Columbia River Project Water Use Plan

Kinbasket Reservoir Fish and Wildlife Information Plan

Kinbasket Reservoir Burbot Life History and Habitat Use Assessment

Implementation Year 4

Reference: CLBMON-05

WLR Monitoring Study CLBMON-05 (Year 4) Kinbasket Reservoir Burbot Life History and Habitat Use Assessment

Study Period: April 2017 to Nov 2017

Ktunaxa Nation Council
7825 Mission Rd, Cranbrook, BC, V1C 7E5

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WLR Monitoring Study CLBMON-05 (Year 4)

Kinbasket Reservoir Burbot Life History and Habitat Use Assessment

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Cover Photo:

View of Kinbasket Reservoir at the entrance of the Columbia Reach located north of Encampment Creek (May 27, 2017). Misun Kang, Ktunaxa Nation Council.

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EXECUTIVE SUMMARY

Burbot (*Lota lota*) were historically distributed throughout the Columbia and Canoe Rivers, and Kinbasket Lake, which were impounded by the construction of Mica Dam in 1973. Mica Dam created Kinbasket Reservoir, a 216 km long, 43,200 ha ultraoligotrophic water body. Burbot are present throughout Kinbasket Reservoir. This technical report summarizes the findings of the fourth year of a five year monitoring study (2014-2018) of their life history and habitat use. A more in-depth quantitative analysis of Burbot detections will be conducted in the final report, along with an assessment of impacts of dam operations.

Kinbasket reservoir has a normal operating range of approximately 35 m. The reservoir experiences rapid drawdown during the winter months from January to April, when reservoir elevations decline by an average of 4.3 m/month. Burbot spawn during this time period, and the success of their spawning may be affected by declining water levels. Burbot often spawn in shallow water, and developing eggs require several weeks to develop before hatching, at which time larvae spend several days resting in substrate before becoming planktonic. It is during this time period that optimal spawning habitat, developing eggs or newly hatched larvae may become stranded by declining water levels in Kinbasket Reservoir. The fact that Burbot still exist in Kinbasket Reservoir implies that their population persists, however, anecdotal evidence suggests there has been a declining population trend over the last two decades. One hypothesis is that spawning success of a component of the population may be affected by operations.

This study uses biotelemetry to determine biological characteristics, movement and depth preferences of Burbot during the period of time that spawning is expected to occur. Previous data on capture rates and logistical constraints limited the capture locations to seven areas focused between the Canoe Arm and Surprise Rapids. Burbot were captured by baited cod traps during the immediate post-spawning period of late April and early May, 2014 and 2015, shortly after ice-off and during the period of minimum reservoir elevation. Capture was conducted in 48 h soaks, in shallow depths (< 20 m) to minimize decompression trauma of captured fish.

Ninety-eight (98) Burbot of a broad size range (0.84 – 4.60 kg) were surgically implanted (Spring 2014 and Spring 2015) with combined acoustic-radio transmitters (CART) that transmit depth and temperature sensor data. These fish were tracked year-round by fixed acoustic receivers from Spring 2014 to Spring 2017. Sixteen fixed acoustic receivers were redeployed in May 2015 and 14 new receivers were deployed in July 2015. Aerial radio tracking had been attempted in Winter/Spring 2015 but has since been discontinued due to poor detection rates. Receivers were placed in areas designed to detect broad scale movements and in the vicinity of stream confluence areas that are suspected spawning areas. Burbot depth and water temperature data were recorded by receivers year-round and used to determine movements towards spawning areas and depths used during the spawning season.

Mobile and fixed receiver tracking data collected from 2014 to 2017 indicated no clear movement pattern towards a specific congregation location in the pre-spawning and early spawning season. Most detections were made at Wood Arm/River, Sullivan Arm/River, Kinbasket River, and Kinbasket

Outlet/Inlet. While data from fixed acoustic receivers indicated variability in the depths occupied by Burbot, significant differences among seasonal depth occupation patterns were observed in shallower habitat (approximately <14 m) use during assumed periods of spawning and deeper habitat use (approximately >19 m) during fall/early winter. A thorough assessment of Burbot detection data (for all years) will be evaluated in Year 5, as well as an analysis of potential impacts of drawdown on spawning success.

