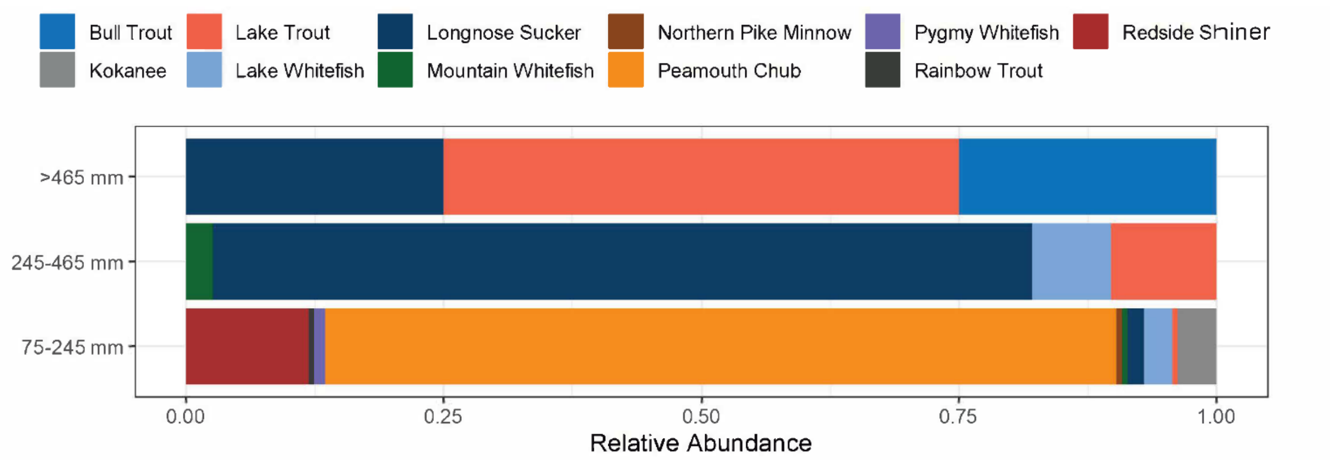


Figure 19: Relative Species Abundance by Size Class of Fish Captured in the Forebay

Fish tracks greater than 1.25 m in length were detected by both transducers during sampling, but these targets were eliminated from the analysis as they were thought to be biologically unreasonable based on the species composition and observed length distributions in the fish catch (both current and historical data). However, both Lake Trout and Bull Trout have been known to approach this size. Although some of these targets may have been large fish, it was deemed more likely that targets of this size were floating debris passing under the acoustic beam. In either case, targets of this size made up less than 0.01% of total tracks detected by either transducer and their occurrence appeared to be random and did not follow any obvious pattern.

3.3.1 Species-Specific Abundance Estimates in Forebay

The relative abundance of each species by size category described above was combined with the length distribution of fish tracks detected during the mobile survey to evaluate the approximate species composition in the forebay above the W.A.C. Bennett Dam. Species composition was then combined with densities generated by the vertical transducer (22.7 fish/ha). If considering a surface area of the entire Peace Reach of 31,345 hectares, the estimated population was 711,453 fish. A subset of the total population includes fish within the forebay that has been subject to fish community sampling efforts to characterize species relative abundance. Within the forebay, the estimated abundance was 158,514 fish given a surface area of 6,983 ha for zones 31 and 32 combined. Of the total estimated abundance, the estimated abundance of fish less than 75 mm in length was 80,419 fish or 50.7% of the total population, and the abundance of fish 245 mm in length or less was 130,158 fish or roughly 82.1% of the total population. Larger fish (greater than 245 mm to 465 mm in length) totalled 19,059 fish, and the largest size category totalled 9,297 fish (Table 11).

