Peace River Project Water Use Plan

W.A.C. Bennett Dam Entrainment

Implementation Year 2020

Reference: GMSMON-4

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

Study Period: July 2020 - September 2020

Golder Associates Ltd.

July 20, 2021

REPORT

Fish Entrainment at the W.A.C. Bennett Dam Spillway

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20149134-002-R-Rev0

20 July 2021

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 2020 spill occurring between 12 July and 1 September. The general 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 to the extent required to provide results that could be compared and contrasted between 2012 and 2020.

On 22 July 2020, two split-beam transducers were mounted on the upstream pier of the central spill gate, which were connected to a remotely operating echosounder in the spillway gallery for continuous recording of fish targets moving through the spill gates. The installation of the first transducer was consistent with previous monitoring with the acoustic beam aimed vertically in the water column. The second transducer was mounted horizontally to evaluate targets in the upper portion of the water column, an area typically under-represented when only a vertically-oriented transducer is deployed. The hydroacoustic results from the transducers installed at the central gate were then extrapolated across the other two gates where transducers were not deployed and for the spill period preceding equipment installation to estimate total fish entrainment during the spill event.

To evaluate the species composition of fish detected by hydroacoustics, index netting was deployed in the forebay area of the Peace Arm of Williston Reservoir from 25 to 29 July 2020. Eight species were captured with greater than 66% of fish caught in the upper depth strata of the sampling area. Furthermore, the catch per unit effort (CPUE) generally increased with distance from the spill gates. Longnose Sucker was the most abundant species captured (55.0% of total catch), followed by Lake Whitefish (19.3%), Peamouth Chub (12.1%), Lake Trout (7.9%), and other species (5.7%). Lake Trout have not been captured in the forebay area prior to this year. Relatively few Kokanee were captured compared to historical data and previous sampling events in the reservoir.

Over the duration of the spill an estimated 1,057,278 fish (+/- 1 standard deviation = 93,232) were entrained, 88% of which were less than 75 mm in length, representing a mix of age 0+ Kokanee and Lake Whitefish, Peamouth Chub (up to age 2), and Redside Shiner based on historical and current catch data for the reservoir. Of the remaining targets, 117,149 fish were between 75 and 465 mm lengths and 9,013 fish were larger than 465 mm. Despite a relatively consistent spill rate (522 – 670 m^3/s) during monitoring, high variability in daily entrainment was observed ranging from 2,778 fish to 126,380 fish per day, with three days (24, 25 July and 2 August) accounting for greater than a third of total fish entrained. The spikes in entrainment were associated with the detection of large schools of small fish passing through the acoustic beam, where each event occurred over a relatively short duration (approximately 2 hours). High variability in hourly entrainment rates was also observed within a given day, with higher hourly rates of entrainment estimated for sun rise and late morning hours.

The results estimated from the vertical transducer data were consistent with results from 2012, showing similar levels of entrainment over the same spill rates. The results also provide confidence in the Biosonics equation for predicting entrainment in the lower depth strata of the spillway, while revealing that the equation underestimates entrainment in the upper depth strata. Future studies incorporating a horizontally oriented transducer deployed over variable flows would better quantify the relationship between spill rate and fish entrainment, expanding the utility of this equation when on-site monitoring can not be conducted. In conclusion, the monitoring effort and approach deployed during summer 2020 successfully met the objectives of the monitoring program.

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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. The reservoir was created as a result of construction of the W.A.C. Bennett Dam in 1967 across the Peace River. The reservoir surface area ranges from 1,647 to 1,800 km^2, receiving flows from, and flooding the Parsnip River, Finlay River, and the Peace River. The reservoir and upper Peace watershed and the aquatic resources they support are important to local First Nations 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 recommendations from the Peace River Water Use Plan Committee, the GMSMON-4 Bennett Dam Entrainment Monitoring Program (BC Hydro 2008) was created to address the concern that fish were being entrained through the W.A.C. Bennett Dam (the dam) spillway during spill events. 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 the magnitude of fish entrainment through the spillway, including species and size composition;
- Quantify the relationship between spill discharge rate and the number of fish entrained, and;
- Evaluate diel and spatial variability in the number of fish entrained.

Three previous studies have monitored entrainment at the W.A.C. Bennett Dam through the use of hydroacoustics. A 1996 study included mark-recapture methods combined with a hydroacoustic assessment that was conducted during the final five days of a spill that occurred over a two-month period (Ebel 1996). Single-beam data from this study estimated the number of fish entrained per day was approximately 15,000 individuals, with higher entrainment rates during twilight and evening hours, but could not provide size class information due to equipment limitations. A study in 2002 focused on providing estimates of mortality associated with the spill using only a mark-recapture program (BC Hydro 2002). More recently, a 2012 study similar to that conducted in 1996 included hydroacoustic surveys, supplemented with gill netting (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 amount 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. The estimated total numbers of fish entrained during the 26 days of spilling during the 2012 study was approximately 455,700 fish (or 17,500 fish/day).

In July 2020, BC Hydro requested environmental services from Golder Associates Ltd (Golder) to continue the monitoring program (similar to the monitoring completed in 2012). The spills at W.A.C. Bennett and Peace Canyon started on July 12, but due to challenges associated with the global COVID 19 pandemic, entrainment monitoring didn’t start until July 22. The 2020 monitoring program used stationary hydroacoustics to estimate fish entrainment rates through the spillway at W.A.C. Bennett Dam and efforts were focused on the central gate only due to equipment limitations. Recognizing that the detection of fish targets within the top 2 m of the water column is marginal for a vertical transducer, and that fish targets in the spillway are typically distributed throughout the water column (BioSonics 2012), a vertically-oriented split-beam transducer was combined with a horizontally -oriented split-beam transducer to better detect fish in the spillway in summer 2020. The inclusion of a horizontal beam increases the volume of water scanned in the upper strata, an area largely missed by a vertically oriented transducer due to the cone shape of the acoustic beam, providing a more robust estimate of entrainment rates in this upper stratum of the water column. Similar to the 2012 study, index netting was used to collect data on fish sizes and species relative abundance in the Williston Reservoir. The 2012 study also completed a hydroacoustic survey of the forebay and surrounding area of the Peace Reach to support the index netting information. This forebay and areas hydroacoustic survey was not included in the 2020 monitoring due to limitations in equipment availability resulting from the pandemic.

Report objectives include the calculation of fish entrainment estimates (including species specific entrainment results) using data collected from hydroacoustic monitoring and index netting methods. Details are provided further below on the monitoring program methods for hydroacoustic monitoring (including equipment set up, data acquisition, and analysis), and index netting 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 in an attempt to minimize impacts on Williston Reservoir fish populations.

LEGEND

- NEARSHORE GILL NET SAMPLING AREA
- LOG STOP GILL NET SAMPLING AREA
- GILL NET STATION
- WAC BENNETT DAM SPILL GATE
- TOWN/ CITY
- ROAD

0 1 2

1:50,000 KILOMETRES

REFERENCES

1. ROAD, WATERCOURSE AND WATERBODY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
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COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N

CLIENT
BC HYDRO

PROJECT
W.A.C BENNETT DAM ENTRAINMENT

TITLE
SPILLWAY ENTRAINMENT MONITORING AREA

CONSULTANT

GOLDER

YYYY-MM-DD	2021-01-14
DESIGNED	MT
PREPARED	MH
REVIEWED	CS
APPROVED	CS

PROJECT NO.	PHASE	REV.	FIGURE
20149134	2004	0	1

1.1 Fisheries Setting

The creation of the W.A.C. Bennett Dan had a marked effect on fish populations with initial biological productivity in the reservoir described to be “boom and bust” with a 10-year boom period followed by a subsequent decline in production as the system gradually lost nutrients, transitioning to its current oligotrophic state (Stockner et al. 2005). Loading models indicate that after impoundment, Williston Reservoir was initially a moderately productive ecosystem, but the system has progressively lost nutrients through sedimentation and outflow, but also by the scarcity of littoral carbon production due to severe water level fluctuations (drawdown) and winter ice-scouring. Hence, within the past three decades, the ecosystem has gradually lost biological productive capacity and now lies within the ultra-oligotrophic status and supports a low level of fish production.

The 2012 study completed by Biosonics Inc. (Biosonics) and LGL Ltd. (LGL) concluded that based on the gill netting survey, the composition of fish targets detected in the mobile and stationary hydroacoustic surveys were mainly Kokanee and Peamouth Chub, and to a lesser degree, Lake Whitefish. When compared to previous results, the species composition in the Peace Reach and in the vicinity of the W.A.C. Bennett Dam appeared to be shifting from a Lake Whitefish (*Coregonus clupeaformis*) dominated fish fauna to a Kokanee (*Oncorhynchus nerka*) and Peamouth Chub (*Mylocheilus caurinus*) dominated one. Over the same period of time, Rainbow Trout (*Oncorhynchus mykiss*), and other foremost abundant species such as Longnose Sucker (*Catostomus catostomus*) and Arctic Grayling (*Thymallus arcticus*) appeared to have decreased to very low numbers.

Species Composition and Distribution

Previous assessments by Barrett and Halsey (1985) and Blackman (1992) indicate the fish community in Williston Reservoir consists of a variety of different species including: Lake Whitefish, Bull Trout (*Salvelinus confluentus*), Rainbow Trout, Kokanee, Arctic Grayling, Lake Trout (*Salvelinus Namaycush*), Burbot (*Lota lota*), Mountain Whitefish (*Prosopium williamsoni*), Longnose Sucker, Largescale Sucker (*Catostomus macrocheilus*), White Sucker (*Catostomus commersonii*), Peamouth Chub, Northern Pike-minnow (*Ptychocheilus oregonensis*) and Redside Shiner (*Richardsonius balteatus*).

A review of the British Columbia Ministry of Environment Fish Inventory Data Query (MOE 2020) records five additional species as being present within the Williston Reservoir from 1977 to 2018. These species include: Dolly Varden (*Salvelinus malma*), Lake Chub (*Couesius plumbeus*), Prickly Sculpin (*Cottus asper*), Pygmy Whitefish (*Prosopium coulterii*), and Slimy Sculpin (*Cottus cognatus*).

Of the 19 fish species identified as being present in Williston Reservoir (Table 1), Bull Trout (specifically the Western Arctic Population) is 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). Bull Trout are also listed provincially as special concern (Government of British Columbia 2020).
Four 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 are data deficient (not yet assessed). The remaining 12 species are Provincially designated as ‘demonstrably widespread, abundant, and secure’ (Government of British Columbia 2020).

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 Pike-minnow	*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 Index Netting

Gill netting was used to determine the fish species composition in the Peace Arm (forebay area) of the Williston Reservoir in the vicinity of W.A.C. Bennet Dam (the Dam), as well as the spatial distribution of fish near the spill gates. All sampling occurred from 25 to 29 July 2020 and netting locations were chosen to evaluate the spatial distribution of fish in the upper 20 m of the water column where fish were more likely to be entrained through the Dam 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: FJ20-591655).

The index netting was completed using fall walleye index nets (FWIN), consisting of eight panels, with a total length of 61 m x 1.8 m in height. The mesh sizes (stretched) of the eight panels were 25 mm, 38 mm, 51 mm, 64 mm, 76 mm, 102 mm, 127 mm, and 152 mm. All nets were set perpendicular to shore and were set at depths of either 5, 10, or 20 m with slightly more effort directed towards the 5 m stratum (i.e., 119 hours of the 293 hours total). To evaluate any diel variations, sampling was completed with both day-time and overnight sets. Day-time sets were deployed between 07:35 and 11:20 and had an average soak time of 4.9 hours, whereas overnight sets were typically deployed between 14:00 and 16:30 and had an average soak time of 17.5 hours.

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).

Net Locations

A series of index nets were placed just outside the log-stop surrounding the Dam spillway to apportion the fish species composition surrounding the spill gates. Nets in this area were set in clusters of three to cover the three sampling depth strata indicated above and all nets were located within 500 m of the spill gate. Following the completion of initial sampling in this area, nets were set with increasing distance from the spill gates along the west bank to examine differences in the spatial distribution of fish in the area. The western bank was chosen for additional sampling as windy conditions prevented the deployment and retrieval of nets in the open water. All nets were placed in regions where the average water depth exceeded 20 m. The UTM coordinates of each net were recorded and the proximity to the spill gates were later calculated in GIS.

To provide a comparison to previous survey years, two nets were set in the vicinity of Gillnet Station 1, which was used in previous studies (Sebastian et al. 2008, and Plate et al. 2012), and the nets were allowed to soak over night. However, due to high winds and low capture rates at this location, no additional netting occurred at this location.

2.2 Hydroacoustic Monitoring

Data collection was initiated at approximately 18:00 on 22 July and ran until 09:00 on 2 September 2020 with the exception of a one-week period when spilling was ceased (19 to 26 August). Since spilling was in progress when monitoring began, the data was extrapolated to account for the periods missed, including the period between 20:30 on 22 July and 10:00 on the 23 July, and between 16:00 on 29 July and 12:30 on 30 July when technical issues resulted in the temporary loss of data. During the monitoring period the spill rate remained relatively constant when gates were open, ranging from 522 – 670 cubic metres per second (m^3/s). In total the spill event occurred over a 43-day period (with the gate open for 35 days or 841 hours) and a complete record of the spill period and flow rates can be found in Table 2.

Table 2: Spill period and flow rates at W.A.C. Bennett Dam, 12 July to 1 September 2020.

Start Date/Time		End Date/Time		Flow (m^3/s)	Hydroacoustic Monitoring
12-Jul-20	19:15	13-Jul-20	08:36	570	No data
13-Jul-20	08:36	17-Jul-20	06:28	0	No data
17-Jul-20	06:29	21-Jul-20	11:29	566	No data
21-Jul-20	11:29	05-Aug-20	17:30	670	Data collection started 18:00 22 July
05-Aug-20	17:30	18-Aug-20	20:01	566 – 522*	Period monitored
18-Aug-20	20:01	26-Aug-20	09:40	0	Not monitored
26-Aug-20	09:40	26-Aug-20	13:36	566	Period monitored
26-Aug-20	13:36	27-Aug-20	09:06	0	Period monitored
27-Aug-20	09:06	27-Aug-20	15:05	650	Period monitored
27-Aug-20	15:05	29-Aug-20	09:01	0	Period monitored
29-Aug-20	09:01	29-Aug-20	16:00	600	Period monitored
29-Aug-20	16:00	30-Aug-20	09:00	0	Period monitored
30-Aug-20	09:00	30-Aug-20	16:01	600	Period monitored
30-Aug-20	16:01	31-Aug-20	09:07	0	Period monitored
31-Aug-20	09:07	31-Aug-20	16:03	600	Period monitored
31-Aug-20	16:03	01-Sep-20	09:01	0	Period monitored
01-Sep-20	09:01	01-Sep-20	16:30	600	Period monitored

* Flow decreased due to dropping reservoir level at the static gate position.

2.2.1 Equipment and Set-Up

Hydroacoustic monitoring utilized two BioSonics split-beam transducers (199 and 418 kHz) connected to a DTX echosounder located in the wheelhouse. The 418 kHz transducer with a 7.2º beam angle was mounted vertically to reproduce the monitoring methods used during 2012 entrainment monitoring which implemented a similar frequency transducer. 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 (199 kHz, 6.8º beam angle) 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.

The results from the previous study indicate there was no significant difference in total entrainment between gates (BioSonics 2012) and additional equipment was not available, therefore monitoring efforts were focused on a single gate. The assumed variability in entrainment estimates across gates was described using a coefficient of variation (CV) of 8.8%, as per the vertical beam results in Biosonics (2012). Transducers were secured to the mounting equipment provided by BC Hydro and lowered into place along the stoplog track on the upstream piers

and aimed towards the central gate (Figure 2). The echosounder and computer were located in the spillway galley and installation was completed with the assistance of BC Hydro personal following the guideline presented in the BioSonics equipment installation summary memo provided by BC Hydro. Transducers were mounted with an approximate 5-degree tilt towards the spill gate so 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.

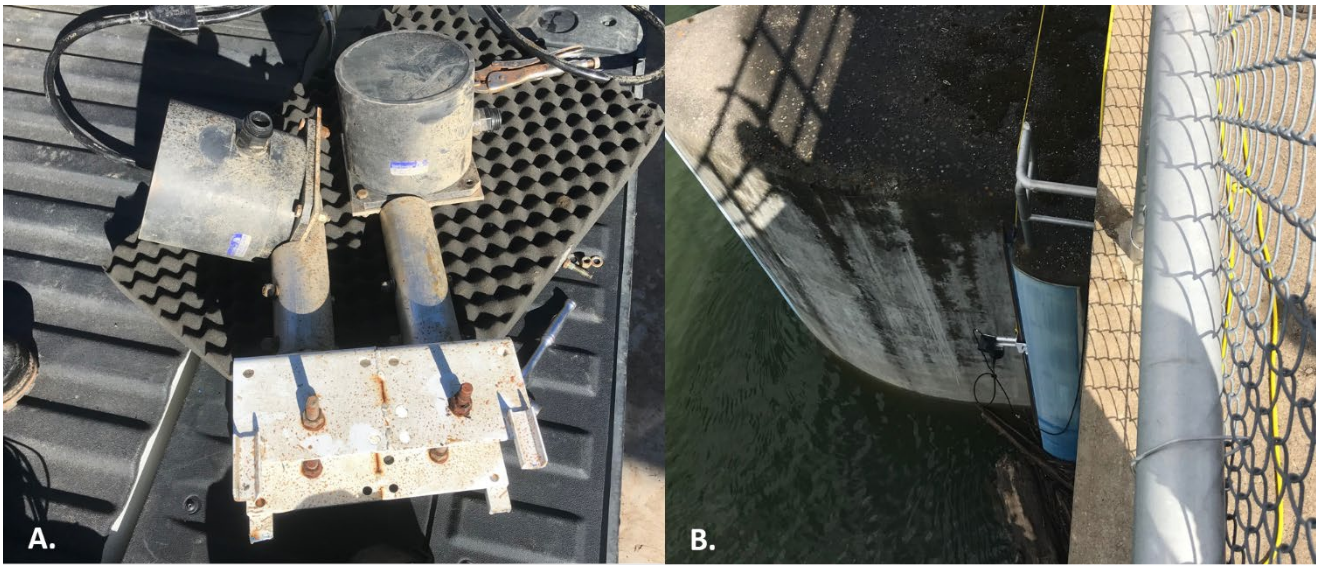

Figure 2: Hydroacoustic equipment set up on the eastern upstream pier of the central gate. Image A shows the position and angle of transducers on the mount and image B shows the position of transducers on logstop rail just prior to being lowered to a depth of 1.25 m below the water surface.

2.2.2 Data Acquisition

At the beginning and end of the program, a field calibration was performed using a standard-sized tungsten-carbide sphere with a known theoretical target strength to ensure data accuracy. The calibration sphere was lowered to approximately 5 m below the transducer and target strength information was collected for a minimum of 3,000 pings, with approximately 500 – 700 pings per beam quadrant and a minimum of 500 pings within ± 3 degrees from the centre of the beam. Target strength data was analyzed in Echoview® 11.0 (Echoview) and the difference between the measured and theoretical value was applied to all target strength data during post-processing. In addition, two water quality profiles were conducted during the initial week of sampling (23 and 27 July) to establish a temperature profile for calculating the speed of sound in water and the target strength range for the water temperature profile. These procedures increased the accuracy of target strength measurements by offsetting for equipment drift and environmental factors.