Management Question	Hypotheses	Status (2015; Year 4)
What are some basic biological characteristics of Burbot populations in Kinbasket Reservoir (e.g., distribution, abundance, growth and age structure)?		Distribution and abundance of Kinbasket Burbot assessed in 2014 to 2017. To be further addressed in Year 5.
Does winter drawdown of Kinbasket Reservoir cause the dewatering of Burbot spawning habitat and affect spawning success?	H1: Winter drawdown of Kinbasket Reservoir causes dewatering of Burbot spawning habitat, which reduces egg survival and Burbot spawning success. H2: Winter drawdown of Kinbasket Reservoir causes dewatering of access to Burbot spawning habitat in some years.	To be addressed in Year 5.
Can modifications be made to the operation of Kinbasket Reservoir to protect or enhance spawning success of these Burbot populations?		To be addressed in Year 5.

ACKNOWLEDGEMENTS

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INTRODUCTION

Background

Kinbasket Reservoir was created by the construction of Mica Dam in 1973, under the terms of the Columbia River Treaty. The purposes of the creation of this earthfill, high head dam and reservoir were for optimized, coordinated power generation between Columbia River mainstem dams in the US and Canada and for downstream flood control. The reservoir inundated 216 km of the length of the Columbia River between Mica and Donald, and is among the largest reservoirs in British Columbia, with a maximum surface area of 43,200 ha. Prior to dam construction, the majority of this habitat was free flowing, with the exception of a lacustrine portion known as Kinbasket Lake that was 13 km long and had a surface area of 2,250 ha (Prince, 2011). The reservoir can be coarsely segregated into two main reaches, with the Columbia and Canoe reaches meeting at the historic confluence of the Canoe and Columbia rivers, where the Columbia River turns southward approximately where Mica Dam is currently situated. The reaches of the reservoir are typically bounded by steep valleys and are narrow, with stretches becoming riverine at low pool. Three large lacustrine portions of the reservoir occur at the confluence of the Canoe and Columbia Reaches, at the historic location of Kinbasket Lake near the confluence with the Sullivan River, and at the confluence with the Bush River. Stream inputs are largely glacial, draining the high elevation northern tips of the Selkirk and Monashee mountains from the West, and the extensively glaciated West slopes of the Canadian Rockies from the East.

Operations of Mica Dam result in Kinbasket reservoir elevations varying between a maximum of 754.38 m and a minimum 707.41 m, and being occasionally brought up to a maximum elevation of 754.68m if there is a high probability of spill. Normal operating level for the 2008-2012 period was from a mean maximum of 753.26 m and a minimum of 718.12 m, with a normal operating range of 35.14 m. Drawdown from full pool normally begins slowly in September, and draft rate increases through the winter, with a levelling off of drafting and normal low pool occurring in mid-late April. During the spring period, discharge from Mica dam decreases, which coincides with the normal spring freshet, which rapidly refills the reservoir through the spring and early summer.

Burbot (*Lota lota*) were identified by the Columbia River Water Use Plan Consultative Committee (WUP CC) as a key fish species of concern in Kinbasket Reservoir because of their importance to the sport fishery, because of the potential for links between reservoir operations and Burbot population productivity, and due to the dearth of information regarding Burbot biology in the reservoir (but see Harrison et al., 2013). The WUP CC hypothesized that the greatest potential impact of reservoir operations on Burbot populations may be the dewatering effect of winter drawdown on spawning success and egg survival in sites along the shoreline and in lower sections of tributaries. The WUP CC also had concerns that winter drawdown could affect Burbot spawning habitat in tributary streams of Kinbasket Reservoir. To address these concerns, the WUP CC recommended that a life history and habitat use assessment be undertaken in Kinbasket Reservoir to gain a better understanding of how the current operating regime might be affecting Burbot populations.