Table 11: Species Specific Abundance Estimates for the Forebay within the Peace Reach of Williston Reservoir from Mobile Hydroacoustic Surveys, June 2021

Species	<75 mm	75-245 mm	>245-465 mm	>465 mm	Total
Bull Trout	0	0	0	2,324	2,324
Kokanee	0	907	0	0	907
Lake Trout	0	130	1,955	4,649	6,733
Lake Whitefish	0	648	1,466	0	2,114
Longnose Sucker	0	389	15,149	2,324	17,862
Mountain Whitefish	0	130	489	0	618
Northern Pike Minnow	0	130	0	0	130
Peamouth Chub	0	44,169	0	0	44,169
Pygmy Whitefish	0	259	0	0	259
Rainbow Trout	0	130	0	0	130
Redside Shiner	0	2,850	0	0	2,850
Unknown Species[(a)]	80,419	0	0	0	80,419
Total	**80,419**	**49,739**	**19,059**	**9,297**	**158,514**

a) Representing a mix of age 0+ Kokanee and Lake Whitefish, Pygmy Whitefish, Redside Shiner and Peamouth Chub (up to age 2) based on historical catch data for the reservoir.

After applying the relative abundance of each species to the total abundance of the corresponding size category for fish 75 mm in length or greater (78,095 fish), estimates were summed across size classes to get the total abundance of each species. Peamouth Chub was the most abundant species (44,169 fish or 56.6% of the 'non-fry' population) and it is expected that most of the unidentified fish in the 'fry' category were also Peamouth Chub (Table 11).

Longnose Sucker was the second most abundant species for fish 75 mm in length or greater (17,862), and occupied at least three length classes, with the majority of individuals (84.8%) between 245 and 465 mm in length (Table 11). Lake Trout also spanned all three length classes with a total estimated abundance of 6,733 fish. The species that occupied the large size class only was Bull Trout with an estimated abundance of 2,324, all exceeding 465 mm in length.

3.3.2 Species-Specific Entrainment Estimates

Compared to the results of the mobile hydroacoustic survey, there were relatively more small fish detected by the stationary transducers at the spillway gates: approximately 92.3% of total detections were less than 75 mm in length and 99.4% of total detections were 245 mm in length or shorter (Table 12). Species-specific entrainment estimates were provided for 11 species and for fish tracks that were 75 mm in length or longer. The species with the highest entrainment estimate was Peamouth Chub (all within the 75 to 245 mm length class), representing 82.1% of the total entrainment estimate for fish 75 mm in length or longer. Most of the entrained Peamouth Chub were assumed to be spawning adults given that all Peamouth Chub captured during fish community index sampling displayed spawning colours. No juvenile Peamouth Chub were captured during sampling with the gill nets and minnow traps. After Peamouth Chub, Longnose Sucker was the next most vulnerable species to entrainment, representing 5.6% of all 'non-fry' fish (75 mm in length or longer), followed by Redside Shiner, representing 5.3% of entrained non-fry fish (Table 12). Less than 0.2% of total entrainment was of large-bodied fish greater than 465 mm in length. Estimated entrainment of large-bodied fish greater than 465 mm in length was 172 Lake Trout, 86 Bull Trout, and 86 Longnose Sucker.

Table 12: Species Specific Entrainment Estimates Calculated from the Relative Abundance of Fish in Each Size Category

Species	<75 mm	75 - 245 mm	>245 - 465 mm	>465 mm	Total
Bull Trout	-	0	0	86	86
Kokanee	-	282	0	0	282
Lake Trout	-	40	94	172	307
Lake Whitefish	-	201	71	0	272
Longnose Sucker	-	121	732	86	939
Mountain Whitefish	-	40	24	0	64
Northern Pike Minnow	-	40	0	0	40
Peamouth Chub	-	13,731	0	0	13,731
Pygmy Whitefish	-	81	0	0	81
Rainbow Trout	-	40	0	0	40
Redside Shiner	-	886	0	0	886
Unknown Species[a]	200,896	0	0	0	200,896
Total	**200,896**	**15,462**	**920**	**345**	**217,624**

a) Representing a mix of age 0+ Kokanee and Lake Whitefish, Pygmy Whitefish, Redside Shiner and Peamouth Chub (up to age 2) based on historical catch data for the reservoir.