All data above a -130 decibel (dB) threshold was collected by the 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 at least 5 pings per second and each ping had a pulse duration of 0.2 milliseconds (ms). Hydroacoustic data files were saved in 15 minute increments to prevent the loss of large portions of data due to power failure or equipment damage by floating debris.

2.2.3 Analysis

Data was managed and analyzed in Echoview, and was analyzed as per standard operating procedures for fisheries acoustic studies (Parker Stetter et al. 2009). Transducer-specific thresholds were applied to data to reduce background noise and remove non-fish targets. Fish passing through the acoustic beam were identified using single echo detection and fish tracking analysis methods which identifies targets in the water as fish based on specified echo characteristics (Table 3) and is the preferred method when individual fish are sufficiently separated in the water column and fish densities are relatively low (Simmonds and MacLennan 2005). 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 can provide information on the path of the fish through the acoustic beam and an estimate of approximate fish size.

A minimum threshold of -60 dB was applied to all data to remove smaller, non-fish targets from the analysis. According to Love's (1977) equation this threshold corresponds to a target that is 27 mm in length or smaller. 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. Target signal-to-noise ratios were considered in assessing whether targets were valid fish echoes.

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

On 2 August, a large piece of debris floated in view of the horizontal transducer obstructing a small proportion of the acoustic beam at a range of approximately 7.5 m. This piece of debris remained in place until the 18 August when spilling was temporarily stopped. However, there was no evidence of an acoustic dead-zone resulting from the debris and it did not appear to affect the detection of targets beyond this range. The obstructed region accounted for a 0.4 m section of the total 15-m sampling range and the acoustic backscatter from this object was removed from further analysis (Figure 3).

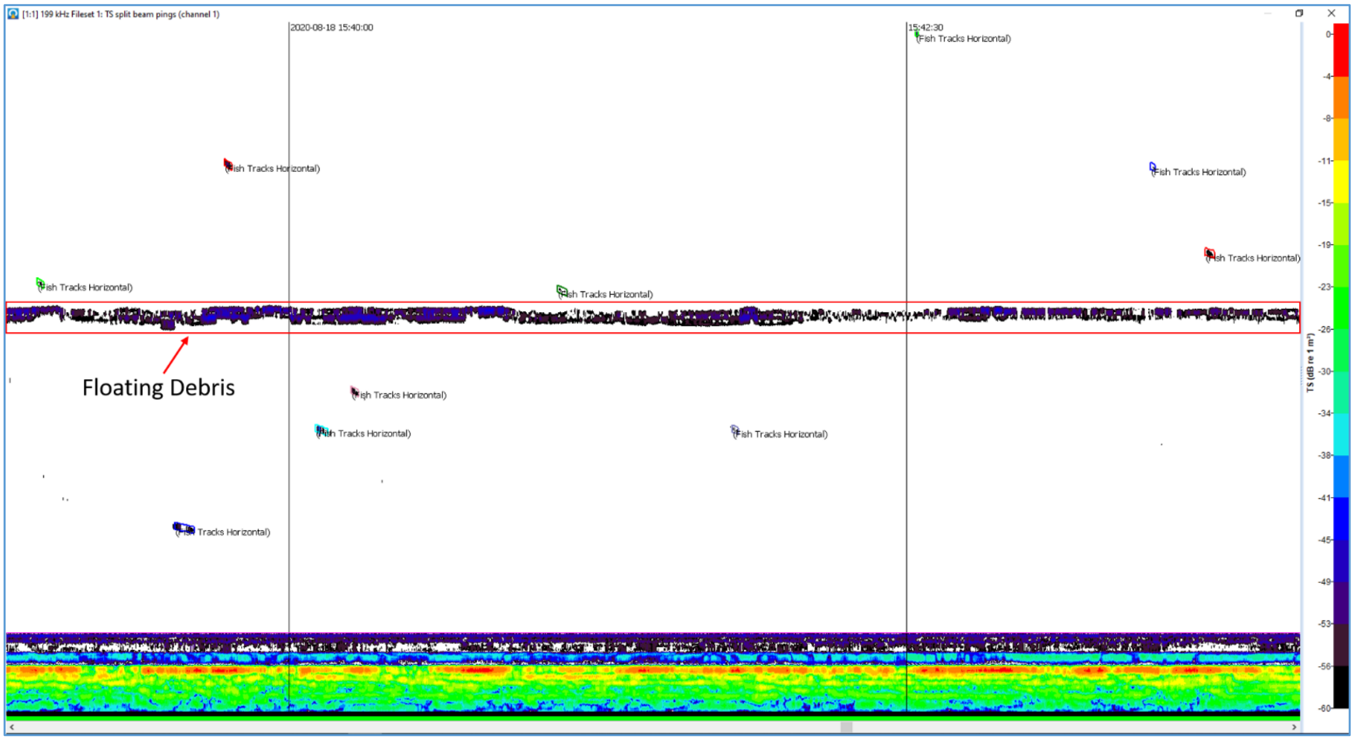

Figure 3: Screen capture of echogram from horizontal beam illustrating the region obstructed by floating debris and fish tracks detected in the acoustic beam on either side of the debris. Echogram shows a period of approximately 5 minutes of data.

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 and 2). Love's equation was based on data from eight different species of teleostean fishes and was developed for various 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, 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.

For the horizontal beam data, a variation of Love's (1977) all-aspect equation was used. The selected equation accounted for the potential for fish to be isonified in any position (i.e., any amount of rolling, pitching, or yawing; Equation 1). This equation was deemed appropriate for the horizontal data as fish, particularly small fish, could be theoretically oriented in any direction, with no predictably dominant orientation. Alternatively, the equation was adjusted for the vertical beam data to reflect fish only being isonified at angles up to a maximum of ±90º from the standard upright position (Equation 2). This range was deemed more appropriate for vertical data as fish are considered to be primarily isonified 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 in the Horizontal Beam

$$L = \sqrt[1.87]{\frac{10^{(TS \div 10)} \times 4\pi}{0.007302^2 \times 0.021}} \times 0.007302$$

Equation 2 - Love's Dorsal-Aspect Equation for Fish Length in the Vertical Beam

$$L = \sqrt[1.85]{\frac{10^{(TS \div 10)} \times 4\pi}{0.003476^2 \times 0.021}} \times 0.003476$$

Where L refers to fish length (m) and Target Strength (TS).

2.2.4 Direction of Travel

The use of split-beam technology in this study allows for the direction of travel of each fish track to be determined and incorporated into estimates of fish entrainment. Split-beam transducers are divided into 4 quadrants, each with their own 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 15º with 195º indicating travel away from the spill gate. Only fish with a direction of travel within 90º of 15º were considered to be entrained.

2.3 Entrainment Estimation

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, the full beam pattern of both 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 4). This function accounts for a transducer's beam pattern when calculating the effective angle, or more specifically, that the highest acoustic intensity occurs 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

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

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 the central gate was calculated per hour as the sum of weights over the corresponding interval. Extrapolation to total entrainment assumed a uniform distribution of fish across all open gates, based on the findings by BioSonics (2012), and was calculated by multiplying the results from the central gate by a factor of three to account for the two gates that were not sampled. Entrainment rates for the portion of the spill that was not directly monitored (i.e., prior to equipment set up, instrumentation delay) was estimated by applying the mean hourly rates for the corresponding hour that was missed. Each hour was assigned a variance estimate based on the differences recorded for the respective hour through the monitoring period. The variability in the total entrainment estimate for the spill period was based on the reported 8.8% CV BioSonics (2012), to account for differences in entrainment rates across gates.

A small number of tracks were observed moving away from the spill gate during active spilling periods. Furthermore, during equipment checks, fish were observed feeding in spill bays, using the built-up woody debris as cover. This suggests larger fish are capable of swimming against the flow. Therefore, entrainment was based off the net difference in the number of fish heading upstream versus downstream. The proportion of fish moving upstream was minimal, never exceeding 14% of total daily tracks.

Finally, results for total entrainment generated for the monitoring period were compared to the entrainment predicted using the equation developed by BioSonics (2012), which quantified the relationship between spill rate and the number of fish entrained. To provide a direct comparison to the 2012 results, total entrainment was also calculated using only the vertical transducer data following the same methodology. The Biosonics function is described as a third order polynomial with X representing spill discharge rate and Y equal to fish entrainment:

Equation 4 - Relationship between fish entrainment and flow category:

$$Fish\ Entrainment\ per\ hour = 35.966x^3 - 538.81x^2 + \ 2180.20x - 1711.6.$$

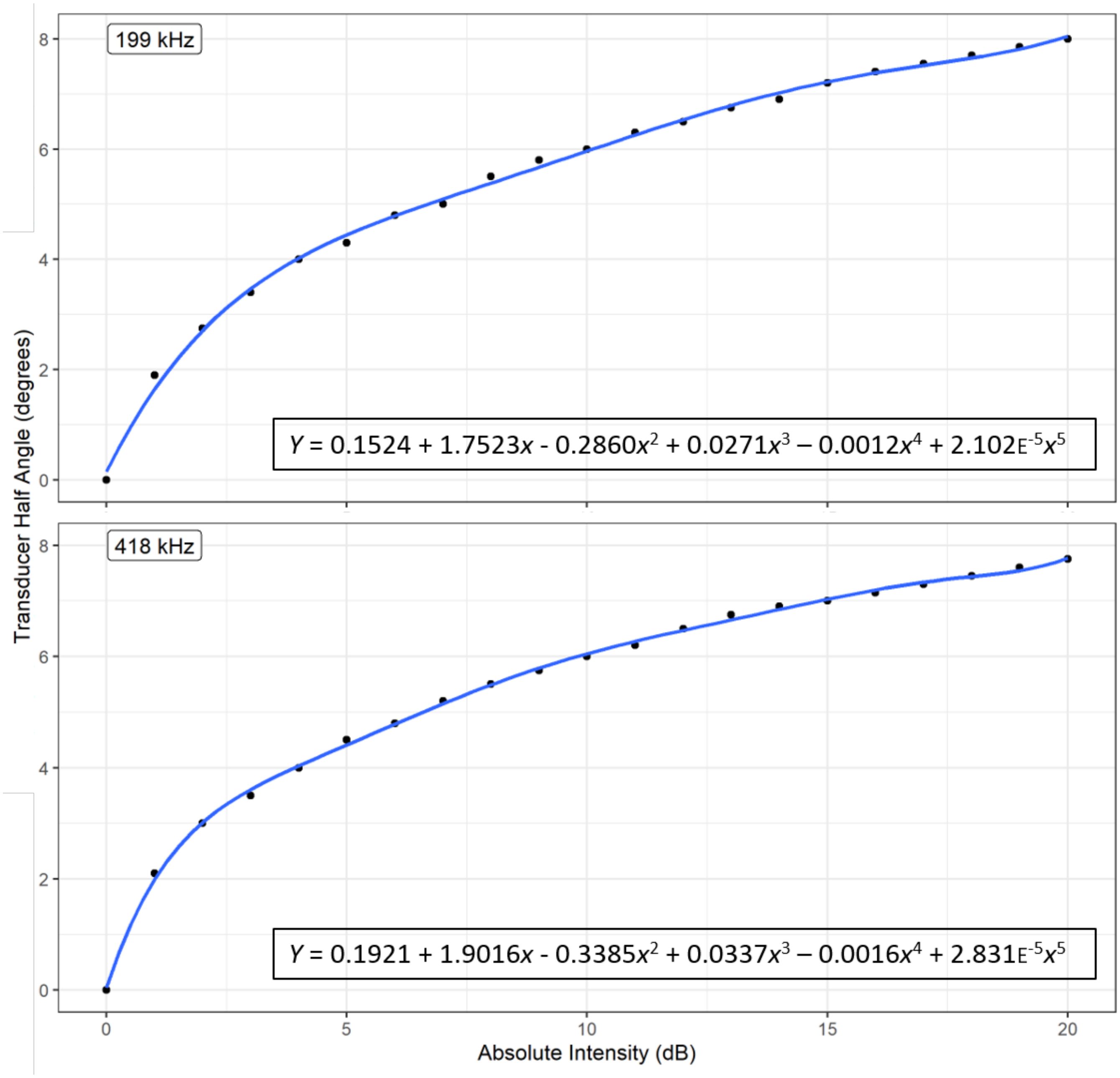

Figure 4: Transducer beam pattern directivity function.

2.3.1 Species Specific Entrainment

The approximate species composition of entrained fish will be estimated using the length class and relative species composition collected during concurrent index netting upstream of the dam. For consistency, this study used the same size classifications as the previous entrainment studies with 75 and 465 mm as fish length boundaries for delineating fish as small, medium, or large.

3.0 RESULTS AND DISCUSSION

3.1 Index Netting

A total of eight species were captured during index netting with a cumulative total of 140 fish captured in the forebay area of W.A.C Bennett Dam. Species composition was generally consistent with previous sampling events conducted in the forebay. Longnose Sucker made up greater than half the total catch (55.0 %) with Lake Whitefish making up an additional 19.3%. The next most abundant species was Peamouth Chub at 12.1% of the catch followed by Lake trout at 7.9% with Kokanee, Bull Trout, Burbot, and Redside Shiner making up the remainder (Figure 5). While captured in other areas of Williston Reservoir, Lake Trout and Redside Shiner have not been captured in the forebay during gill netting prior to this year. The only species that was not captured in 2020 that was present in the forebay in previous sampling years was Rainbow Trout.

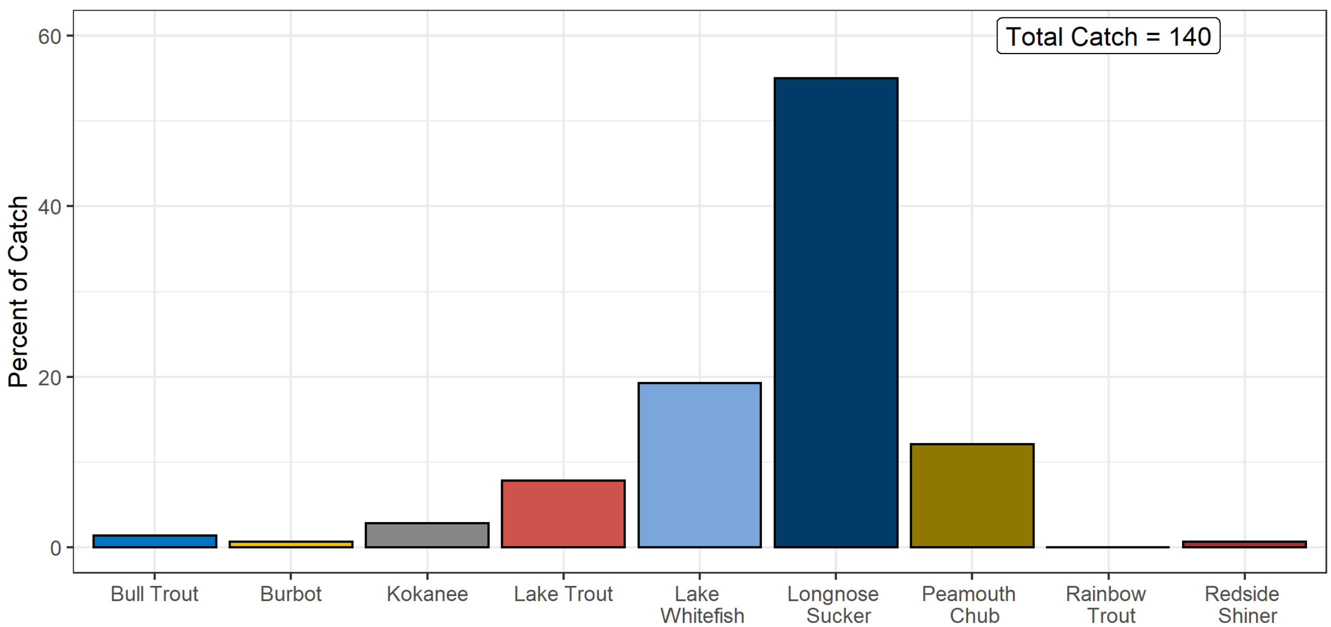

Figure 5: Relative species composition in gillnet catch, forebay or W.A.C. Bennett Dam, Williston Reservoir, July 2020.

CPUE by Location

Greater than 66% of the fish captured during 2020 gill netting were caught in nets set at a depth of 5 m, 31.4% at 10 m, and 2.1% in 20-m sets. Although this trend may reflect a slight bias in effort towards the 5-m stratum (118.9 of the total 293 hours; Table 4), when corrected for effort, the 5-m stratum also had the highest total CPUE (0.039 fish/100m^2/hr) with Bull Trout, Burbot, and Redside Shiner being captured at this depth. Total CPUE declined with net depth dropping to 0.022 fish/100m^2/hr in the 10-m sets. Only five nets were set at a depth of 20 m, for a total of 84 hours of effort. These deeper sets captured a total of three fish, generating a CPUE of 0.003 fish/100m^2/hr.

Kokanee was the only species that had a higher CPUE at depths below 5 meters (Figure 6). Although the capture rate of Kokanee was low in 2020, these results demonstrate that Kokanee are utilizing a range of depths in the forebay area, likely reflecting vertical trends in water temperature and the species preferred thermal range (i.e., 10 – 15 ºC; Scott and Crossman 1998). Besides Kokanee, Lake Trout were the only other species captured in 20-m sets, though the CPUE for Lake Trout was still higher in the upper strata (Figure 6). Interestingly, Lake Trout have not been captured in the forebay during previous gillnetting efforts indicating a potential shift in the community assemblage structure in this area.

Longnose Sucker were also only captured in the upper 10 meters of the water column and were caught exclusively in the nearshore net sets and were captured in 9 out of the 13 nets set along the west bank, with just under half the specimens being captured in a single net (Net 23). This suggests that Longnose Sucker are the most abundant species in this area and are widely distributed along the littoral zones surrounding the spill gate. Lake Whitefish and Peamouth Chub catch rates were highly variable between nets but showed a general trend of a higher abundance in at depths of 5 meters.

Biomass per unit effort (BPUE) generally showed similar patterns across depths as illustrated by CPUE. The only exception being Lake Trout which showed a lower BPUE at 10 meters compared to the 20 meter sampling strata, indicating a smaller average size of fish at this depth. Overall, the data suggests that the majority of species typically inhabit the area around the thermocline while Kokanee and Lake Trout occupy a wider range of depths.

Table 4: Location of nets on the Peace Arm of Williston Reservoir between 25 – 29 July 2020.