Burbot typically spawn between late January and April, with timing on major Columbia River system reservoirs (Duncan and Arrow) occurring in mid-February to early April (Arndt and Hutchinson, 2000;

Bisset and Cope, 2002; Prince and Cope, 2008; Cope, 2011; Robichaud et al., 2013), either in lake habitats or low velocity stream habitats, and have an egg incubation period of 30-60 days (Taylor and McPhail, 2000; McPhail, 2007). After hatching, larvae spend several days resting on the bottom before becoming free-swimming and planktonic in the water column. It can be expected that the period of spawning and egg and early larval development occurs between February and May-June in Kinbasket Reservoir, which coincides with the period when reservoir water levels can decline by an average of 4.3 m/month before reaching low pool elevation (Figure 1).

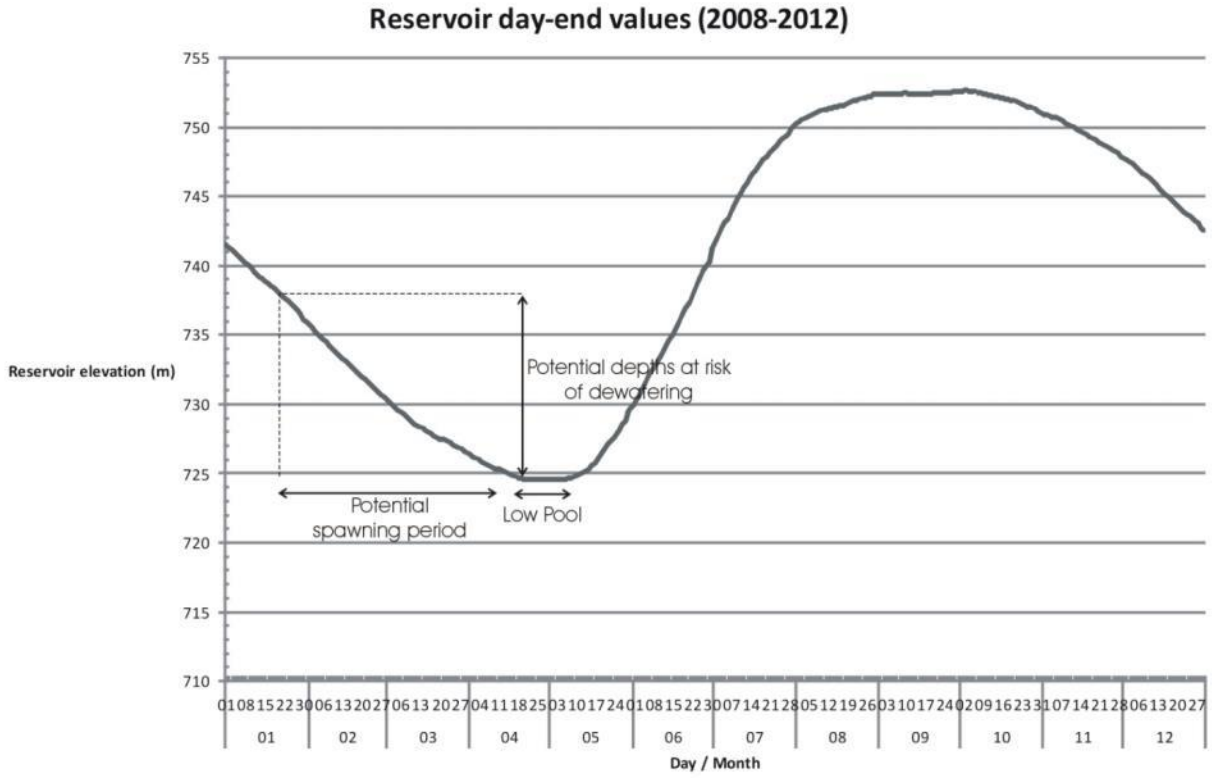


Figure 1: Potential elevations used by Burbot during the spawning period that are at risk of dewatering in an average year of reservoir operation. Lower elevations are at less risk for dewatering as the spawning season progresses. Line represents mean water elevation from 2008 to 2012.