4.0 SUMMARY

The Williston Reservoir has been previously characterized as a dynamic fishery subject to changes in species composition and abundance over time. The results from this study when compared to previous work also suggest that fish catch composition in the reservoir has changed, for example, 2012 sampling captured far more Kokanee than 2020 and 2021. In 2021, Peamouth Chub was the dominant fish species in the catch, and the relative abundance of Peamouth Chub was measurably higher than that recorded in 2020 when Longnose Sucker and Lake Whitefish were the dominant species (Golder 2021). As discussed in Golder (2021), differences in species compositions of the fish catch may be explained, in part, by sampling biases related to sampling dates, sampling gear and locations. The effects of which can be exacerbated by the challenges of capturing schooling fish in the reservoir such as Kokanee over a relatively short-duration sampling program.

Mobile hydroacoustic surveys were used to estimate the density of fish in the forebay in 2021. The density of fish observed across each transect in 2021 was lower than previous monitoring programs and the average density for each transect increased from west to east, with transects closest to the dam having higher fish densities. For all transects combined, the average fish density in 2021 was 22.70 fish/ha, 73% lower than the 85 fish per hectare in 2008 and 82% lower than the 128 fish/ha in 2012. The apparent decline in fish densities relative to previous mobile surveys could be attributed to various factors, including those discussed above for species composition.

The duration of the spill event in 2021 was within 29 June to 7 July (within a 7-day period), with gates open for 106 hours of the 168-hour period from the first hour the gates were open to when they were closed for the remainder of the season. The spill rate remained relatively constant when gates were open (568 to 602 m^3/s). Hydroacoustic data were recorded over the entire spill period by both vertical and horizontal transducers mounted on the upstream pier of the Central Gate, and a vertical transducer mounted on the upstream pier of the East Gate. Total cumulative entrainment at all gates was estimated at 217,500 fish, with a variance estimate of 167,258 to 267,743 fish. The East Gate recorded the highest entrainment, which was statistically higher than the Central Gate. It could not be determined if the higher entrainment rates at the East Gate were driven by high numbers of fish travelling along the shorelines of the reservoir or due to higher fish densities east of the spill gate. Further analysis of the hydroacoustic data and catch data determined that most of the fish entrained during the 2021 spill period (92%) were small-bodied fish less than 75 mm in length, primarily Peamouth Chub and Redside Shiner.

Based on the findings from 2020 entrainment monitoring on peak entrainment during the early morning hours surrounding sunrise (Golder 2021), BC Hydro applied intermittent gate closure mitigation during this time for the 2021 spill, potentially reducing entrainment numbers by a minimum of 127,236 fish and up to 224,102 fish. Intermittent gate closures also have the potential to reduce the hourly entrainment rates through behavioural mechanisms (e.g., gate movements displace fish), supporting this hypothesis would be the differences in hourly trends between 2021 and 2020, and the relatively low entrainment rates consistently observed during the two-hour interval following gate opening in the mornings of 2021. A mixed-effects model of the 2021 data showed that time since gates opened had a non-linear significant effect on entrainment (but significant only for the vertical beam data). After accounting for the influence of covariates in the model developed for the data, entrainment rates exponentially increased as time elapsed since the gates opened.

Interpretation of annual trends in entrainment rates and the benefits of mitigation closure are challenging, recognizing annual differences in the timing of the spill, environmental conditions, and the fish community composition in the forebay at the time of the spill. Continued investigations into fish responses to intermittent gate closure spills are warranted to confirm the benefits of the mitigation on overall entrainment.

5.0 CLOSURE

We trust that this report provides the information required. If there are any questions or require further detail, please contact the undersigned.

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https://golderassociates.sharepoint.com/sites/145856/project files/6 deliverables/2021 draft report/21460846-002-r-rev0-bc hydro 2021 field program 04nov_22.docx