Net	Net Depth (m)	Start		End		Effort (hr)	UTM (Zone U10)		Distance from Spill Gate (m)
		Date	Time	Date	Time		Easting	Northing	
1	10	25-Jul	7:35	25-Jul	8:35	1.00	548270	6209298	867
2	10	25-Jul	8:30	25-Jul	16:00	7.50	548262	6209239	820
3	20	25-Jul	14:00	26-Jul	7:30	17.50	548384	6209233	755
4	10	25-Jul	16:20	26-Jul	7:00	14.67	548566	6209086	252
5	10	26-Jul	7:45	26-Jul	15:15	7.50	549096	6208598	368
6	20	26-Jul	8:15	26-Jul	15:20	7.08	549116	6208592	384
7	5	26-Jul	15:05	27-Jul	10:15	19.17	548267	6209314	882
8	20	26-Jul	15:30	27-Jul	7:30	16.00	549141	6208605	408
9	10	26-Jul	15:45	27-Jul	7:45	16.00	549066	6208611	335
10	20	27-Jul	7:50	28-Jul	7:30	23.67	548906	6208916	387
11	10	27-Jul	9:45	27-Jul	16:00	6.25	548949	6208984	471
12	5	27-Jul	15:45	28-Jul	8:00	16.25	549112	6208584	379
13	10	27-Jul	16:15	28-Jul	7:45	15.50	548960	6208996	484
14	5	28-Jul	10:45	29-Jul	7:15	20.50	548388	6210085	1561
15	20	28-Jul	11:05	29-Jul	7:30	20.42	548346	6210081	1569
16	5	28-Jul	11:20	28-Jul	14:30	3.17	547537	6209852	1757
17	5	28-Jul	15:30	29-Jul	7:45	16.25	548046	6209574	1217
18	5	29-Jul	8:00	29-Jul	13:30	5.50	547718	6209711	1528
19	10	29-Jul	8:15	29-Jul	10:35	2.33	547721	6209764	1571
20	5	29-Jul	8:40	29-Jul	14:00	5.33	547311	6209857	1923
21	10	29-Jul	10:40	29-Jul	13:45	3.08	547611	6209825	1681
22	5	29-Jul	16:00	30-Jul	8:15	16.25	547736	6209700	1510
23	5	29-Jul	16:15	30-Jul	8:45	16.50	547311	6209857	1921
24	10	29-Jul	16:30	30-Jul	8:30	16.00	547611	6209825	1687

Note: All nets were standard FWINs approximately 61 m long by 1.8 m wide.

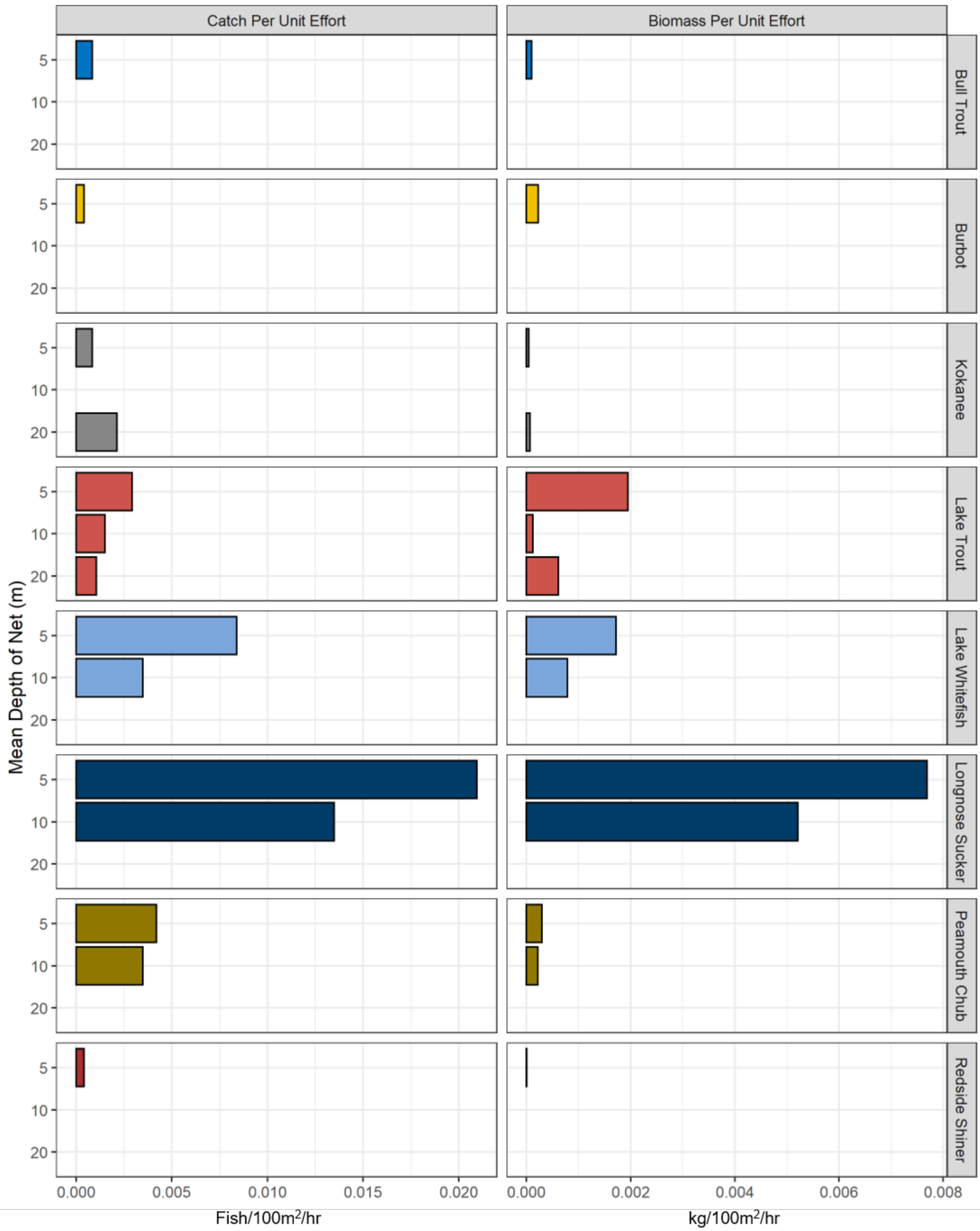

Figure 6: Gill net catch per unit effort (Fish/100m^2/hr) and biomass per unit effort (kg.100m^2/hr) by species and depth strata, forebay of W.A.C. Bennett Dam, Williston Reservoir, July 2020.

Over half (13 out of the 24 nets) were set in nearshore areas adjacent to the littoral zone, along the west bank of the forebay area, and in general, the CPUE per net was highly variable across the reservoir ranging from 0 to 2.408 fish/100m^2/hr, increasing with distance from the spill gate (Figure 7). The one obvious exception to this trend would be the catch results from the two pelagic net sets (Net 14 and 15), which were located near the primary sampling area used in 2008 and 2012. These net sets did not capture any fish despite greater than 20 hours of effort per net.

In an effort to better characterize the fish community in the areas directly adjacent to the spill gate the remaining nets (9 in total) were set just outside of the log-stop surrounding the gate. These net sets include all nets located within 500 m of the spill gate and the CPUE observed at these sites was considerably lower that in other areas with all but three nets catching zero fish. The results suggest fish were actively avoiding areas closer to the spill gates. As fish index sampling occurred 12 days or more after the start of spilling, it is also possible that some fish in this area had already been entrained downstream resulting in a reduced density in this area.

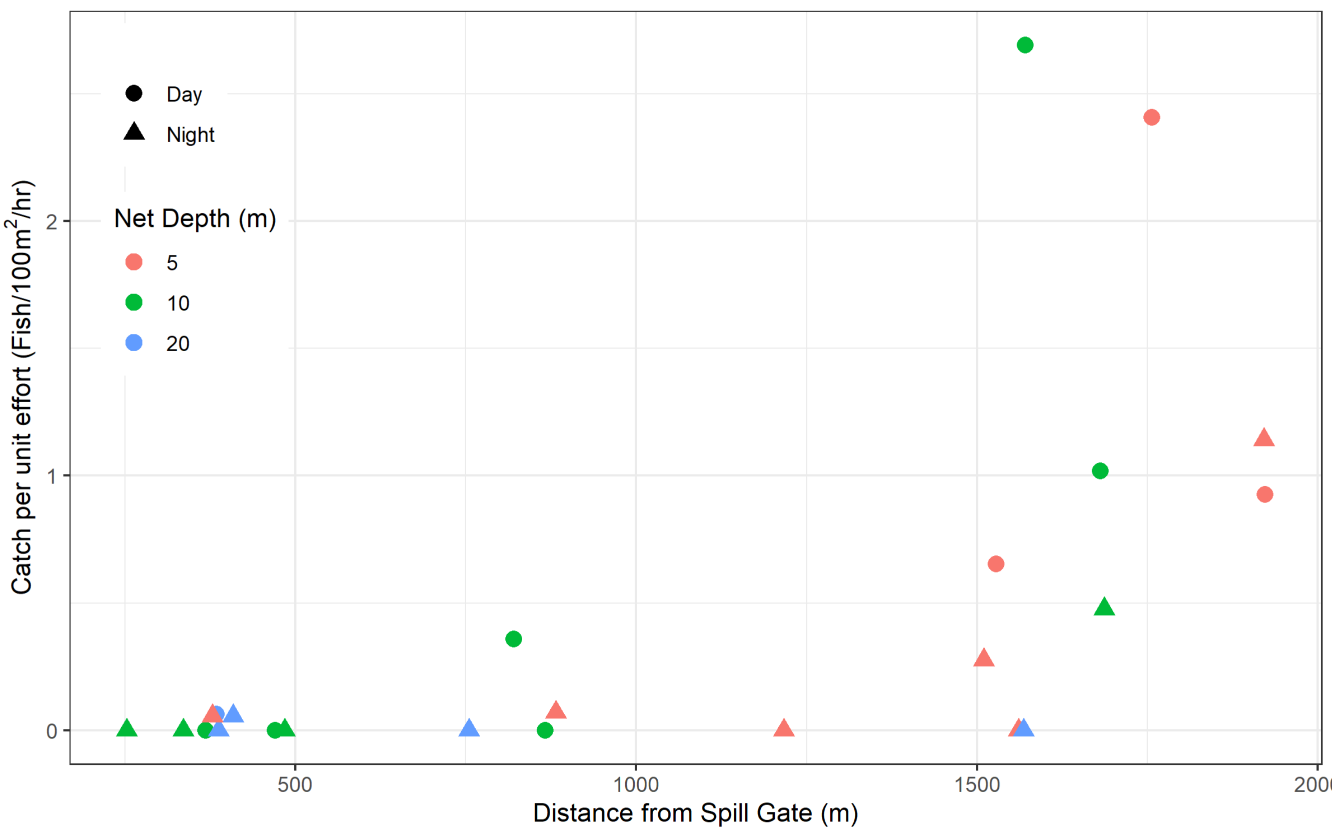

Figure 7: Catch per unit effort (Fish/100m2/hr) with increasing distance from spill gate, forebay of W.A.C. Bennett Dam, Williston Reservoir, July 2020.

Catch Trends Across Monitoring Years

Prior to this year, a comparison of gill net catch between years (1988 to 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). However, the 2020 results show a decline in the relative abundance and CPUE for Kokanee and Peamouth Chub (Figure 8), even while considering that methods (sampling locations and depths) were inconsistent between years. A closer comparison of results using the same sampling location deployed by Sebastian et al. (2008) and Plate et al. (2012), which was approximately 800 m from shore and 1500 m from the spill gate, yielded no fish (Net 14 and 15) in 2020 (Table 4) versus the Kokanee and Peamouth Chub that were sampled during previous monitoring years.

Similar to the 2008 sampling event, sampling in 2000 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. Plate et al. (2012) expanded on this sampling plan by incorporating additional net sets at depths of 5 and 10 meters in an attempt to better evaluate the vertical distribution of fish in the water column to support entrainment estimates. Overall, the 2020 species composition was most similar to that reported in 1974 (Barrett and Halsey 1985) and this similarity was likely the result of: i) incorporation of nearshore areas (and associated littoral fish) in 2020 leading to the capture of a variety of other species including Longnose Sucker that have not been caught in the pelagic zone, and ii) setting nets at deeper locations in 2020 in an attempt to catch larger bodied individuals to better characterize the large targets observed during hydroacoustic entrainment monitoring at the spill gate.

Based on the inclusion of nearshore sampling and the diurnal summertime movement of Peamouth Chub into shallow water, the catch rate of this species was expected to increase relative to previous years, specifically in relation to Kokanee and Lake Whitefish which are more pelagic. However, this was not the case and a decrease in the CPUE of Peamouth Chub was observed since 2008 and 2012 monitoring efforts (Figure 8). The catch rate of Kokanee saw the largest decline over this period with only four fish captured during the 2020 sampling program. In contrast to declines in Peamouth Chub and Kokanee, the CPUE for Lake Whitefish remained relatively constant between years (Figure 8).

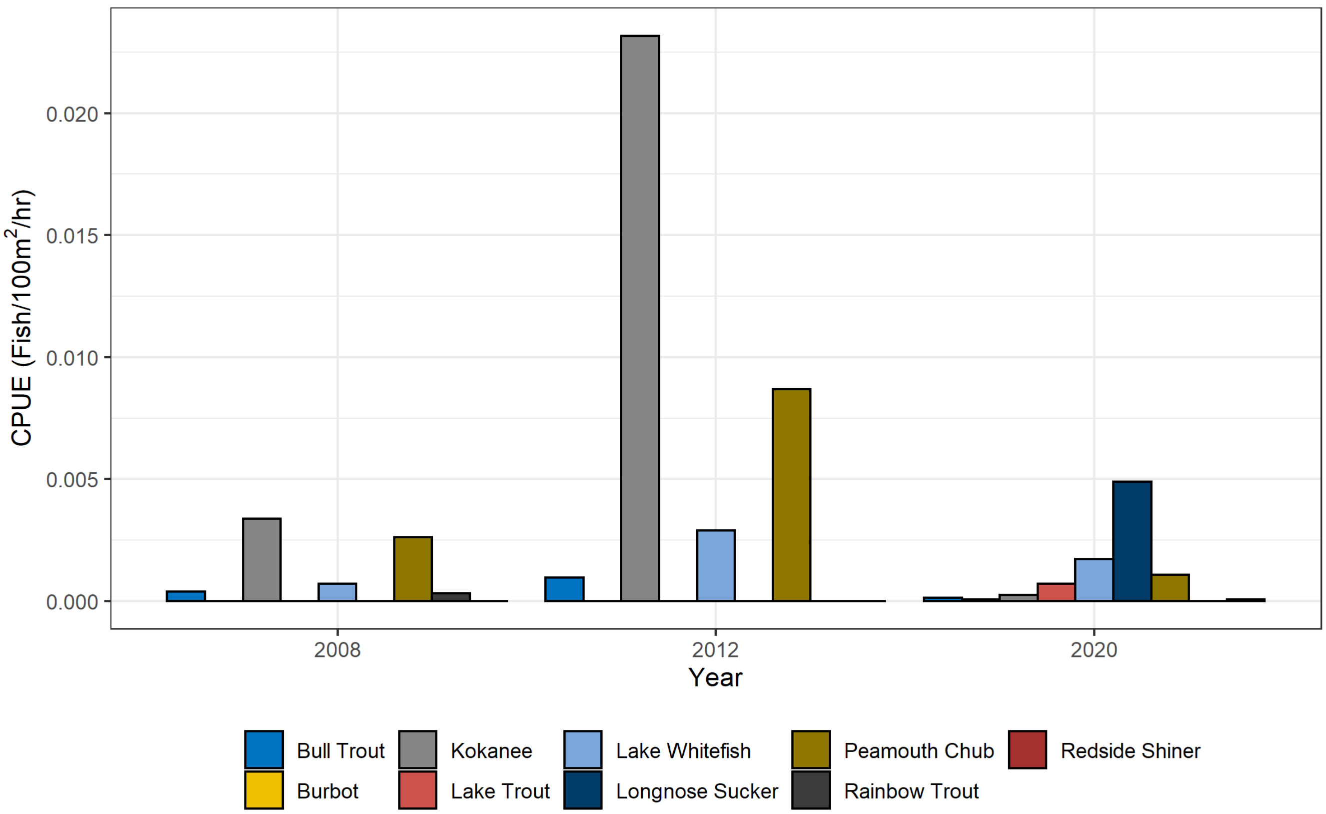

Figure 8: Historical Catch per unit effort (Fish/100m2/hr), Peace Arm of Williston Reservoir, 2008 – 2020.

3.2 Hydroacoustics

Field calibrations performed at the start and end of the monitoring period confirmed both transducers were functioning appropriately and within acceptable limits. The water column profile provided the necessary information required to calculate the speed of sound in water, which in turn is required for the calculation of a target's range from the transducer. Water profiles conducted on 23 and 27 July showed similar temperature profiles with a slight increase in temperature over this period. The average surface temperature for these two profiles was 17.8 ºC which is typical 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 on 23 July and the first 4 m on 27 July dropping by over 3 ºC over this range (Figure 9). Temperatures continued to decline with depth reaching 11.4 and 12.7 ºC at a depth of 20 m, depending on the sampling day, with an average water temperature of approximately 14 ºC across the first 20 m. This slight difference in temperature between profiles could be attributed to periods of high winds and rough water resulting in increased mixing of the upper water column by 27 July.

Similar to the water temperature trend, an increase in the amount of dissolved oxygen (mg/L) was observe on 27 July compared to the earlier profile and the observed concentration remained relatively stable across all depths, averaging 10.1 mg/L. On 23 July, surface readings indicated a dissolved oxygen concentration of 8.3 mg/L with a slight decrease with depth until reaching the thermocline. At an approximate depth of 7 m, the amount of dissolved oxygen increased by 0.7 mg/L relative to surface readings, corresponding with an increased solubility of oxygen in colder water, prior to slowly declining with depth (Figure 9).

In summary, the forebay area of the Peace Reach was stratified during sampling, which is consistent with the dimictic nature of Williston Reservoir with mixing typically occurring in May and November (Stockner et al. 2005). Due to this change in temperature with depth the average temperature was used to calculate the speed of sound in water. Based on the above profiles the average speed of sound in water in the area surrounding the spill gate was estimated at 1,464 m/s, which was subsequently used to calculate the range of each target from the transducer.

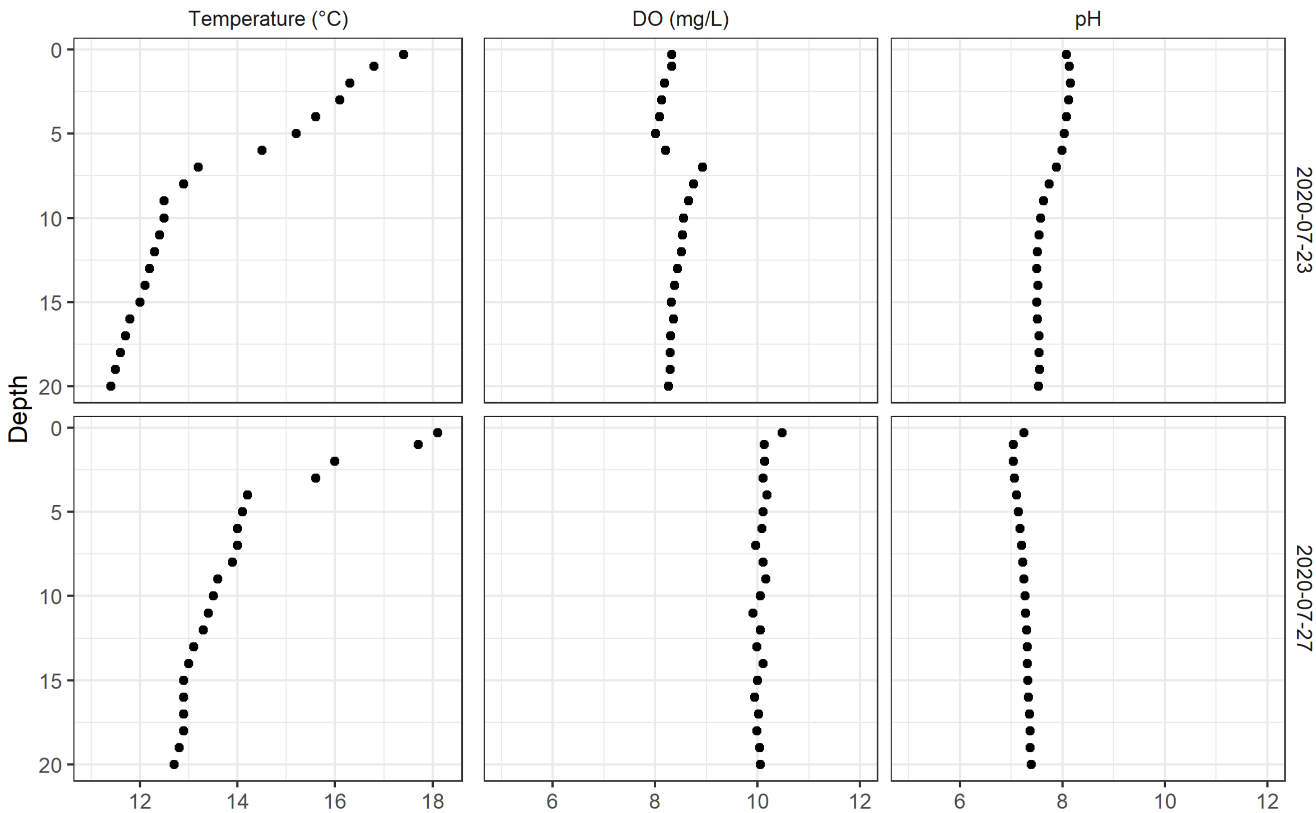

Figure 9: Water quality profile at depth (m), forebay of W.A.C. Bennett Dam, Williston Reservoir, July 2020.