The greatest potential impact of reservoir operations on Burbot populations may be the dewatering effect of winter drawdown on spawning success and egg survival in sites along the shoreline and in lower sections of tributaries. Burbot spawn in aggregations, often at night (McPhail, 2007), and vocalization appears to be a key behaviour that may aid Burbot in locating each other for spawning (Cott et al., 2014). In lakes and reservoirs, spawning may occur over near-shore shallows or over shallow offshore reefs and shoals (Ford et al., 1995; McPhail, 2007; Spence, 1999; Prince and Cope, 2008); however, deeper spawning (>20m) may also take place (Robichaud et al., 2013). In rivers and tributaries, Burbot spawn in low velocity areas in main channels and in side channels behind depositional bars (McPhail, 2007). In many cases, spawning in lakes is often associated with tributary confluences or

upwelling; however microhabitat preferences for spawning appears to be general, as Burbot may select a range of substrate, habitat characteristics and depths to spawn (Ford et al., 1995; McPhail, 2007; Andrusak, 1998; Baxter et al., 2002; Spence and Neufeld, 2002; Prince and Cope, 2008; Cope, 2011). The depth at which spawning takes place, coupled with the timing of spawning until the period of maximum drawdown in April, dictates whether there is a risk of spawning failure due to reservoir operations (Figure 1).

Declining water levels may also interfere with Burbot spawning migration and spawning activity. In a radio telemetry study of adult Burbot in Duncan Reservoir, the extent of spawning migration into the upper Duncan River appeared to be influenced by reservoir water levels and their impacts on back-flooding and stream velocity (Spence and Neufeld, 2002; Cope 2011). As back flooding from Duncan Reservoir declined, Burbot tended to move downstream into areas with lower water velocities than the locations they had abandoned. Since stream spawning Burbot tend to spawn in low velocity stream habitats (McPhail, 2007), the Burbot may have been moving downstream to more suitable lower velocity spawning sites. Burbot are known to have low swimming endurance and biotelemetry results in the Kootenay River below Libby Dam suggest that spawning migrations of Burbot in the Kootenay River may be disrupted by high flows produced during hydropower production and flood control (Paragamian, 2000).

The operational impacts of Mica Dam depend on the life history strategy of resident Burbot populations. As there is no pre-dam life history information available for Burbot populations in this area, assessment of impacts must rely on estimation based on habitat features, other species, and other Burbot populations. What is known is that there was habitat connectivity between the historic Kinbasket Lake and the upper Columbia watershed prior to dam construction and operation. The literature suggests that all three life history forms of Burbot (lacustrine, adfluvial, fluvial) often co-exist within the same system (McPhail, 2007) and this may have been the case for Burbot occupying the historic Kinbasket Lake and upper Columbia system that is now inundated by Kinbasket Reservoir. Adfluvial and lacustrine remnant life history forms may still be present, the population may be supported by fluvial immigrants from upstream sources, or a combination of life history forms may exist. The relative contributions or existence of these three life history forms to the current Kinbasket Burbot population is unknown.

While the life history and population status of Kinbasket Lake and Columbia River Burbot before dam construction are largely unknown, recent studies have provided some insights into important habitats and distribution of remnant stocks (Prince, 2001; Harrison et al., 2013). Growth rate is highly variable, as within other populations (Cope, 2011). Burbot capture is relatively consistent and successful in the confluence, Bush pool, and historic Kinbasket Lake areas of the reservoir, as well as near tributary confluences in the Sullivan, Bush and Wood arms and Hugh Allan Creek (Prince, 2001; Prince, 2011; Harrison et al., 2013). Most Burbot (~2/3 of fish captured in the confluence area between the Columbia and Canoe Reaches) appear to make limited seasonal movements, as well, diel vertical migration and shifts to shallower habitats in winter are common (Harrison et al., 2013). This suggests that there may be many, non-central spawning areas, and/or that fish may not spawn annually, a common observation for Burbot (Paragamian and Wakkinen, 2008), especially those in reservoirs (Dunnigan and Sinclair,

2008). Burbot that move out of the confluence area do not appear to migrate towards a central spawning area (Harrison, pers. comm.).

Management Questions

The management questions (MQs) associated with this monitoring program are (BC Hydro, 2007):

1) What are some basic biological characteristics of Burbot populations in Kinbasket Reservoir (e.g., distribution, abundance, growth and age structure)?

2) Does winter drawdown of Kinbasket Reservoir cause the dewatering of Burbot spawning habitat and affect spawning success?

3) Can modifications be made to the operation of Kinbasket Reservoir to protect or enhance spawning success of these Burbot populations?