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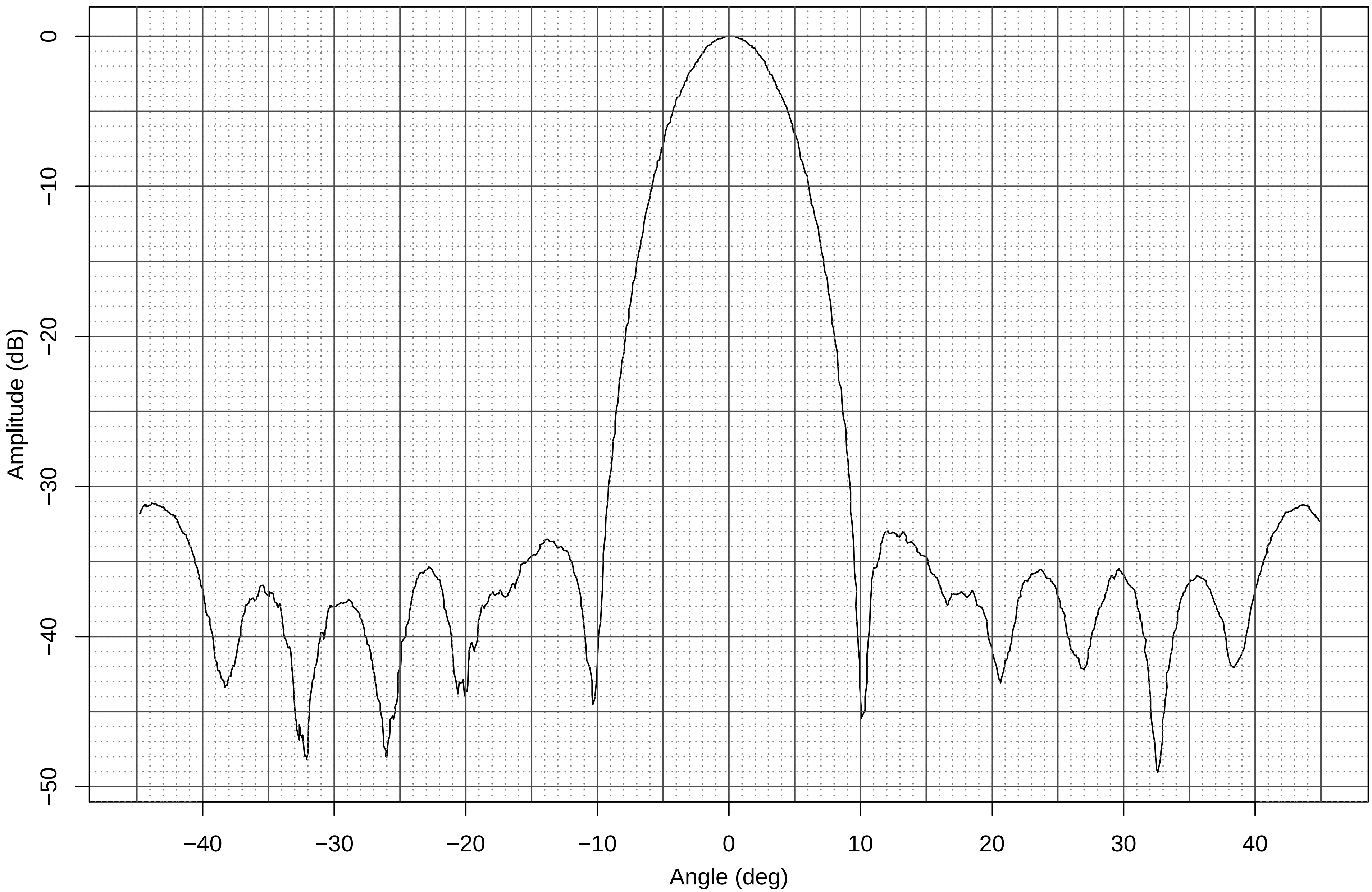
APPENDIX A