During 2020 entrainment monitoring at W.A.C. Bennett Dam a total of 779 hours of data was recorded by both the vertical and horizontal transducer mounted on the upstream pier of the center spill gate. Approximately 118 hours of the total effort was during periods when the gates were closed, most of which occurring near the end of the spill. The remaining 661 hours were recorded with the gates open, accounting for approximately 78% of the total time the spill was in progress.

During the entire monitoring period a total of 21,066 tracks were detected with approximately three times more fish tracks detected by the horizontal beam compared to the vertical. As the beam angle and the total range of each transducer was approximately equal, the area of water each transducer scanned was roughly equivalent. In other words, the observed difference in the number of tracks can be attributed to a difference in fish density. Furthermore, a larger proportion of tracks detected in the vertical beam was less than 75 mm in length (77% of tracks in the horizontal beam compared to 55% in the vertical beam) based on Love's (1977) equation (Figure 10). In comparison, all but two of the fish captured in the reservoir in 2020 had a fork length within the medium-sized fish category (75 – 465 mm). The remaining two fish were large-bodied Lake Trout with fork lengths of 535 and 620 mm. The smallest fish captured during 2020 sampling was a Redside Shiner with a fork length of 105 mm, which is consistent with the expected minimum capture length of 116 mm based on a minimum mesh size of 25 mm (Hamley 1972, Plate 2007).

To better evaluate the length distributions of each species, 2020 catch data were combined with the results from 2008 and 2012 gillnetting and the resulting length distributions are shown in the top panel of Figure 10. Although gear limitations preclude a precise apportionment of the small size class (< 75 mm) to species, a few assumptions can be made about this group using the life history characteristics of the species captured. Length at-age data from Sebastian et al (2008) and Plate et al. (2012) suggests this size category includes age 0+ Kokanee and Lake Whitefish, Peamouth Chub up to age 2, and now Redside Shiner based on its recent catch in the area. Length at-age information from Sebastian et al. (2003) and Sebastian et al. (2008) indicate the average length of an age 1 Kokanee and Lake Whitefish exceeds 150 mm in length and would subsequently fall into the medium-sized fish category.

As previously mentioned, all fish but two captured in 2020 fell into the medium size category, while this category made up approximately 25% of all targets detected (Figure 10). Looking at each transducer independently shows the proportion of medium-sized tracks was higher in the vertical beam compared to the horizontal (35.3% versus 21.2%). Of note, this size category includes the majority of the life stages of each species encountered during the sampling program, with the exception of the age groups of the species noted above. All tracks with lengths greater than 465 mm were considered to be Lake Trout as this is the species most frequently captured that was found to exceed this size. While it is worth mentioning that Burbot and Bull Trout do routinely exceed this size the probability of a Burbot of that size being entrained was thought to be low due to the species preference for deep water habitat (Scott and Crossman 1998), and the low capture numbers in the index netting for both species.

Fish tracks greater than 1.1 meters 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.

A complete summary of all fish tracks per hour, including a breakdown of size classes can be found in Appendix B – Fish Track Data.

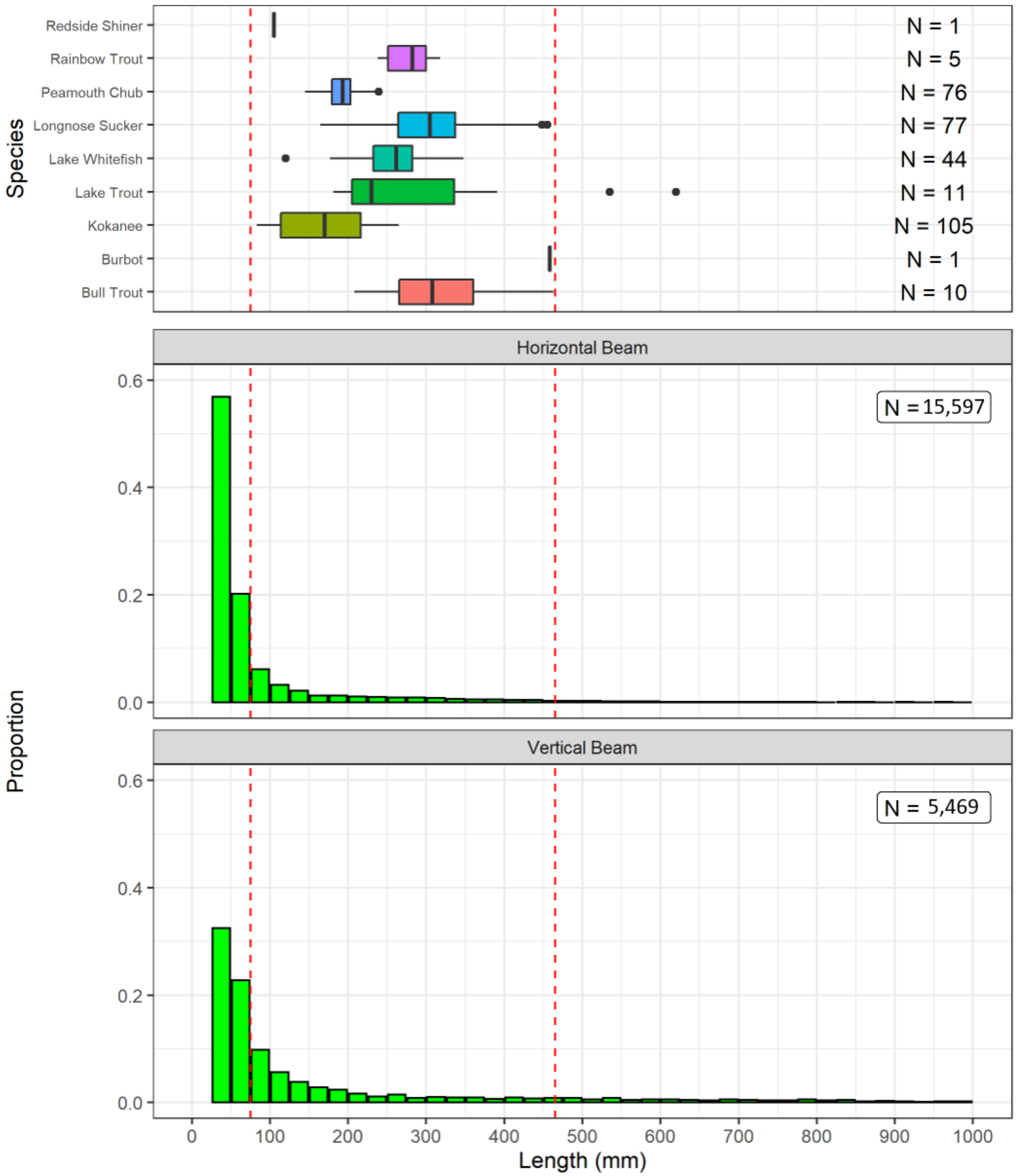

Figure 10: Length distribution of gill net catch (top) in forebay of Williston Reservoir and length distribution of targets detected by the horizontal and vertical beams during 2020 sampling. Vertical dashed lines indicated boundaries used to delineate small (<75 mm), medium (75 – 465 mm), and large fish (>465 mm).

3.3 Daily Entrainment

All data presented to this point are based on data collected over the entire monitoring period including times when the gates were closed. The following section will focus on data collected only when gates were open, beginning with an evaluation of horizontal movements for classifying entrainment.

Analysis of the direction of travel of all targets showed a median of approximately 15º for all fish. This was therefore set as the true direction of the spill gate relative to the position of the transducers. Based on this, any targets with a direction of travel of 15º ± 90º were considered to be entrained (shown as the areas in red in Figure 11). All fish traveling outside of this range were thought to have escaped entrainment. Of the 15,597 tracks detected by the vertical beam, 14,108 tracks were observed when the gates were open, and of 5,469 tracks detected by the horizontal beam, 5,108 tracks were observed when the gates were open. Based on the above criteria, 87.5% and 82.5% of the detected tracks in the vertical and horizontal beam were moving towards the gate when it was open (Figure 11).

Each fish track detected during the spill event was assigned a weight that was used as an indication of the number of fish that would have been detected if the entire width of the spill bay were covered by the acoustic beam. This methodology allowed for the extrapolation of the data to the areas not sampled and provided an estimate of total fish entrainment during the 2020 spill event. Figure 12 shows the estimated cumulative entrainment rates for each day that was monitored by hydroacoustics. Over the duration of hydroacoustic monitoring an estimated 806,964 fish were entrained (see further below the entrainment estimate for the entire spill period in Section 3.2.2). Data from the horizontal beam accounted for a nearly equivalent number of entrained fish (404,764) compared to the vertical beam (402,199) in about a quarter of the total gate area (Figure 12). This observation was consistent with catch data which found a higher catch rate in the top 5 meters of the water column, supporting the early conclusion that fish density declines with depth.

The vast majority of the entrained fish had an estimated length of less than 75 mm with medium and large-sized fish combined accounting for only 12% of entrained fish. This trend was even more skewed towards small fish in the horizontal beam where 95% of entrained fish belonging to the small size category. Large fish (> 465 mm) were almost exclusively detected in the vertical beam (Figure 10) with only 60 of the 6,838 entrained large fish being observed in the horizontal beam. This bias was also observed with regards to medium-sized fish, however, the difference was less dramatic with only about three times as many medium-sized fish being observed in the vertical beam compared to the horizontal beam. A summary of daily entrainment numbers and corresponding size class information can be found in Appendix C.

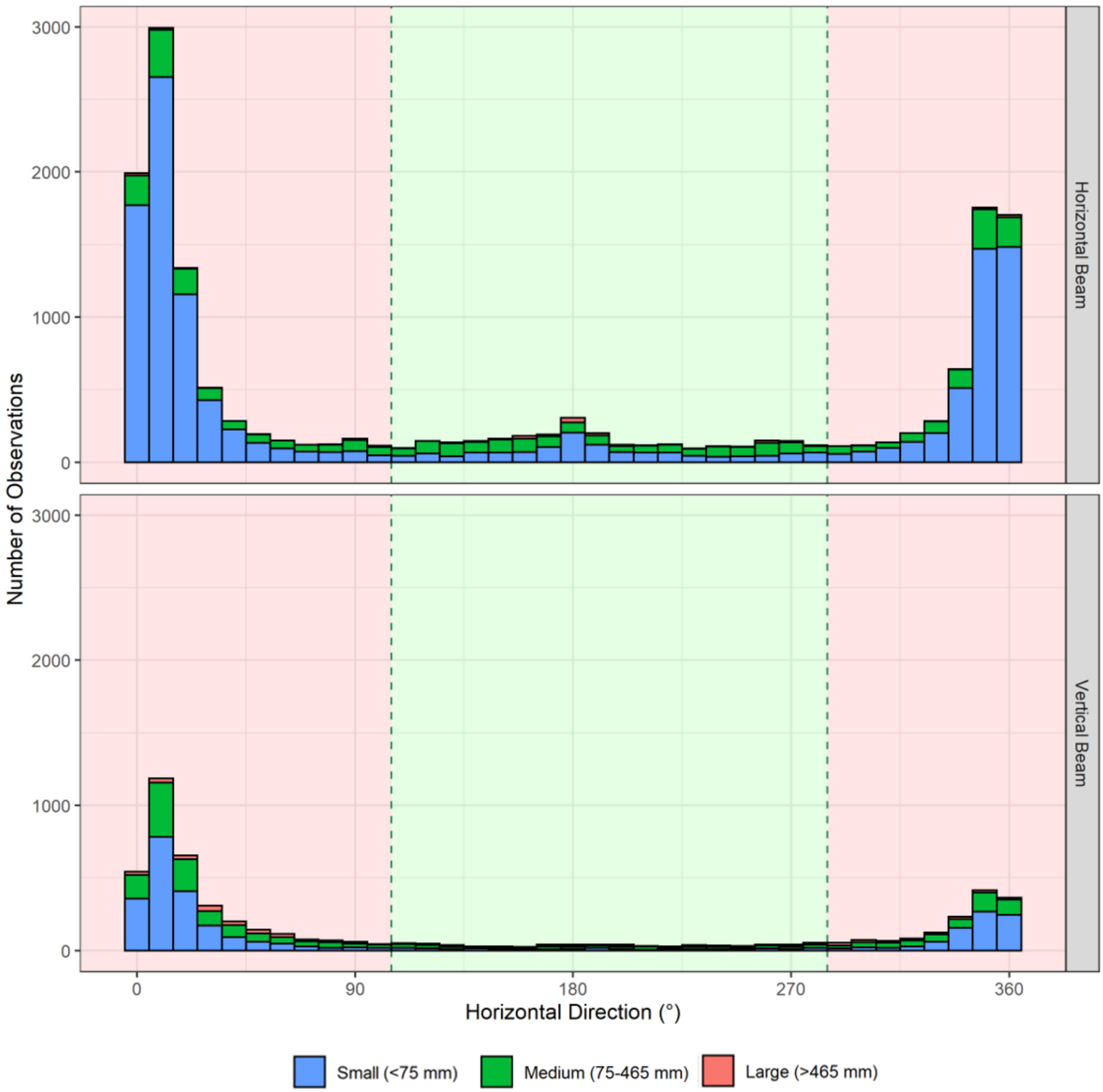

Figure 11: Horizontal direction of fish tracks detected in the horizontal versus vertical beam at W.A.C. Bennet Dam Spillway. Areas shaded in red indicate fish that were considered to be entrained based on their direction of travel (15º ± 90º). Green areas indicate fish moving away from the spill gate. Includes only data collected when gates were open between 22 July to 1 September 2020.

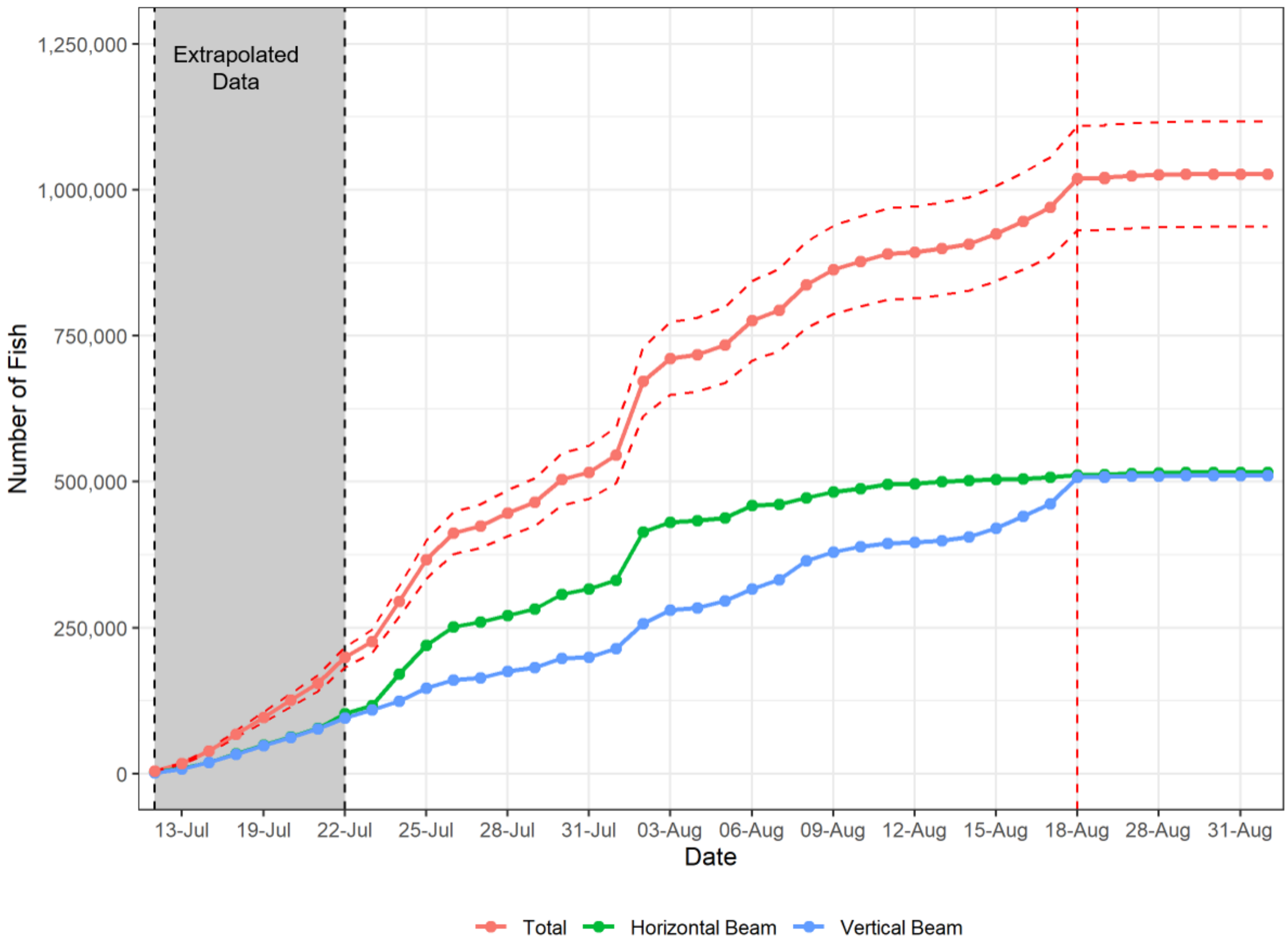

Figure 12: Cumulative entrainment between 12 July and 2 September 2020, with gate variance applied to total entrainment estimates (red lines). Area in grey indicates extrapolated entrainment estimates for days that were not monitored by hydroacoustics. Vertical dashed red line indicates the timepoint spill gates were closed from 19 to 26 August.