The monitoring program will provide a quantitative baseline dataset to establish basic biological characteristics of the Burbot populations in Kinbasket Reservoir. It will provide information on habitat use, life history and rough estimates of abundance, and possible factors affecting Burbot productivity. Specifically, the assessment will address uncertainty regarding the extent to which Burbot are present in the drawdown zone during the spawning season, and if these areas are at risk for dewatering during the operational years of the study. A comprehensive drawdown risk assessment will be conducted in Year 5.

Management Hypotheses

The primary aim of this monitoring program is to provide baseline information on the Burbot population in Kinbasket Reservoir to better inform on the relationship between reservoir operations and recruitment. It is designed to specifically test the following hypotheses using assumptions of winter (January-April) habitat use being linked to spawning activity:

H1: Winter drawdown of Kinbasket Reservoir causes dewatering of Burbot spawning habitat, which reduces egg survival and Burbot spawning success.

H2: Winter drawdown of Kinbasket Reservoir causes dewatering of access to Burbot spawning habitat in some years.

Key Water Use Decision Affected

Implementation of the proposed monitoring program will provide information to support more informed decision making with respect to the need to balance storage in Kinbasket Reservoir with impacts on fish populations in the reservoir. Specifically, it will provide the information that is required to support future decisions around maintaining the current operating regime or modifying operations to protect reservoir Burbot populations.

METHODS

Overview, study objectives and limitations

The general approach of this study draws upon the designs of previous Water Use Planning Burbot life history and habitat use studies, particularly CLBMON-31 (Glova et al., 2009, 2010; Robichaud et al., 2011, 2012, 2013) and DDMON-11 (Cope; 2009, 2010, 2011), and refines them.

The study is designed to answer the management questions (MQs) outlined in the previous section. Unfortunately, the main drawbacks of work on Kinbasket reservoir are the size of the system, and inability to conduct on-reservoir work during the spawning season in February-March, which differs from the conditions of the previous two Water Use Planning studies on Arrow and Duncan Reservoirs.

The study is concentrated in a reduced area of the reservoir, between the Wood Arm and Columbia Reach (**Error! Reference source not found.**). This reduced area was chosen based on previous information of Burbot occurrence and logistical considerations for working from the only accessible boat launch near Mica Dam during the low pool period. During the Burbot spawning season, Kinbasket reservoir has unpredictable, dynamic ice conditions that make on-reservoir winter work unsafe. In addition, the remoteness of the reservoir requires extensive travel with limited safe access and contact points. Given these safety and logistical constraints, the following study design attempts to answer MQs 2 and 3 without working on-reservoir during the spawning season, and used a combination of fixed receiver and mobile helicopter tracking. These methods attempt to infer whether fish are present and congregating in shallow drawdown habitats during the spawning season. This approach cannot confirm spawning activity. Presence of aggregations of Burbot and occupation of relatively shallow depths over multiple days during the potential spawning period are treated as indicative of potential spawning activity when addressing the management hypotheses outlined in the previous section.

Burbot Capture/Tagging and Fixed Receiver Tracking

Capture, tagging and mobile/fixed receiver tracking methodologies are outlined in the Year 1 and Year 2 reports (Kang et al. 2014, 2016). A total of 48 Burbot were tagged in 2014 (Year 1) and 50 Burbot were tagged in 2015 (Year 2). See Figure 2 for capture locations.

Analyses of both mobile and fixed receiver tracking were conducted in Year 2 of the project. Due to limited detection of Burbot from mobile tracking in Year 1, mobile tracking was discontinued and 16 more receivers were deployed during redeployment of original receivers in 2015 (total number of receivers was 30) for Year 3 analyses. Five original receivers could not be retrieved in 2015 so 5 new receivers were deployed in the same locations to replace the lost receivers. See Figure 2 for receiver locations.

Fixed receivers were deployed from May 1-9, 2016 to May 9-12, 2017. Given premature battery failure of receivers deployed in 2014 set to transmit every 100 s, batteries were reprogrammed to transmit every 140 or 180 s, depending on battery life of the previous monitoring period.