Transducer Beam Pattern

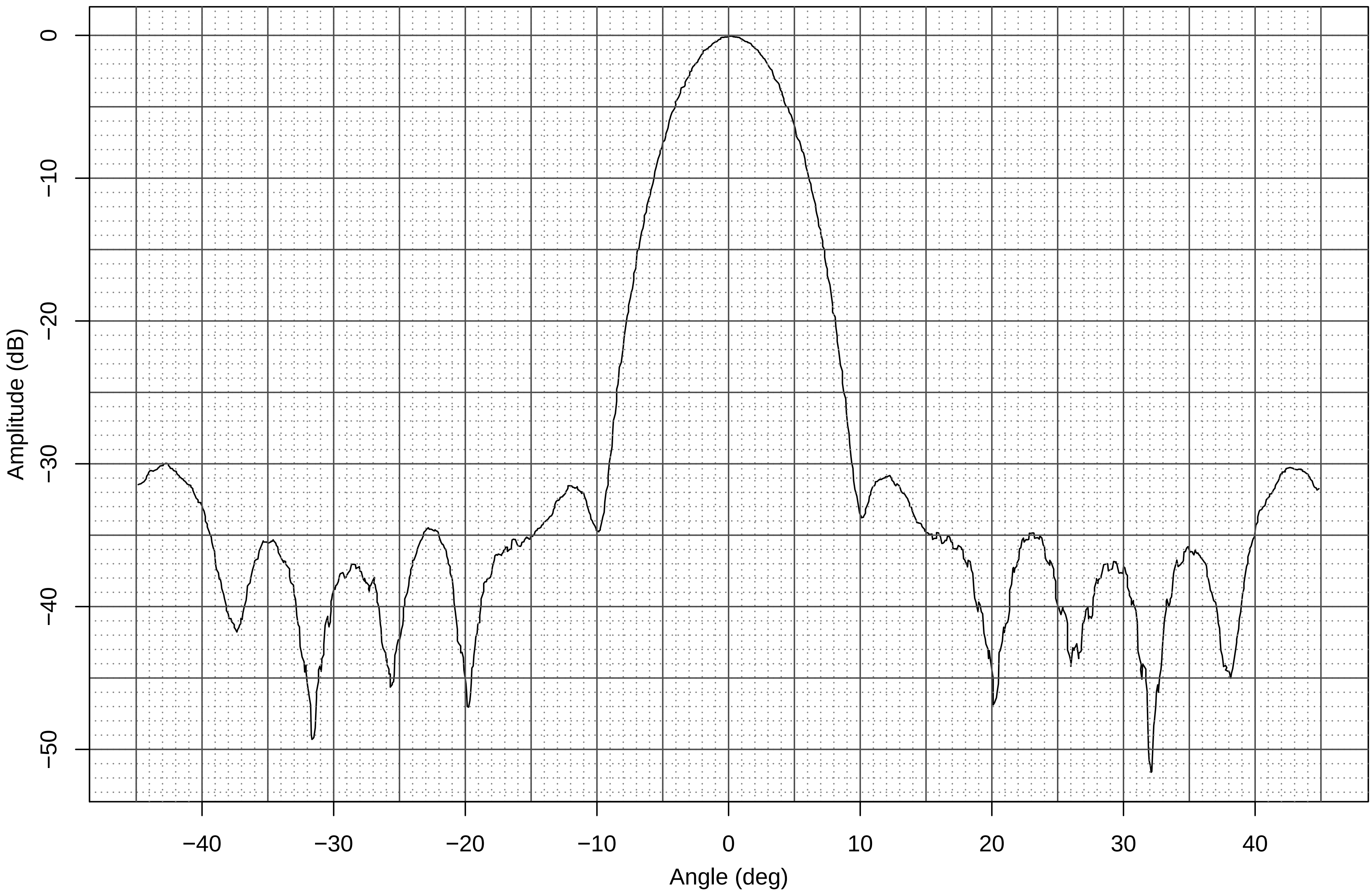
TRANSDUCER BEAM PATTERN

S/N: DT−200−0615−0335 FREQ (kHz): 201.3 BEAM WIDTH (deg): 6.8 XMIT/REC: Xmit
DATE: 04−19−2021 TEMP (*C): 19 CAL STD: EDO S/N: 101 TECH: Pei



TRANSDUCER BEAM PATTERN

S/N: DT−200−0615−0244   FREQ (kHz): 202   BEAM WIDTH (deg): 6.7   XMIT/REC: Xmit
DATE: 06−15−2021   TEMP (*C): 20   CAL STD: EDO   S/N: 101   TECH: Pei