Due to the limited range of flow rates observed during the spill the focus was then to evaluate variability in entrainment rates over the relatively constant flow rate, expanding on previous attempts to quantify the relationship between flow rate and fish entrainment (Ebel 1996, BioSonics 2012). Although the flow rate remained relatively constant throughout the monitoring period a high degree of variability was observed in terms of the number of fish entrained per day. When considering only those days with a full 24 hours of data, the daily rate of entrainment ranged between 2,778 and 126,380 with a mean rate of 28,745 fish per day. Furthermore, three days (24 – 25 July, 2 August) accounted for greater than a third of the total fish entrained over the monitoring phase (Figure 12). A closer look at these days showed the increase in entrainment was due primarily to a large increase in the number of tracks observed in the vertical beam, resulting in an increase in the cumulative totals relative to the horizontal data. After 2 August, the entrainment rate in the vertical beam began to decrease and the total number of fish entrained started to level off. Alternatively, the entrainment rate in the horizontal beam appeared to remain relatively constant over this period and by August 18 the estimated numbers of fish entrained between the two beams were nearly identical.

The higher entrainment rate on 24 – 25 July and 2 August were primarily associated with the detection of large schools of fish passing through the acoustic beam over a relatively short period of time, lasting approximately 2-hours during each of the three days. This pattern did not appear to be related to observed environmental conditions (temperature, wind speed or direction), with the weather conditions during these spikes in entrainment being relatively consistent with times when entrainment was low (Government of Canada 2020). On 24 and 25 July, entrainment pulses occurred during sunrise or daylight hours exclusively. On 2 August, the spike in entrainment occurred around sunset. With the new moon phase occurring on 20 July and the full moon phase occurring on 3 August, there may be a potential relationship between fish entrainment and moon phase. However, this result should be interpreted as preliminary and further analysis and more data points are required to quantify this relationship.

Spill gates were closed between approximately 19 and 26 August, and therefore, no fish were entrained during this period. When spilling resumed on 26 August the spill was restricted to a 4-hour period between 10:00 and 14:00 hours. Between 27 and 28 August this window was extended to 6 hours (09:00 to 15:00) followed by an increase to 7 hours for the final 4 days of the spill event. During this portion of the monitoring period the number of fish entrained was low, contributing only 5,514 fish to the total entrainment numbers (Figure 12). This value is only about 9% of what would be predicted using the average rate of entrainment per hour for each hour interval the gates were open. The lower estimated entrainment over this period could be due to two factors: i) less fish being available for entrainment due to a decrease in fish density, and ii) the additional noise from the gates opening and closing could be causing fish to flee the area immediately surrounding the gate, reducing their probability of entrainment.

The most recent entrainment study at W.A.C. Bennett Dam by BioSonics (2012) developed an equation relating spill rate to the number of fish entrained and is shown in Equation 4. Based on the flow categories presented in that report, all observed flow rates during 2020 fell into the second category or level of spill rate sizes (of categories 1 – 5), which includes spill rates between 300 and 700 m^3/s. Using the Biosonics equation approximately 781 fish are expected to be entrained per hour. Applying this rate to the total number of hours monitored (661) produces a total entrainment of 516,241 fish, which is about 36% lower than the actual estimated number over the same period of time. However, some of this difference could be attributed to BioSonics (2012) relying on the deployment of vertically oriented transducers, resulting in upper portion of the water column being under-sampled, and subsequently, entrainment being underestimated.

To provide a direct comparison to the work done in 2012, total entrainment estimates for the 2020 monitoring period were also calculated using only the vertical data. The removal of the horizontal data and expanding the vertical data to account for the entire water column resulted in an estimated 510,316 entrained fish, a difference of only 5,925 fish compared to the predicted number based on the BioSonics equation. The consistency between these estimates provides confidence in the equation presented by BioSonics (2012) and suggests that without major fluctuations in the population of the Peace Arm of Williston Reservoir this equation provides a reasonable estimate for the number of fish entrained, at least in terms of the deeper strata that is adequately monitored by a vertically oriented transducer. However, this study shows that in the absence of a horizontally oriented transducer the entrainment rates in the upper strata may be underestimated and future studies with more variability in flow rates could look to further refine this equation to better quantify the relationship between flow rate and entrainment in the upper strata.

3.3.1 Diel Variation

Prior to extrapolating entrainment rates quantified from the hydroacoustic monitoring period to days or hours when the hydroacoustic data was not being collected, diel variation in entrainment rates was examined to provide insight on the potential effects of time of day on entrainment. A relatively large amount of natural variability was characterized when comparing the entrainment rate through the day (Figure 13). Ebel (1996) concluded that the highest rates of entrainment were observed during twilight hours, which was consistent with the findings of this study. In particular, the highest rates of entrainment were observed in the hours surrounding sunrise which ranged between 04:49 on 22 July and 06:10 on 2 September. Following this interval entrainment rates decline abruptly by 07:00 and this pattern was evident in both the horizontal and vertical data. Interestingly, this pattern did not extend to the hours surrounding sunset, which ranged between 21:29 and 19:53 over the monitoring period. A secondary peak in entrainment rates was seen in the vertical beam around mid-day which corresponded with a decrease in the rate of entrainment detected by the horizontal beam. This pattern suggests a shift in the spatial distribution of fish, which could be a result of increasing light levels causing fish to move deeper in the water column. Overall, entrainment rates were lower in the mid-afternoon and remained at a relatively constant level through the night, with any decrease in the entrainment rate in the horizontal beam often paired by an increase in the vertical beam, or vice versa.

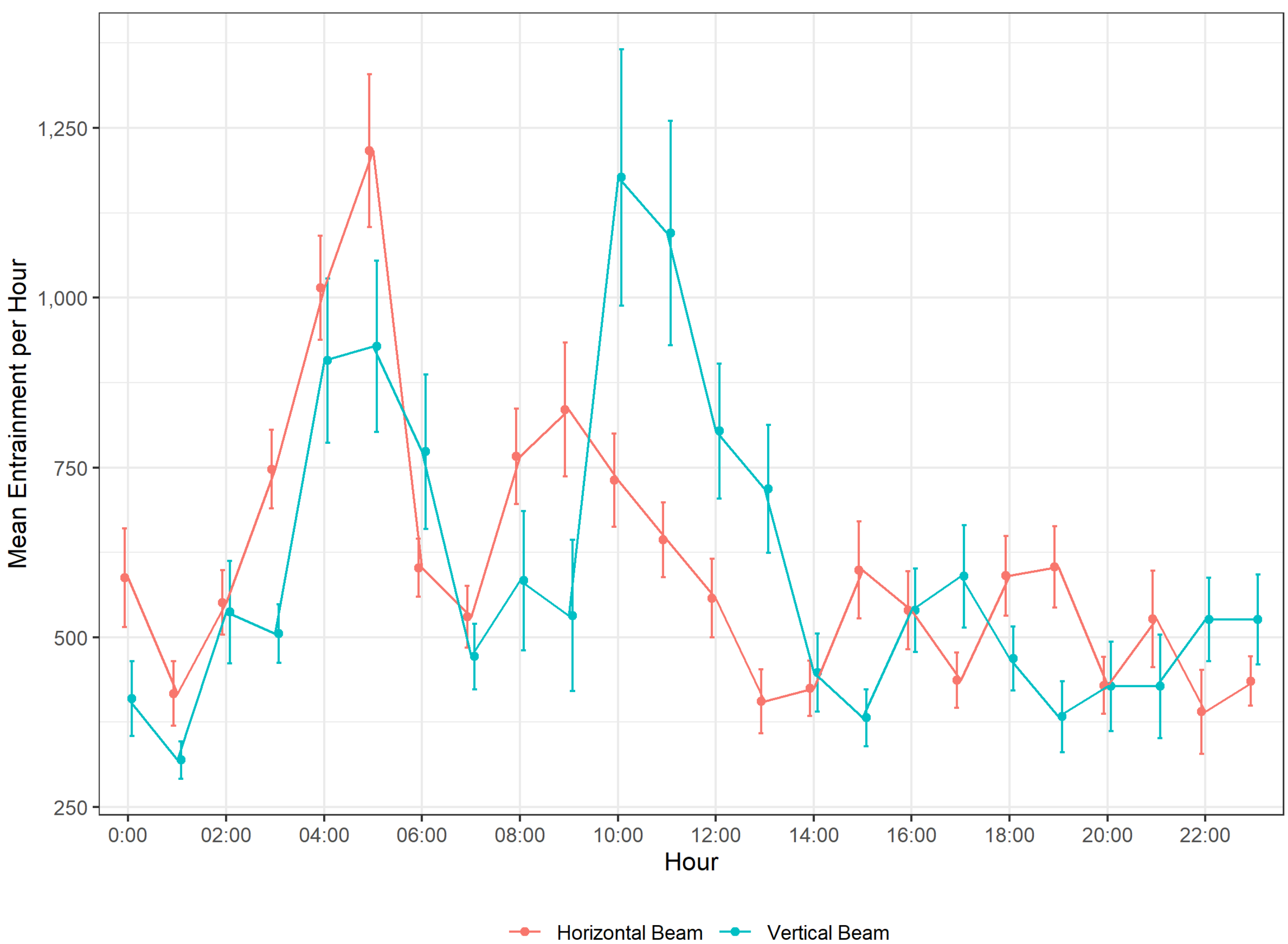

Figure 13: Mean diel (hourly) entrainment rates for vertical and horizontal beam data (with standard error bars) from W.A.C Bennett Dam spillway between 22 July – 2 September 2020.

Changes in the direction of travel from day to night were also visually assessed for the open gate period (Figure 14). Movements towards both deeper water (defined as orientations of less than 0°) and the gate (defined as orientations of 15º ± 90º) were more common during day-time versus night-time hours, which may reflect diel trends in the species and size composition of fish in the reservoir. There was a higher relative abundance of small-sized fish during day-time hours, and these smaller-sized fish may be more susceptible to the effects of the pull of the open gate current compared to larger fish (Figure 14).

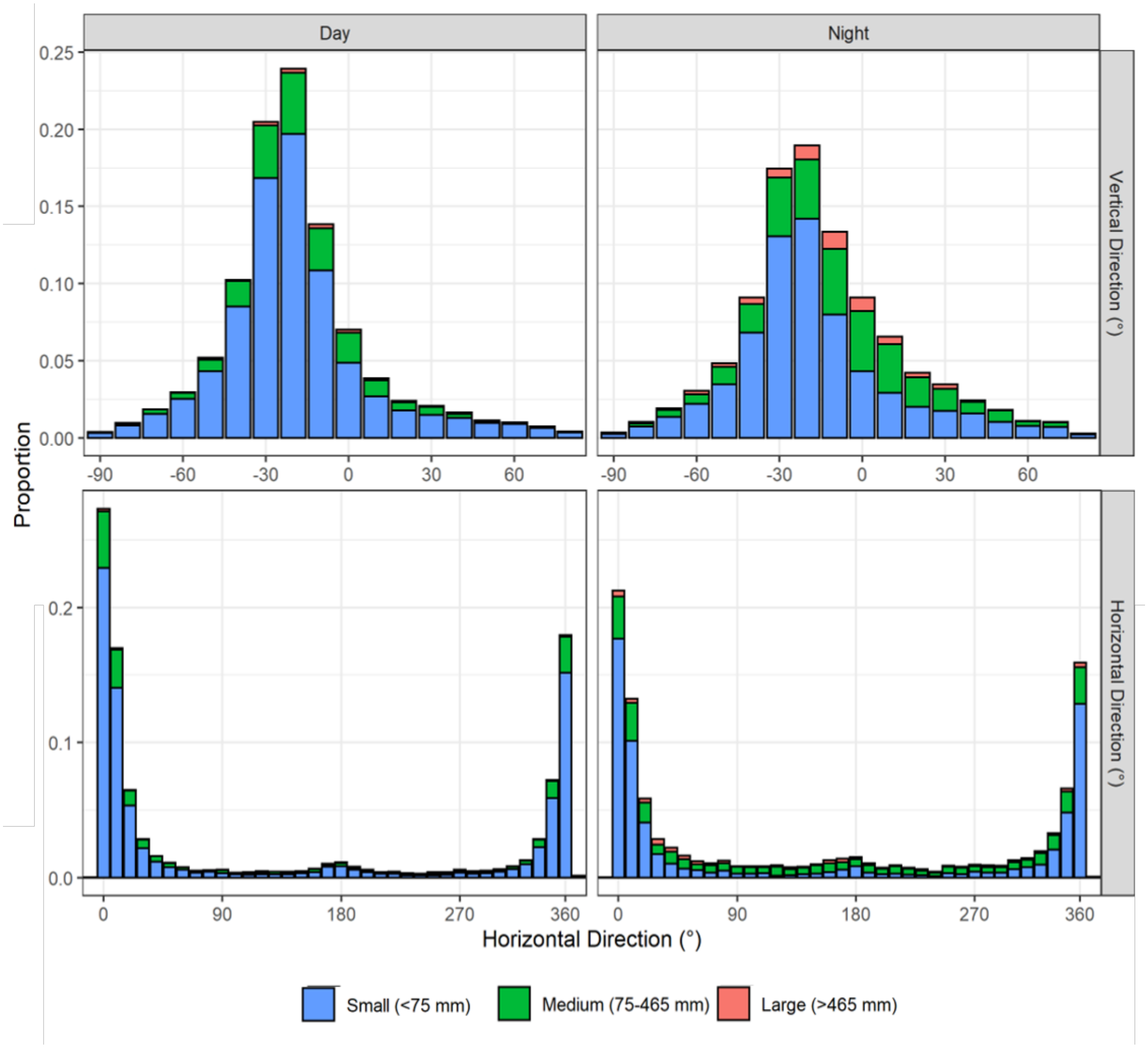

Figure 14: Direction of fish tracks detected when spill gates were open compared to closed during monitoring at W.A.C. Bennet Dam Spillway between 22 July to 1 September 2020. Vertical movements towards deeper water defined at angles of less 0°, whereas horizontal movements towards the gate were defined as 15º ± 90º.

3.3.2 Total Entrainment

A combined 180 hours of the spill was not monitored as the spill had already been in progress when the equipment was installed. Therefore, the above data in Figure 13 was extrapolated to cover this period in an effort to calculate the total entrainment associated with the 2020 spill event. The average entrainment rate was calculated for each hour of the day and these averages were used to estimate entrainment for each hour interval that was not sampled. The days with extrapolated data are shown in the grey region in Figure 12 and the average entrainment by hour is shown in Figure 13. These hourly averages were also used to fill the small gaps in data on 22 July and 29 July when technical issues prevented data collection. Based on these results an additional 250,314 fish were entrained during periods that were not directly monitored for a total of 1,057,278 fish entrained during the 2020 spill. Variance in entrainment estimates was derived from the gate variance reported in Biosonics (2012) as +/- 1 standard deviation of 93,323. This variance estimate provided a 95% confidence interval of approximately +/- 186,643 fish for the cumulative entrainment estimate (i.e., confidence limits of 870,632 to 1,243,924 fish). The total estimate included 931,116 small fish, 117,149 medium fish with the remaining 9,013 fish being categorized as large.

Gear limitations resulted in small sized fish not being captured during 2020 index netting, or in the previous two sampling events (Sebastian et al. 2008, Plate et al. 2012). Therefore, determining the species composition of the small fish that were entrained was not possible. However, based on previously reported age-length data this category was most likely composed of age 0+ Kokanee and Lake Whitefish, Peamouth chub up to age 2, and Redside Shiner. It is possible other forage fish species are present in the forebay area and contributed to a portion of the fish entrained but further apportionment would only be speculative for this size class.

The species composition of the medium-sized fish that were entrained was based off the relative species composition of the gillnet catch and the results can be found in Table 5. Longnose Sucker made up the majority of medium size fish captured (55.8%) and therefore accounted for 65,366 of the 117,149 medium sized fish entrained. Lake Whitefish were the next most abundant species and were estimated to make up 22,920 of the entrained fish in this category, followed by 14,431 Peamouth Chub and 7,640 Lake Trout. Finally, an estimated 3,396 Kokanee and 1,698 Bull Trout were entrained with the remainder being the other species captured in low numbers (Burbot, and possibly Rainbow Trout, although they were not captured in 2020). Lake Trout were the only large species to be captured, and therefore, all 9,013 of the large targets entrained were assigned to this species for a total estimate of 16,653 entrained Lake Trout between the two size classes.

Table 5: Relative species composition of medium-sized fish entrained between 12 July – 2 September 2020 at W.A.C. Bennett Dam spillway.

Species	Proportion of Catch	Number Entrained
Longnose Sucker	0.5580	65,366
Lake Whitefish	0.1957	22,920
Peamouth Chub	0.1232	14,431
Lake Trout	0.0652	7,640
Kokanee	0.0290	3,396
Bull Trout	0.014	1,698
Other	0.014	1,698
Total		117,149

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, though both monitoring years had roughly the same number of fish entrained in the vertical beam calculations. Differences in the fish catch may be best explained by sampling biases related to sampling gear and location, and the effects of which can be exacerbated by the challenges of capturing schooling fish in the reservoir such as Kokanee (i.e., you either catch a lot in a net or none) over a relatively short duration sampling program. Longer duration sampling in the reservoir would be recommended for subsequent monitoring of spill events.

The duration of the spill event under examination at the W.A.C. Bennett Dam was from 12 July to 2 September 2020 (43-day period where the gate was open for 841 hours). During the monitoring period, the spill rate remained relatively constant when gates were open, ranging from 522 – 670 m^3/s. A total of 779 hours of hydroacoustic data were recorded over this spill period by both the vertical and horizontal transducers mounted on the upstream pier of the center spill gate. The analysis of that data determined that most of the fish entrained (88%) during the 2020 spill period were less than 75 mm of length. It is assumed that these fish were a mix of age 0+ Kokanee and Lake Whitefish, Peamouth Chub up to age 2, and Redside Shiner.

Although the flow rate remained relatively constant throughout the monitoring period, a high degree of variability was observed in terms of the number of fish entrained per day. When considering only those days with a full 24 hours of data, the daily rate of entrainment ranged between 2,778 and 126,380 with a mean rate of 28,745 fish per day. Furthermore, three days (24, 25 July and 2 August) accounted for greater than a third of the total fish entrained over the monitoring phase. These peaks in daily entrainment numbers were associated with the detection of large schools of small fish being detected in the vertical beam.

Hourly entrainment rates also showed a high degree of variability, with hourly rates varying by more than six-times through the day. The highest rates of entrainment were observed in the hours surrounding sunrise which ranged between 04:49 on 22 July and 06:10 on 2 September. Entrainment rates decline abruptly by 07:00 following this interval, and the pattern was evident in both the horizontal and vertical data. A secondary peak in entrainment rates was noted during late morning hours. Entrainment rates were relatively low through late afternoon into the early evening hours.

Despite differences in catch data across monitoring years, consistent levels of entrainment were estimated in 2020 compared to 2012 when relying only on data collected from the vertical transducer. The consistency between estimates provides confidence in the equation presented by BioSonics (2012) in providing precise estimates for the number of fish entrained during a spilling period, with the caveat that the equation underestimates entrainment of fish in the upper depth strata, as demonstrated by this study. If there is an opportunity during the next monitoring effort, it is recommended that data be collected from both horizontal and vertical transducers under a range of flow conditions to expand the utility of the Biosonics equation for forecasting entrainment without the need for hydroacoustic monitoring.

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.

Golder Associates Ltd.

Original Signed by

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MT/CS/cmc/tt

https://golderassociates.sharepoint.com/sites/131918/project files/6 deliverables/issued to client_for wp/20149134-002-r-rev0/20149134-002-r-rev0-bc hydro fish entrainment 09jun_21 v2.docx

6.0 REFERENCES

Barrett, D.T., and T.G. Halsey. 1985. Fisheries resources and fisheries potential of Williston reservoir and its Tributary Streams. Vol. 1 Fisheries resources and fisheries potential of Williston reservoir. Fisheries Tech. Circular 68, Ministry of Environment.