TRANSDUCER BEAM PATTERN

S/N: DT−200−1025−0020 FREQ (kHz): 213 BEAM WIDTH (deg): 11.7 XMIT/REC: Xmit
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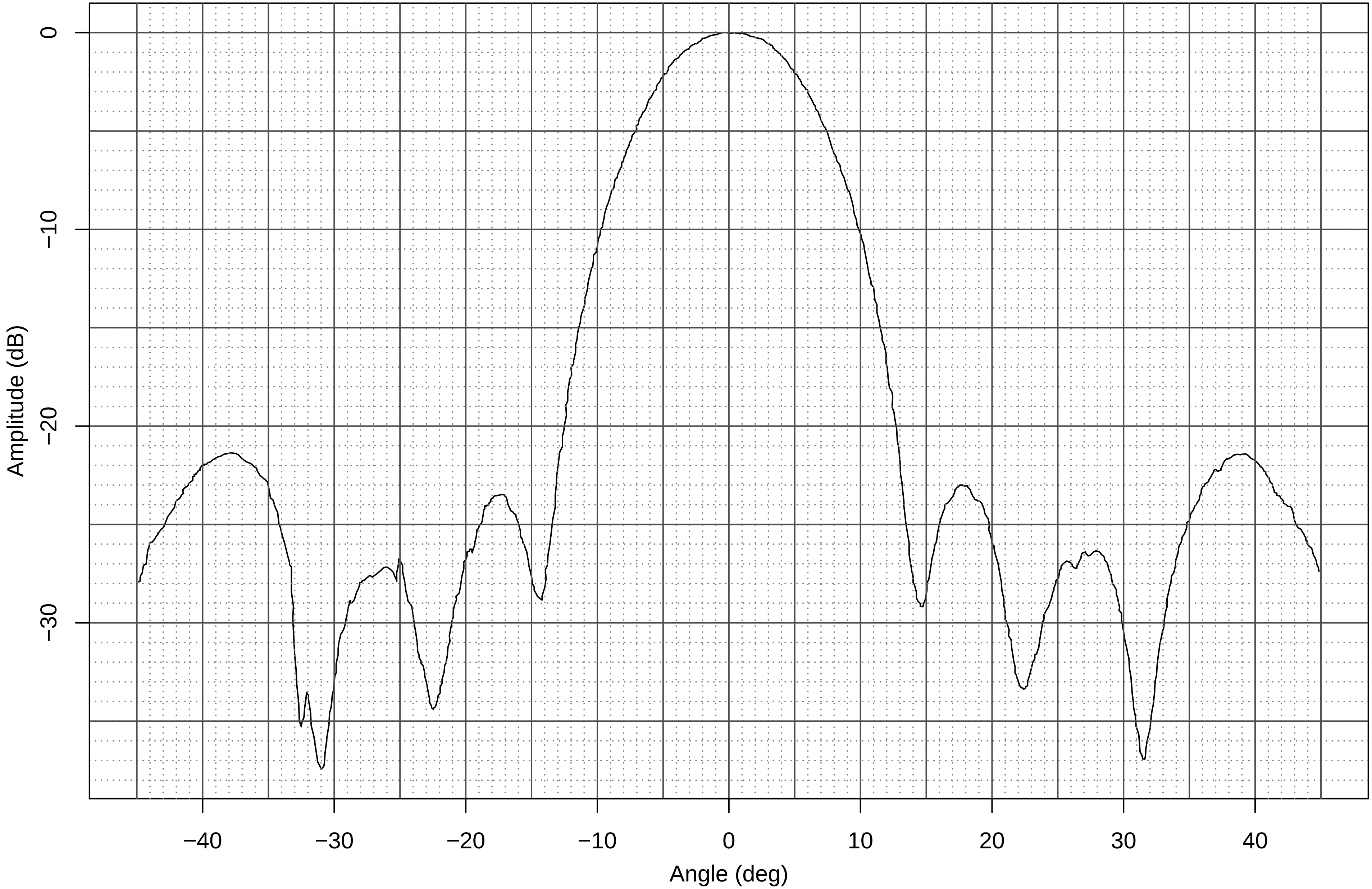

APPENDIX B

2021 Fish Track Data Summary (Electronic File)

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