BC Hydro 2002. Peace River Generation spill 2002. Environmental Information Summary Report. August 26, 2002.

BC Hydro 2003. Consultant committee report: Peace River water use plan. Prepared by the Peace River water use plan consultative committee.

BC Hydro. 2008. Peace Project Water Use Plan. Monitoring Program Terms of Reference, Peace Spill Protocol. GMSMON-4 WAC Bennett Dam Entrainment.

Biosonics. 2012. Monitoring Program No GMSMON-4 WAC Bennett Dam Entrainment, Reference No. EC12-465080. Project Final Report: December 31, 2012. Submitted to: BC Hydro and Power Authority, 6911 Southpoint Drive (E16), Burnaby, BC, V3N 4X8, Canada: 87 pp.

Blackman, B.G. 1992. Fisheries resources of Williston reservoir twenty years after impoundment. B.C. Environment Fisheries Branch and B.C. Hydro Environmental Resources.

Ebel, C.J. 1996. WAC Bennett Dam Spillway Hydroacoustic Monitoring Feasibility Study, August 1996. Final Report. BioSonics, Inc. Seattle, WA.

Government of British Columbia. 2020. BC Species and Ecosystems Explorer. Available online at: https://a100.gov.bc.ca/pub/eswp/. Accessed December 2020.

Government of Canada. 2020. Species at Risk Public Registry. Available online at: https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html. Accessed December 2020.

Government of Canada. 2020. Historical Climate Data. Available online at: https://climate.weather.gc.ca/historical_data/search_historic_data_e.html. Accessed January 2021.

Hamley, J.M. 1972. Sampling with gillnets. In: Guidelines for sampling fish in inland waters. Edited by T. Backiel and R.L. Welcomme. EIFAC 1980 Tech. Pap. (33):176 p.

Langston, A. R. and E. B. Murphy. 2008. The History of Fish Introductions (to 2005) in the Peace/Williston Fish and Wildlife Compensation Program Area. Peace/ Williston Fish and Wildlife Compensation Program Report No. 325. 59p.

LGL. 2012. Peace Project Water Use Plan: Monitoring Programs for the Peace Spill Protocol (GMSMON-4 WAC Bennett Dam Entrainment Study). Williston Fish Index in the Vicinity of W.A.C Bennett Dam.

McPhail, J. D. 2007. The Freshwater Fishes of British Columbia. University of Alberta Press, Edmonton Alberta. 620p.

Love, R. H. (1977). Target strength of an individual fish at any aspect. *Journal of the Acoustical Society of America, 62*(6), 1397-1403. doi:10.1121/1.381672

MOE (British Columbia Ministry of Environment). 2020. Fish Inventories Data Queries. Data accessed using Williston Lake single waterbody query available at: http://a100.gov.bc.ca/pub/fidq/infoSingleWaterbody.do. Accessed December 2020.

Parker-Stetter, S. L., Rudstam, L. G., Sullivan, P. J., & Warner, D. M. (2009). Standard operating procedures for fisheries acoustic surveys in the great lakes.

Plate, E.P. 2007. An investigation of the fish populations, zooplankton communities and fish diet in Red Red Bluff and Batchellor Lakes in 2007. Prepared for the Gitga'at Development Corporation and Pacific Salmon Commission.

Plate, E.M., R.C. Bocking, & D.J. Degan. 2012. An index of fish distribution and abundance in the Peace Arm of Williston Reservoir close to W.A.C. Bennett Dam based on hydroacoustic and gillnet surveys. Peace Project Water Use Plan: Monitoring Programs for the Peace Spill Protocol (GMSMON-4 WAC Bennett Dam Entrainment Study). Williston Fish Index in the Vicinity of W.A.C. Bennett Dam. Prepared for BC Hydro by LGL Limited, Sidney, BC, and Aquacoustics Inc, Sterling, AK.

Scott, W. B., & Crossman, E. J. (1998). *Freshwater fishes of canada*. Oakville, Ont. Canada: Galt House Publications Ltd.

Sebastian, D.C., G.H. Scholten, P.E.Woodruff. 2003. Williston Reservoir Fish Assessment: Results of Hydroacoustic, Trawl and Gill Net Surveys in August, 2000. Province of British Columbia Ministry of Water Land and Air Protection.

Sebastian, D, G. Andrusak, G. Scholten and A. Langston. 2008. An index of fish distribution and abundance in Peace Arm of Williston Reservoir based on hydroacoustic and gillnet surveys. BC Hydro, Peace Project Water Use Plan. Williston Fish Index, Reference: GMSMON #13.

Simmonds, E. J., & MacLennan, D. N. (2005). *Fisheries acoustics* (2nd ed.). Oxford: Blackwell Science.

Stockner, J., Langston, A.R., Sebastian D.H. and G. Wilson. 2005. The Limnology of Williston Reservoir: British Columbia's Largest Lacustrine Ecosystem. Water Quality Research Journal of Canada 40: 28–50.

APPENDIX A

Transducer Beam Patterns

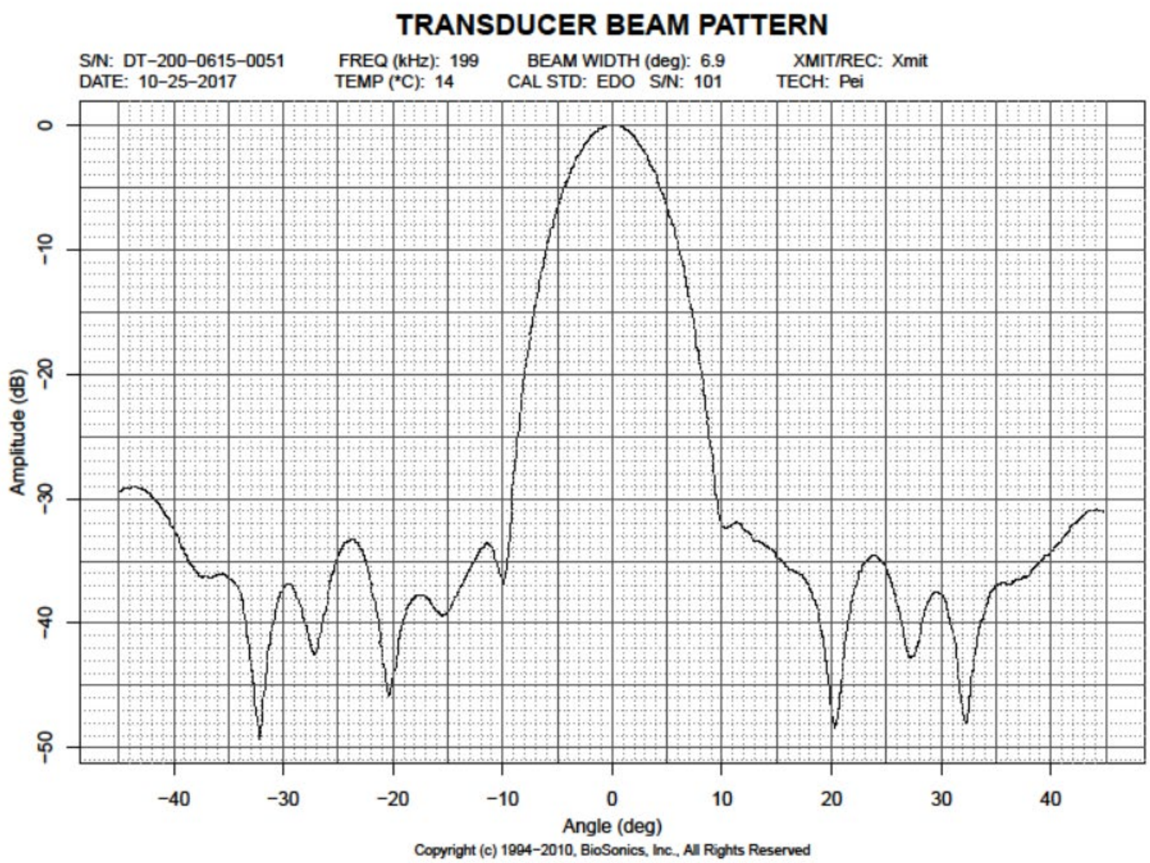

Figure A1. Beam pattern for the 199 kHz transducer mounted horizontally at W.A.C. Bennett Dam central spill gate between 22 July and 2 September.

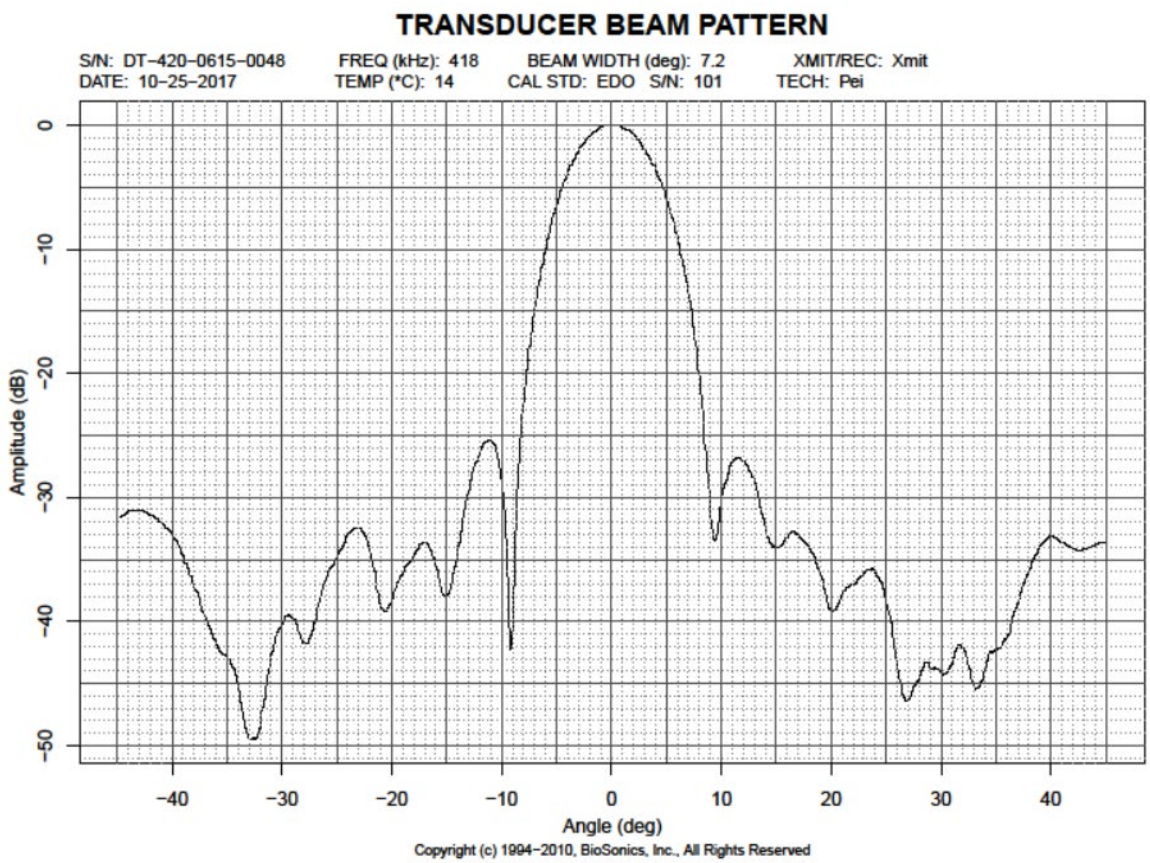

Figure A2. Beam pattern for the 418 kHz transducer mounted vertically at W.A.C. Bennett Dam central spill gate between 22 July and 2 September.

APPENDIX B

Fish Track Data

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
16	2020-07-22	0	0	0	0	0	0	0	670
17	2020-07-22	1846	26	0	4168	1475	0	7515	670
18	2020-07-22	2379	28	0	2878	432	0	5717	670
19	2020-07-22	1377	9	0	2696	400	27	4508	670
20	2020-07-22	567	0	0	777	170	0	1514	670
Total	2020-07-22	6168	63	0	10518	2477	27	19254	
10	2020-07-23	998	62	0	864	208	0	2132	670
11	2020-07-23	562	0	0	0	232	0	794	670
12	2020-07-23	0	0	0	0	0	0	0	670
13	2020-07-23	0	0	0	0	0	0	0	670
14	2020-07-23	0	0	0	0	0	0	0	670
15	2020-07-23	7	7	0	0	51	60	125	670
16	2020-07-23	468	0	0	128	0	0	595	670
17	2020-07-23	194	32	0	154	28	0	407	670
18	2020-07-23	406	36	0	1150	63	31	1686	670
19	2020-07-23	3503	46	0	2140	263	0	5953	670
20	2020-07-23	1250	8	0	125	0	25	1408	670
21	2020-07-23	449	0	0	0	91	0	540	670
22	2020-07-23	42	0	0	0	414	29	486	670
23	2020-07-23	74	6	0	108	91	124	402	670
Total	2020-07-23	7953	197	0	4669	1441	269	14529	
0	2020-07-24	252	0	0	223	0	43	518	670
1	2020-07-24	222	0	2	213	360	113	911	670
2	2020-07-24	130	0	0	439	8	56	633	670
3	2020-07-24	292	17	0	468	175	109	1061	670
4	2020-07-24	1919	61	0	5275	1789	111	9155	670
5	2020-07-24	2132	3	0	7153	642	0	9932	670
6	2020-07-24	1655	26	0	2324	15	0	4019	670
7	2020-07-24	251	0	0	1264	153	87	1755	670
8	2020-07-24	102	20	0	46	93	0	260	670
9	2020-07-24	184	0	0	59	0	0	243	670
10	2020-07-24	1517	108	0	7852	167	0	9643	670
11	2020-07-24	2851	75	0	8192	519	0	11637	670
12	2020-07-24	1337	9	0	4771	916	0	7032	670
13	2020-07-24	381	9	0	4011	276	0	4677	670
14	2020-07-24	82	15	0	135	0	0	233	670
15	2020-07-24	54	0	0	407	0	0	461	670
16	2020-07-24	238	20	0	1298	62	0	1617	670
17	2020-07-24	164	0	0	1603	139	0	1906	670
18	2020-07-24	26	0	0	527	167	0	720	670
19	2020-07-24	0	0	0	90	0	0	90	670
20	2020-07-24	0	13	0	279	30	0	322	670
21	2020-07-24	42	0	0	566	0	40	648	670
22	2020-07-24	105	0	0	177	45	275	602	670
23	2020-07-24	138	26	0	101	108	114	487	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
Total	2020-07-24	14074	401	2	47473	5664	948	68562	
0	2020-07-25	42	10	0	0	231	200	483	670
1	2020-07-25	0	2	0	47	201	25	275	670
2	2020-07-25	1717	64	0	4401	853	112	7147	670
3	2020-07-25	64	0	0	141	337	0	542	670
4	2020-07-25	1675	51	0	144	460	41	2371	670
5	2020-07-25	1309	95	0	767	59	0	2230	670
6	2020-07-25	215	0	0	445	187	0	847	670
7	2020-07-25	182	131	0	412	159	0	885	670
8	2020-07-25	2465	427	9	5169	2194	93	10356	670
9	2020-07-25	4045	453	0	6970	2668	64	14201	670
10	2020-07-25	4348	211	0	10431	3334	114	18438	670
11	2020-07-25	1673	96	0	2209	680	38	4695	670
12	2020-07-25	842	3	0	0	91	0	936	670
13	2020-07-25	154	18	0	0	0	0	173	670
14	2020-07-25	766	56	0	691	323	33	1868	670
15	2020-07-25	281	4	0	309	140	0	734	670
16	2020-07-25	556	1	0	473	220	37	1287	670
17	2020-07-25	533	0	0	499	130	0	1162	670
18	2020-07-25	96	0	0	1410	68	0	1574	670
19	2020-07-25	0	0	0	241	71	0	312	670
20	2020-07-25	55	0	0	121	0	0	176	670
21	2020-07-25	198	11	0	103	47	0	360	670
22	2020-07-25	62	17	0	126	165	31	400	670
23	2020-07-25	76	0	0	289	66	61	493	670
Total	2020-07-25	21356	1651	9	35396	12684	849	71945	
0	2020-07-26	77	23	0	109	0	26	235	670
1	2020-07-26	44	0	0	261	45	26	376	670
2	2020-07-26	1	72	0	169	43	0	286	670
3	2020-07-26	387	1	0	629	345	0	1362	670
4	2020-07-26	131	0	0	746	24	0	901	670
5	2020-07-26	674	22	0	302	51	0	1048	670
6	2020-07-26	83	0	16	0	108	0	208	670
7	2020-07-26	360	51	0	584	55	0	1050	670
8	2020-07-26	104	8	0	501	73	0	685	670
9	2020-07-26	22	0	0	108	0	0	129	670
10	2020-07-26	67	16	0	236	0	28	346	670
11	2020-07-26	2131	60	0	2337	576	23	5128	670
12	2020-07-26	1303	39	0	6120	493	0	7956	670
13	2020-07-26	717	0	0	6363	1412	91	8583	670
14	2020-07-26	1418	21	0	1261	289	0	2989	670
15	2020-07-26	1727	45	0	1905	287	0	3964	670
16	2020-07-26	1086	0	0	1183	215	0	2484	670
17	2020-07-26	156	0	0	261	106	0	523	670
18	2020-07-26	60	13	0	218	62	0	353	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
19	2020-07-26	12	0	3	336	0	0	350	670
20	2020-07-26	0	0	0	0	0	0	0	670
21	2020-07-26	265	0	0	610	60	0	935	670
22	2020-07-26	593	0	0	1061	84	71	1808	670
23	2020-07-26	1754	84	0	1423	211	85	3556	670
Total	2020-07-26	13171	456	19	26722	4539	349	45257	
0	2020-07-27	249	0	0	88	1	0	339	670
1	2020-07-27	41	28	3	196	75	0	343	670
2	2020-07-27	15	23	0	0	41	72	151	670
3	2020-07-27	79	0	0	84	274	0	437	670
4	2020-07-27	22	0	0	308	0	68	398	670
5	2020-07-27	49	16	0	0	0	0	65	670
6	2020-07-27	60	21	0	102	60	0	243	670
7	2020-07-27	345	0	0	192	221	0	758	670
8	2020-07-27	443	8	0	996	206	0	1653	670
9	2020-07-27	527	0	0	344	98	0	970	670
10	2020-07-27	82	0	0	76	43	0	201	670
11	2020-07-27	166	28	0	608	72	0	873	670
12	2020-07-27	17	0	0	84	32	0	133	670
13	2020-07-27	10	0	0	135	0	0	145	670
14	2020-07-27	100	9	0	443	56	0	608	670
15	2020-07-27	480	7	0	1428	180	22	2118	670
16	2020-07-27	59	30	0	630	126	0	845	670
17	2020-07-27	57	0	0	338	403	0	798	670
18	2020-07-27	62	0	0	0	50	0	111	670
19	2020-07-27	0	11	0	0	0	0	11	670
20	2020-07-27	12	0	0	0	0	0	12	670
21	2020-07-27	152	0	0	93	30	0	275	670
22	2020-07-27	171	0	0	62	0	0	233	670
23	2020-07-27	718	0	0	294	75	0	1086	670
Total	2020-07-27	3915	181	3	6502	2043	163	12805	
0	2020-07-28	4	0	0	50	42	30	126	670
1	2020-07-28	191	0	0	102	75	0	368	670
2	2020-07-28	28	0	0	0	197	30	255	670
3	2020-07-28	288	0	0	1296	383	0	1967	670
4	2020-07-28	3149	85	6	2092	669	0	6000	670
5	2020-07-28	4990	84	0	712	0	0	5786	670
6	2020-07-28	566	17	0	271	103	0	957	670
7	2020-07-28	181	0	0	437	151	84	853	670
8	2020-07-28	238	0	0	147	33	0	418	670
9	2020-07-28	225	9	0	0	0	0	234	670
10	2020-07-28	215	21	0	102	0	0	337	670
11	2020-07-28	255	0	0	107	37	0	399	670
12	2020-07-28	13	0	0	675	69	0	757	670
13	2020-07-28	119	0	0	608	5	0	732	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
14	2020-07-28	42	8	0	379	111	0	540	670
15	2020-07-28	0	0	0	0	0	0	0	670
16	2020-07-28	9	2	0	552	380	0	942	670
17	2020-07-28	87	11	0	330	75	0	504	670
18	2020-07-28	0	0	0	75	0	0	75	670
19	2020-07-28	11	9	0	88	0	0	108	670
20	2020-07-28	0	0	0	130	0	0	130	670
21	2020-07-28	130	0	0	0	33	2	165	670
22	2020-07-28	262	0	0	0	134	83	479	670
23	2020-07-28	37	6	0	77	141	33	294	670
Total	2020-07-28	11039	252	6	8230	2639	263	22429	
0	2020-07-29	36	20	0	0	115	0	172	670
1	2020-07-29	2	0	0	274	31	0	307	670
2	2020-07-29	57	0	0	201	0	0	258	670
3	2020-07-29	78	0	0	149	75	0	303	670
4	2020-07-29	329	13	0	131	0	0	473	670
5	2020-07-29	398	8	0	837	25	0	1269	670
6	2020-07-29	902	25	0	1447	120	0	2495	670
7	2020-07-29	886	8	0	1719	74	0	2687	670
8	2020-07-29	88	0	0	829	103	0	1020	670
9	2020-07-29	0	9	0	394	35	0	438	670
10	2020-07-29	41	0	0	501	0	0	542	670
11	2020-07-29	0	0	0	157	66	0	223	670
12	2020-07-29	16	0	0	0	62	0	79	670
13	2020-07-29	41	0	0	0	0	0	41	670
14	2020-07-29	63	0	0	485	59	0	607	670
15	2020-07-29	0	0	0	0	0	0	0	670
Total	2020-07-29	2938	84	0	7124	765	0	10912	
12	2020-07-30	0	0	0	1616	31	0	1647	
13	2020-07-30	204	18	0	1886	121	0	2230	670
14	2020-07-30	842	22	0	442	286	0	1593	670
15	2020-07-30	311	7	7	517	90	0	932	670
16	2020-07-30	1552	110	0	2081	347	0	4090	670
17	2020-07-30	131	0	0	1190	34	0	1355	670
18	2020-07-30	199	23	0	728	258	0	1208	670
19	2020-07-30	1432	20	0	1432	452	0	3336	670
20	2020-07-30	663	11	0	1489	198	0	2361	670
21	2020-07-30	227	21	0	265	58	0	571	670
22	2020-07-30	97	0	0	818	57	57	1029	670
23	2020-07-30	356	0	0	514	119	60	1049	670
Total	2020-07-30	8951	316	7	20102	2818	117	32312	
0	2020-07-31	354	0	0	218	375	0	947	670
1	2020-07-31	426	26	0	132	26	22	631	670
2	2020-07-31	90	0	0	0	327	0	417	670
3	2020-07-31	324	0	11	127	174	26	662	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
4	2020-07-31	284	0	0	224	184	162	853	670
5	2020-07-31	195	0	0	315	177	50	737	670
6	2020-07-31	65	29	0	104	134	0	332	670
7	2020-07-31	24	0	0	152	26	0	201	670
8	2020-07-31	47	0	0	442	0	0	489	670
9	2020-07-31	0	0	0	0	62	0	62	670
10	2020-07-31	0	0	0	163	0	0	163	670
11	2020-07-31	48	8	0	52	0	0	108	670
12	2020-07-31	87	0	0	0	0	0	87	670
13	2020-07-31	40	0	0	93	47	0	180	670
14	2020-07-31	0	0	0	74	0	0	74	670
15	2020-07-31	0	0	0	80	0	0	80	670
16	2020-07-31	10	0	0	0	34	0	44	670
17	2020-07-31	0	0	0	0	0	0	0	670
18	2020-07-31	0	0	0	0	0	0	0	670
19	2020-07-31	0	9	0	0	0	0	9	670
20	2020-07-31	188	0	0	0	0	0	188	670
21	2020-07-31	44	1	0	162	96	42	346	670
22	2020-07-31	46	0	0	1078	194	94	1413	670
23	2020-07-31	332	0	0	2643	1629	92	4695	670
Total	2020-07-31	2604	73	11	6059	3485	487	12719	
0	2020-08-01	607	29	0	301	111	30	1078	670
1	2020-08-01	389	28	0	275	112	30	834	670
2	2020-08-01	554	33	1	264	173	27	1052	670
3	2020-08-01	802	51	1	504	120	32	1510	670
4	2020-08-01	1213	42	1	624	142	39	2061	670
5	2020-08-01	757	35	0	722	201	21	1736	670
6	2020-08-01	531	37	0	713	80	9	1370	670
7	2020-08-01	401	39	0	334	56	7	837	670
8	2020-08-01	883	69	0	464	142	6	1564	670
9	2020-08-01	766	66	1	512	123	6	1474	670
10	2020-08-01	664	60	0	997	146	3	1870	670
11	2020-08-01	579	31	0	931	171	3	1715	670
12	2020-08-01	347	19	0	687	58	6	1117	670
13	2020-08-01	376	18	0	726	101	6	1227	670
14	2020-08-01	402	27	0	351	43	5	828	670
15	2020-08-01	555	22	0	331	74	4	986	670
16	2020-08-01	377	18	1	413	70	4	883	670
17	2020-08-01	524	19	0	502	92	4	1141	670
18	2020-08-01	603	18	0	374	71	2	1068	670
19	2020-08-01	619	14	0	303	81	6	1023	670
20	2020-08-01	435	33	1	418	53	2	942	670
21	2020-08-01	606	39	1	296	102	9	1053	670
22	2020-08-01	471	20	1	333	154	37	1016	670
23	2020-08-01	441	41	1	277	125	44	929	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
Total	2020-08-01	13901	808	9	11652	2601	342	29313	
0	2020-08-02	4736	46	4	2286	419	23	7515	670
1	2020-08-02	2973	168	0	1528	443	36	5149	670
2	2020-08-02	1703	58	0	1315	388	91	3555	670
3	2020-08-02	1919	55	0	2333	204	48	4559	670
4	2020-08-02	2254	29	0	4101	267	112	6764	670
5	2020-08-02	6296	168	0	3517	591	107	10679	670
6	2020-08-02	1749	10	0	1275	105	55	3195	670
7	2020-08-02	1094	61	3	1111	64	0	2333	670
8	2020-08-02	1379	0	0	811	176	0	2367	670
9	2020-08-02	1054	4	0	2907	305	0	4270	670
10	2020-08-02	2566	58	0	7944	1059	0	11626	670
11	2020-08-02	1777	163	0	11784	1589	64	15377	670
12	2020-08-02	282	9	0	3670	435	0	4395	670
13	2020-08-02	335	0	0	2867	483	40	3725	670
14	2020-08-02	725	126	0	4870	537	0	6257	670
15	2020-08-02	808	0	0	2819	0	0	3627	670
16	2020-08-02	154	3	0	767	106	0	1030	670
17	2020-08-02	337	0	0	963	109	0	1408	670
18	2020-08-02	761	44	1	837	123	0	1766	670
19	2020-08-02	379	0	0	249	341	0	969	670
20	2020-08-02	952	0	0	4077	690	0	5718	670
21	2020-08-02	2936	65	0	4608	860	0	8468	670
22	2020-08-02	4372	123	0	4244	120	24	8883	670
23	2020-08-02	520	0	0	1758	460	47	2784	670
Total	2020-08-02	42062	1189	9	72640	9874	647	126421	
0	2020-08-03	2617	193	0	2712	386	154	6061	670
1	2020-08-03	1297	4	0	526	184	18	2029	670
2	2020-08-03	2647	125	0	680	70	123	3645	670
3	2020-08-03	2092	41	0	1192	174	0	3499	670
4	2020-08-03	238	21	0	657	144	47	1106	670
5	2020-08-03	790	69	0	629	442	30	1960	670
6	2020-08-03	336	18	0	2033	49	24	2460	670
7	2020-08-03	113	0	0	90	0	0	203	670
8	2020-08-03	207	18	0	37	51	0	313	670
9	2020-08-03	522	22	0	0	0	0	544	670
10	2020-08-03	116	0	0	110	49	0	275	670
11	2020-08-03	556	0	0	383	52	0	991	670
12	2020-08-03	2974	52	0	510	80	0	3617	670
13	2020-08-03	2446	38	0	1791	105	0	4380	670
14	2020-08-03	1194	13	0	459	43	0	1710	670
15	2020-08-03	1950	19	0	158	60	0	2187	670
16	2020-08-03	442	10	0	402	48	0	902	670
17	2020-08-03	275	0	0	619	33	0	927	670
18	2020-08-03	417	0	0	0	53	21	491	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
19	2020-08-03	294	0	0	213	59	0	566	670
20	2020-08-03	213	90	0	0	78	17	398	670
21	2020-08-03	99	3	1	102	40	22	268	670
22	2020-08-03	167	0	0	69	268	0	503	670
23	2020-08-03	313	35	0	17	118	39	521	670
Total	2020-08-03	22316	770	1	13389	2588	494	39558	
0	2020-08-04	278	0	0	61	279	7	625	670
1	2020-08-04	374	96	0	0	140	20	630	670
2	2020-08-04	404	0	0	181	183	0	767	670
3	2020-08-04	291	70	6	425	93	160	1044	670
4	2020-08-04	404	0	0	232	0	69	705	670
5	2020-08-04	140	22	0	0	68	0	230	670
6	2020-08-04	19	35	0	0	0	0	55	670
7	2020-08-04	95	8	0	0	0	0	103	670
8	2020-08-04	114	12	4	0	0	0	130	670
9	2020-08-04	93	0	0	122	0	0	215	670
10	2020-08-04	76	26	0	0	0	0	102	670
11	2020-08-04	56	0	0	0	0	0	56	670
12	2020-08-04	116	16	0	0	0	0	132	670
13	2020-08-04	165	14	0	0	0	0	178	670
14	2020-08-04	216	29	4	114	235	0	598	670
15	2020-08-04	144	0	0	0	0	0	144	670
16	2020-08-04	190	0	0	0	0	0	190	670
17	2020-08-04	55	0	0	0	0	0	55	670
18	2020-08-04	19	0	0	0	0	0	19	670
19	2020-08-04	0	31	0	0	43	0	74	670
20	2020-08-04	51	22	0	0	107	0	179	670
21	2020-08-04	31	2	0	85	0	0	118	670
22	2020-08-04	88	35	0	0	307	28	458	670
23	2020-08-04	31	8	0	56	45	56	197	670
Total	2020-08-04	3450	425	14	1275	1499	340	7003	
0	2020-08-05	142	0	6	0	2	0	150	670
1	2020-08-05	12	21	0	49	164	0	246	670
2	2020-08-05	256	3	0	0	34	72	365	670
3	2020-08-05	161	15	0	479	153	50	858	670
4	2020-08-05	477	0	0	85	60	0	621	670
5	2020-08-05	491	0	0	0	0	0	491	670
6	2020-08-05	144	12	0	0	30	0	186	670
7	2020-08-05	68	20	0	0	0	0	87	670
8	2020-08-05	144	51	0	782	0	0	978	670
9	2020-08-05	92	86	0	0	0	0	178	670
10	2020-08-05	152	15	0	0	0	0	166	670
11	2020-08-05	309	0	0	0	0	0	309	670
12	2020-08-05	121	0	0	0	0	0	121	670
13	2020-08-05	21	0	0	0	98	31	150	670

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
14	2020-08-05	0	0	0	0	0	0	0	670
15	2020-08-05	18	0	0	0	32	0	50	670
16	2020-08-05	127	0	0	0	59	0	185	670
17	2020-08-05	45	0	0	0	0	0	45	566
18	2020-08-05	19	0	0	0	46	0	65	566
19	2020-08-05	712	20	0	0	0	0	732	566
20	2020-08-05	1914	677	17	466	49	0	3122	566
21	2020-08-05	3983	542	0	691	548	129	5893	566
22	2020-08-05	1012	88	0	341	404	0	1845	566
23	2020-08-05	405	28	0	73	0	0	506	566
Total	2020-08-05	10821	1577	23	2966	1680	281	17349	
0	2020-08-06	1254	50	0	388	29	21	1743	566
1	2020-08-06	1434	98	0	0	46	0	1578	566
2	2020-08-06	713	53	0	0	137	0	902	566
3	2020-08-06	2856	235	0	463	360	88	4001	566
4	2020-08-06	3841	442	0	2825	524	0	7632	566
5	2020-08-06	2386	209	0	3627	437	84	6743	566
6	2020-08-06	1515	222	9	6940	970	0	9656	566
7	2020-08-06	1322	199	0	2353	486	0	4360	566
8	2020-08-06	226	60	0	497	72	0	855	566
9	2020-08-06	618	10	0	172	0	0	800	566
10	2020-08-06	170	11	0	0	0	0	181	566
11	2020-08-06	191	0	0	211	0	0	402	566
12	2020-08-06	298	86	0	259	57	0	700	566
13	2020-08-06	48	0	0	226	0	0	275	566
14	2020-08-06	40	0	0	0	0	0	40	566
15	2020-08-06	49	0	0	0	0	0	49	566
16	2020-08-06	0	0	0	148	0	0	148	566
17	2020-08-06	303	0	0	0	0	0	303	566
18	2020-08-06	416	31	0	0	0	0	447	566
19	2020-08-06	21	0	0	0	0	0	21	566
20	2020-08-06	66	6	0	0	0	0	72	566
21	2020-08-06	55	11	4	0	0	0	70	566
22	2020-08-06	175	0	0	0	0	0	175	566
23	2020-08-06	261	26	0	0	110	24	422	566
Total	2020-08-06	18261	1749	12	18109	3228	217	41576	
0	2020-08-07	453	12	0	0	0	0	466	566
1	2020-08-07	209	46	0	0	34	0	288	566
2	2020-08-07	859	79	0	0	296	34	1267	566
3	2020-08-07	502	41	0	0	57	0	600	566
4	2020-08-07	123	51	0	57	34	36	302	566
5	2020-08-07	54	11	0	0	54	0	119	566
6	2020-08-07	469	16	0	0	0	23	508	566
7	2020-08-07	85	20	0	0	0	0	105	566
8	2020-08-07	0	0	0	0	0	0	0	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
9	2020-08-07	226	19	0	0	0	0	245	566
10	2020-08-07	131	15	0	175	0	0	320	566
11	2020-08-07	607	38	0	0	0	0	645	566
12	2020-08-07	920	114	0	0	0	0	1034	566
13	2020-08-07	1500	216	0	222	0	0	1939	566
14	2020-08-07	2009	194	0	225	0	0	2427	566
15	2020-08-07	1812	192	4	166	0	0	2173	566
16	2020-08-07	1158	139	0	0	0	0	1297	566
17	2020-08-07	1309	199	0	0	0	0	1508	566
18	2020-08-07	1208	66	2	0	133	0	1408	566
19	2020-08-07	740	41	0	0	0	0	781	566
20	2020-08-07	287	14	0	0	0	0	301	566
21	2020-08-07	89	0	0	49	0	0	138	566
22	2020-08-07	92	5	0	127	192	76	492	566
23	2020-08-07	11	0	0	0	178	0	189	566
Total	2020-08-07	14853	1527	6	1020	978	168	18551	
0	2020-08-08	280	0	0	0	0	35	316	566
1	2020-08-08	28	10	0	0	59	42	140	566
2	2020-08-08	141	20	2	144	71	54	432	566
3	2020-08-08	774	72	0	0	0	0	846	566
4	2020-08-08	1785	164	0	0	51	0	2000	566
5	2020-08-08	2807	394	0	313	25	0	3538	566
6	2020-08-08	1200	179	0	163	0	35	1576	566
7	2020-08-08	285	31	0	0	0	0	316	566
8	2020-08-08	1138	196	0	47	0	0	1381	566
9	2020-08-08	2671	412	0	0	0	0	3083	566
10	2020-08-08	1538	277	0	0	0	0	1815	566
11	2020-08-08	901	86	0	0	0	0	988	566
12	2020-08-08	1926	214	0	0	0	0	2140	566
13	2020-08-08	3571	387	0	440	72	0	4470	566
14	2020-08-08	2594	317	0	308	84	0	3302	566
15	2020-08-08	1483	219	0	655	91	0	2449	566
16	2020-08-08	1564	189	0	3949	158	0	5860	566
17	2020-08-08	1691	69	0	1539	183	0	3482	566
18	2020-08-08	568	122	0	898	62	2	1652	566
19	2020-08-08	357	9	0	166	199	0	731	566
20	2020-08-08	633	62	0	497	115	15	1323	566
21	2020-08-08	391	70	0	0	0	0	461	566
22	2020-08-08	204	29	0	0	193	0	425	566
23	2020-08-08	268	0	0	62	133	48	511	566
Total	2020-08-08	28800	3527	2	9180	1497	231	43237	
0	2020-08-09	48	0	0	0	90	0	138	566
1	2020-08-09	158	16	0	457	15	61	707	566
2	2020-08-09	442	52	0	0	0	0	495	566
3	2020-08-09	897	87	0	156	0	0	1140	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
4	2020-08-09	833	94	0	0	31	0	958	566
5	2020-08-09	860	128	0	0	73	0	1061	566
6	2020-08-09	427	99	0	743	0	0	1270	566
7	2020-08-09	462	0	0	105	0	0	567	566
8	2020-08-09	1999	92	0	249	12	0	2352	566
9	2020-08-09	3059	561	12	659	161	26	4479	566
10	2020-08-09	1104	175	0	581	168	0	2028	566
11	2020-08-09	179	42	0	1241	168	0	1631	566
12	2020-08-09	174	71	0	3946	64	0	4255	566
13	2020-08-09	427	0	4	596	140	0	1166	566
14	2020-08-09	231	25	0	289	0	0	545	566
15	2020-08-09	409	2	4	0	89	0	504	566
16	2020-08-09	235	16	0	0	0	0	251	566
17	2020-08-09	163	8	0	0	0	19	190	566
18	2020-08-09	31	0	0	0	0	39	70	566
19	2020-08-09	0	0	0	0	0	0	0	566
20	2020-08-09	36	27	0	0	0	0	63	566
21	2020-08-09	926	47	0	298	0	0	1270	566
22	2020-08-09	200	4	0	146	365	51	767	566
23	2020-08-09	196	56	1	0	84	121	458	566
Total	2020-08-09	13498	1603	21	9466	1460	317	26364	
0	2020-08-10	118	37	0	0	158	0	313	566
1	2020-08-10	23	0	0	123	52	0	198	566
2	2020-08-10	33	9	0	0	0	0	42	566
3	2020-08-10	78	0	0	0	0	0	78	566
4	2020-08-10	115	21	0	0	0	46	183	566
5	2020-08-10	64	0	0	0	0	44	108	566
6	2020-08-10	12	0	0	0	0	0	12	566
7	2020-08-10	618	21	0	0	0	0	639	566
8	2020-08-10	424	26	0	0	0	0	450	566
9	2020-08-10	327	188	0	0	0	0	515	566
10	2020-08-10	1148	306	0	852	45	0	2351	566
11	2020-08-10	916	43	0	236	40	44	1278	566
12	2020-08-10	392	0	0	267	0	0	660	566
13	2020-08-10	140	18	0	151	0	0	309	566
14	2020-08-10	247	13	0	775	0	0	1035	566
15	2020-08-10	49	0	0	822	0	0	871	566
16	2020-08-10	201	54	0	0	41	21	317	566
17	2020-08-10	279	0	0	0	0	0	279	566
18	2020-08-10	123	0	0	366	45	0	535	566
19	2020-08-10	24	28	0	236	0	0	288	566
20	2020-08-10	207	35	0	810	0	0	1052	566
21	2020-08-10	143	0	0	145	0	0	288	566
22	2020-08-10	323	107	0	0	59	43	533	566
23	2020-08-10	1971	236	0	224	21	43	2496	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
Total	2020-08-10	7976	1141	0	5006	461	241	14826	
0	2020-08-11	859	1	3	291	87	24	1266	566
1	2020-08-11	240	13	0	79	106	65	503	566
2	2020-08-11	97	7	0	0	39	0	144	566
3	2020-08-11	777	104	0	146	0	20	1047	566
4	2020-08-11	108	0	1	0	121	70	300	566
5	2020-08-11	218	20	0	53	110	28	429	566
6	2020-08-11	342	28	1	0	0	58	429	566
7	2020-08-11	95	52	0	0	490	121	758	566
8	2020-08-11	122	5	0	0	25	0	151	566
9	2020-08-11	323	6	0	98	51	24	501	566
10	2020-08-11	91	25	0	333	163	0	612	566
11	2020-08-11	11	0	0	1996	295	40	2343	566
12	2020-08-11	141	14	0	1353	180	0	1688	566
13	2020-08-11	206	14	0	0	27	0	248	566
14	2020-08-11	214	0	0	0	0	0	214	566
15	2020-08-11	44	17	0	0	0	0	61	566
16	2020-08-11	0	2	0	0	0	0	2	566
17	2020-08-11	32	0	0	0	90	0	122	566
18	2020-08-11	1039	0	0	167	30	0	1236	566
19	2020-08-11	234	0	0	0	0	0	234	566
20	2020-08-11	74	0	0	75	35	0	184	566
21	2020-08-11	74	0	0	0	88	0	163	566
22	2020-08-11	44	0	0	0	0	21	65	566
23	2020-08-11	174	7	7	0	68	0	256	566
Total	2020-08-11	5561	313	12	4589	2006	472	12953	
0	2020-08-12	101	38	0	0	72	0	211	566
1	2020-08-12	61	4	0	0	32	0	97	566
2	2020-08-12	29	1	0	221	71	0	322	566
3	2020-08-12	20	24	0	0	0	0	44	566
4	2020-08-12	27	0	0	0	0	39	66	566
5	2020-08-12	30	9	0	0	0	0	39	566
6	2020-08-12	0	0	0	0	0	0	0	566
7	2020-08-12	0	0	0	0	0	60	60	566
8	2020-08-12	36	0	0	0	0	0	36	566
9	2020-08-12	8	0	0	0	0	0	8	566
10	2020-08-12	0	0	0	0	0	0	0	566
11	2020-08-12	0	0	0	0	0	0	0	566
12	2020-08-12	85	15	0	0	24	0	124	566
13	2020-08-12	194	0	0	0	0	0	194	566
14	2020-08-12	73	0	0	97	0	0	170	566
15	2020-08-12	142	0	0	0	71	0	213	566
16	2020-08-12	10	0	0	60	0	0	71	566
17	2020-08-12	224	0	0	0	0	0	224	566
18	2020-08-12	43	13	0	300	0	25	381	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
19	2020-08-12	67	21	0	0	0	0	87	566
20	2020-08-12	279	0	0	0	0	0	279	566
21	2020-08-12	109	0	0	0	0	0	109	566
22	2020-08-12	16	27	0	66	0	0	108	566
23	2020-08-12	305	72	0	0	59	11	447	566
Total	2020-08-12	1860	223	0	744	330	135	3292	
0	2020-08-13	348	0	0	352	57	0	757	566
1	2020-08-13	174	0	0	0	0	100	274	566
2	2020-08-13	129	55	0	176	0	0	360	566
3	2020-08-13	198	0	0	0	66	0	265	566
4	2020-08-13	135	6	0	0	0	0	141	566
5	2020-08-13	80	36	0	0	34	1	151	566
6	2020-08-13	57	0	0	0	0	0	57	566
7	2020-08-13	16	0	0	0	0	0	16	566
8	2020-08-13	66	0	0	0	0	0	66	566
9	2020-08-13	20	16	0	0	76	0	112	566
10	2020-08-13	198	38	0	0	45	0	281	566
11	2020-08-13	58	8	0	0	52	0	118	566
12	2020-08-13	0	0	0	0	0	29	29	566
13	2020-08-13	68	0	0	328	50	0	445	566
14	2020-08-13	0	0	0	585	81	0	666	566
15	2020-08-13	0	13	0	82	71	0	166	566
16	2020-08-13	53	0	0	292	0	0	345	566
17	2020-08-13	152	0	0	354	42	28	576	566
18	2020-08-13	261	0	0	637	0	0	899	566
19	2020-08-13	374	0	0	0	80	0	454	566
20	2020-08-13	0	0	0	0	0	0	0	566
21	2020-08-13	0	14	0	0	0	0	14	566
22	2020-08-13	0	20	0	0	44	19	83	566
23	2020-08-13	226	28	0	0	119	0	373	566
Total	2020-08-13	2612	234	0	2807	818	177	6648	
0	2020-08-14	245	52	0	0	136	0	433	566
1	2020-08-14	93	29	0	73	131	44	371	566
2	2020-08-14	637	0	0	98	85	13	833	566
3	2020-08-14	366	13	0	0	0	19	398	566
4	2020-08-14	214	14	0	0	119	0	347	566
5	2020-08-14	176	0	0	0	107	53	336	566
6	2020-08-14	102	11	0	279	60	0	452	566
7	2020-08-14	0	0	0	77	0	0	77	566
8	2020-08-14	179	9	0	63	0	0	251	566
9	2020-08-14	62	0	8	0	0	28	98	566
10	2020-08-14	463	61	0	0	0	0	524	566
11	2020-08-14	93	0	0	0	0	0	93	566
12	2020-08-14	562	15	0	0	0	0	577	566
13	2020-08-14	232	0	0	0	0	0	232	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
14	2020-08-14	161	0	0	0	52	0	213	566
15	2020-08-14	192	27	0	0	33	66	318	566
16	2020-08-14	14	0	0	0	0	0	14	566
17	2020-08-14	56	0	0	113	57	0	226	566
18	2020-08-14	484	0	0	0	0	0	484	566
19	2020-08-14	649	10	0	116	79	0	854	566
20	2020-08-14	156	16	0	0	0	0	172	566
21	2020-08-14	144	0	0	140	75	0	359	566
22	2020-08-14	230	50	0	0	23	43	346	566
23	2020-08-14	291	30	0	0	0	23	344	566
Total	2020-08-14	5802	338	8	959	956	289	8351	
0	2020-08-15	184	37	8	0	49	78	356	566
1	2020-08-15	169	60	14	241	227	20	731	566
2	2020-08-15	1081	161	0	0	113	0	1355	566
3	2020-08-15	2135	72	0	178	84	0	2468	566
4	2020-08-15	1233	12	0	0	0	76	1321	566
5	2020-08-15	1464	20	0	37	110	46	1676	566
6	2020-08-15	750	0	0	0	0	23	773	566
7	2020-08-15	1071	13	0	0	25	0	1110	566
8	2020-08-15	1237	81	0	0	0	0	1318	566
9	2020-08-15	379	0	0	0	0	0	379	566
10	2020-08-15	464	0	0	0	32	0	496	566
11	2020-08-15	872	0	0	0	0	0	872	566
12	2020-08-15	355	0	0	0	0	0	355	566
13	2020-08-15	89	0	0	254	0	0	343	566
14	2020-08-15	69	0	0	44	0	0	113	566
15	2020-08-15	1067	0	0	0	0	0	1067	566
16	2020-08-15	407	0	0	0	0	0	407	566
17	2020-08-15	163	0	0	0	0	0	163	566
18	2020-08-15	42	0	0	0	0	0	42	566
19	2020-08-15	0	0	0	0	0	0	0	566
20	2020-08-15	35	0	0	345	0	0	380	566
21	2020-08-15	469	8	0	0	0	0	477	566
22	2020-08-15	287	0	0	69	183	24	564	566
23	2020-08-15	845	71	0	158	120	0	1193	566
Total	2020-08-15	14868	534	22	1326	944	266	17960	
0	2020-08-16	502	5	0	0	35	0	542	566
1	2020-08-16	391	0	0	0	158	0	549	566
2	2020-08-16	429	38	0	0	0	0	467	566
3	2020-08-16	799	122	0	0	64	0	984	566
4	2020-08-16	1508	56	0	0	0	51	1615	566
5	2020-08-16	370	0	0	0	35	0	405	566
6	2020-08-16	293	8	0	0	65	0	367	566
7	2020-08-16	190	0	0	0	0	0	190	566
8	2020-08-16	2245	58	0	0	0	0	2303	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
9	2020-08-16	1242	37	0	0	0	0	1279	566
10	2020-08-16	465	34	0	0	0	0	499	566
11	2020-08-16	96	16	0	0	0	0	112	566
12	2020-08-16	438	0	0	0	0	0	438	566
13	2020-08-16	224	0	0	57	0	0	280	566
14	2020-08-16	462	18	0	0	0	0	481	566
15	2020-08-16	388	0	0	0	0	0	388	566
16	2020-08-16	763	33	0	0	0	0	796	566
17	2020-08-16	573	8	0	0	0	0	581	566
18	2020-08-16	3099	80	4	266	0	31	3480	566
19	2020-08-16	2468	0	0	0	0	0	2468	566
20	2020-08-16	1687	23	0	0	0	0	1710	566
21	2020-08-16	723	0	9	114	188	0	1034	566
22	2020-08-16	308	11	0	0	152	32	502	566
23	2020-08-16	85	28	0	0	186	0	299	566
Total	2020-08-16	19747	576	13	437	883	113	21768	
0	2020-08-17	328	0	0	0	0	0	328	566
1	2020-08-17	251	0	0	0	0	51	302	566
2	2020-08-17	575	49	0	798	327	50	1799	566
3	2020-08-17	149	22	0	0	168	168	506	566
4	2020-08-17	1358	0	0	0	100	0	1459	566
5	2020-08-17	473	32	0	264	78	50	896	566
6	2020-08-17	895	42	0	0	0	0	937	566
7	2020-08-17	2255	72	0	127	0	0	2453	566
8	2020-08-17	553	53	0	0	0	0	605	566
9	2020-08-17	496	25	0	256	0	0	777	566
10	2020-08-17	1913	118	0	0	0	0	2031	566
11	2020-08-17	3615	0	0	0	0	0	3615	566
12	2020-08-17	4593	76	0	241	0	0	4910	566
13	2020-08-17	517	0	0	0	0	0	517	566
14	2020-08-17	111	0	0	0	0	0	111	566
15	2020-08-17	86	0	0	0	0	0	86	566
16	2020-08-17	164	0	0	0	0	59	224	566
17	2020-08-17	82	0	0	0	0	0	82	566
18	2020-08-17	292	12	0	0	69	0	374	566
19	2020-08-17	558	0	0	0	0	0	558	566
20	2020-08-17	456	0	0	0	0	0	456	566
21	2020-08-17	454	0	5	0	0	0	459	566
22	2020-08-17	335	0	0	0	0	25	360	566
23	2020-08-17	547	0	5	0	0	0	551	566
Total	2020-08-17	21054	501	9	1686	743	403	24396	
0	2020-08-18	257	16	0	0	35	89	397	566
1	2020-08-18	742	0	3	194	0	0	939	566
2	2020-08-18	337	0	0	141	0	0	478	566
3	2020-08-18	1662	11	0	0	0	0	1672	566

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
4	2020-08-18	1335	41	0	0	0	0	1376	566
5	2020-08-18	1543	0	0	0	140	0	1683	566
6	2020-08-18	1881	0	0	362	0	0	2243	566
7	2020-08-18	2159	19	0	447	0	0	2625	566
8	2020-08-18	3625	98	0	281	0	0	4004	566
9	2020-08-18	7197	260	0	159	0	0	7617	566
10	2020-08-18	3714	218	0	0	0	0	3931	566
11	2020-08-18	1616	103	0	0	0	0	1720	566
12	2020-08-18	485	38	0	0	0	0	522	566
13	2020-08-18	108	35	0	0	0	0	143	566
14	2020-08-18	929	0	0	225	0	0	1154	566
15	2020-08-18	5612	261	0	712	77	0	6662	566
16	2020-08-18	3920	110	0	183	0	0	4213	566
17	2020-08-18	2116	31	0	381	0	0	2528	566
18	2020-08-18	2882	18	0	0	0	0	2900	566
19	2020-08-18	2158	153	0	149	0	0	2459	566
Total	2020-08-18	44279	1411	3	3234	252	89	49269	
10	2020-08-26	0	0	0	0	0	0	0	
11	2020-08-26	31	0	0	0	0	0	31	566
12	2020-08-26	22	0	0	0	0	0	22	566
13	2020-08-26	0	0	0	0	0	0	0	566
Total	2020-08-26	53	0	0	0	0	0	53	
9	2020-08-27	112	61	0	119	0	0	291	580
10	2020-08-27	0	6	0	824	98	0	928	580
11	2020-08-27	303	0	0	439	0	0	742	580
12	2020-08-27	67	0	0	229	0	0	296	580
13	2020-08-27	33	9	0	0	0	0	42	580
14	2020-08-27	16	0	0	110	0	0	127	580
Total	2020-08-27	531	76	0	1722	98	0	2427	
9	2020-08-28	58	0	0	0	0	0	58	650
10	2020-08-28	0	42	0	0	0	0	42	650
11	2020-08-28	0	10	0	478	33	0	521	650
12	2020-08-28	11	0	0	159	0	0	169	650
13	2020-08-28	412	32	0	486	130	22	1082	650
14	2020-08-28	55	0	0	0	0	0	55	650
Total	2020-08-28	534	84	0	1123	163	22	1926	
9	2020-08-29	0	0	0	0	0	0	0	600
10	2020-08-29	0	0	0	101	0	0	101	600
11	2020-08-29	20	8	0	0	0	0	28	600
12	2020-08-29	18	0	0	0	40	0	58	600
13	2020-08-29	86	0	0	55	0	0	141	600
14	2020-08-29	29	0	0	73	175	0	278	600
15	2020-08-29	47	0	0	0	0	0	47	600
Total	2020-08-29	200	8	0	230	215	0	653	
9	2020-08-30	109	0	0	0	0	0	109	600

Table B1: Daily results of fish tracking data for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Hour	Date	Horizontal Beam			Vertical Beam			Total	Spill Rate (m^3/s)
		Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
10	2020-08-30	0	10	0	0	0	0	10	600
11	2020-08-30	19	0	0	0	0	0	19	600
12	2020-08-30	0	0	0	0	0	0	0	600
13	2020-08-30	141	14	0	0	0	0	156	600
14	2020-08-30	29	4	0	0	0	0	33	600
15	2020-08-30	0	0	0	0	0	0	0	600
Total	2020-08-30	299	28	0	0	0	0	327	
9	2020-08-31	0	0	0	0	0	0	0	600
10	2020-08-31	0	0	0	0	0	0	0	600
11	2020-08-31	0	28	0	0	0	0	28	600
12	2020-08-31	12	0	5	0	0	0	17	600
13	2020-08-31	0	0	0	0	0	0	0	600
14	2020-08-31	0	49	0	0	0	0	49	600
15	2020-08-31	0	0	0	0	0	0	0	600
Total	2020-08-31	610	132	5	0	0	0	747	
9	2020-09-01	0	0	0	0	0	0	0	600
10	2020-09-01	0	0	0	0	0	0	0	600
11	2020-09-01	0	0	3	0	0	0	3	600
12	2020-09-01	61	0	0	41	0	0	102	600
13	2020-09-01	0	0	0	0	0	0	0	600
14	2020-09-01	48	0	0	0	0	107	155	600
15	2020-09-01	0	11	0	0	45	0	56	600
Total	2020-09-01	109	11	3	41	45	107	317	

APPENDIX C

Summary of Daily Entrainment

Table C1. Daily entrainment estimates for the monitoring period (22 July – 1 September) at W.A.C. Bennett Dam, Williston Reservoir.

Date	Vertical Beam			Horizontal Beam			# Hours Monitored	Total
	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)	Small (<75 mm)	Medium (75 - 465 mm)	Large (>465 mm)		
2020-07-22	10518	2477	27	6168	63	0	5	19254
2020-07-23	4614	1420	269	8014	179	0	14	14496
2020-07-24	47473	5557	913	14074	209	0	24	68226
2020-07-25	35319	12684	758	21340	1535	0	24	71638
2020-07-26	26722	4539	326	13171	412	0	24	45170
2020-07-27	6502	1855	81	3915	0	0	24	12353
2020-07-28	8230	2614	220	11017	75	0	24	22156
2020-07-29	7124	713	0	2919	0	0	15	10757
2020-07-30	12977	2052	117	5984	190	4	11	21325
2020-07-31	5888	3415	421	2555	0	0	24	12279
2020-08-01	11652	2601	342	13901	808	9	24	29313
2020-08-02	72640	9874	647	42062	1157	0	24	126380
2020-08-03	13389	2588	383	22316	663	0	24	39339
2020-08-04	1275	1416	191	3414	132	0	24	6429
2020-08-05	2800	1570	118	10821	1518	10	24	16837
2020-08-06	18093	3121	197	18261	1669	0	24	41342
2020-08-07	883	923	144	14853	1489	0	24	18292
2020-08-08	9180	1497	107	28800	3456	2	24	43042
2020-08-09	9466	1368	89	13498	1513	0	24	25933
2020-08-10	5006	420	0	7976	1033	0	24	14436
2020-08-11	4589	1982	437	5561	241	0	24	12810
2020-08-12	568	157	21	1860	174	0	24	2778
2020-08-13	2807	818	94	2510	134	0	24	6364
2020-08-14	959	955	126	5802	321	8	24	8170
2020-08-15	1167	887	216	14868	524	22	24	17683
2020-08-16	251	883	50	19747	490	0	24	21421
2020-08-17	1686	680	403	21054	331	0	24	24154
2020-08-18	3234	252	11	44279	1296	0	20	49073
2020-08-26	0	0	0	32	40	0	4	72
2020-08-27	1722	98	0	516	41	0	6	2378
2020-08-28	1123	163	22	502	0	0	6	1810
2020-08-29	230	215	0	200	0	0	7	645
2020-08-30	0	0	0	299	0	0	7	299
2020-08-31	0	0	0	0	58	5	7	63
2020-09-01	41	0	107	99	0	0	7	247
Total	328130	69797	6838	382389	19751	60	661	806964

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