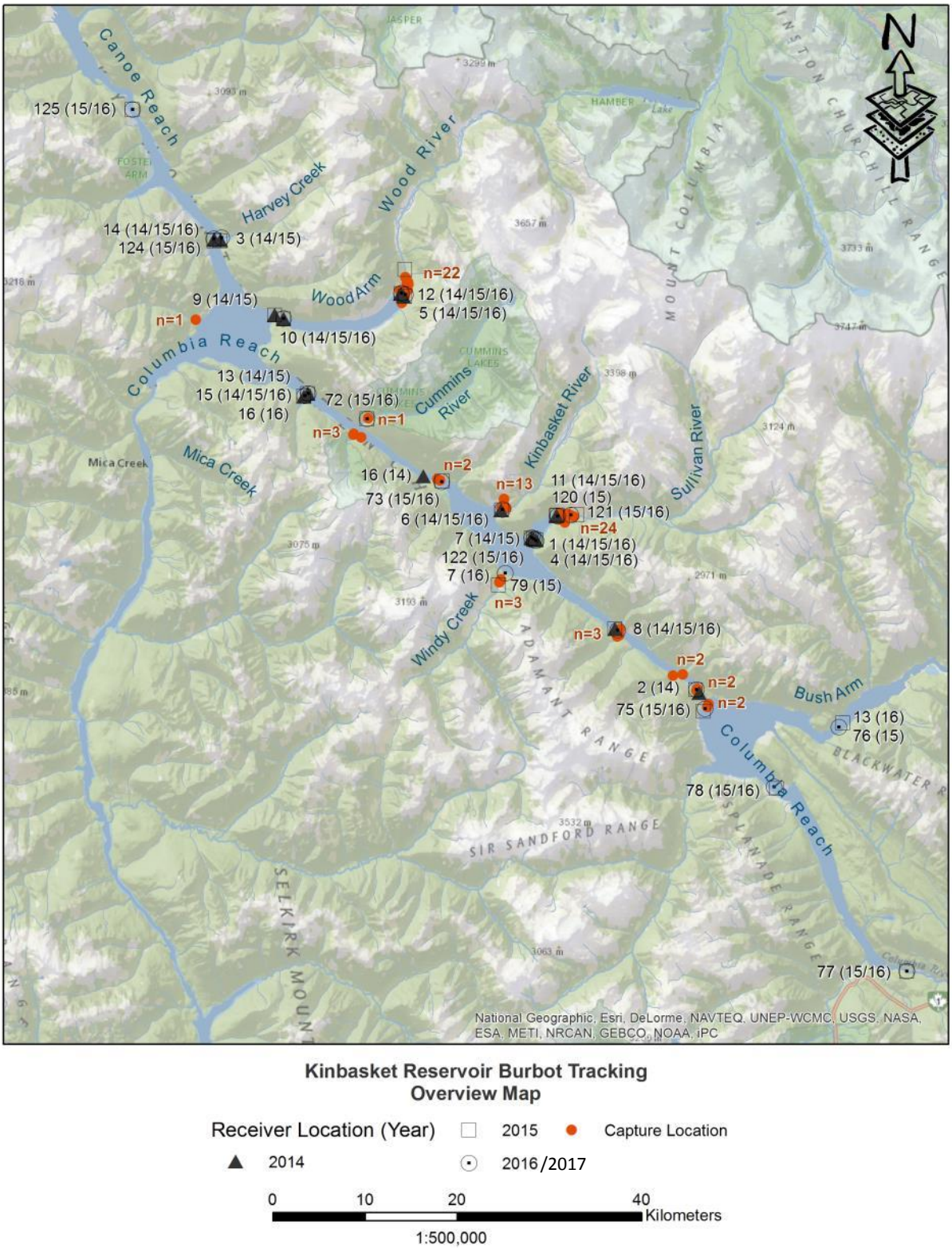


Figure 2: Locations of Burbot captures (orange circles with numbers of captures) and acoustic receivers (n=30) within the Kinbasket Reservoir study area.

RESULTS

Fixed receiver tracking

Nineteen receivers with 2016-2017 data were retrieved and their data are summarized below (Table 1). Fifteen receivers located in suspected spawning areas collected data during the full monitoring period including when spawning is expected to occur (i.e., January to April). Although batteries of receivers deployed in 2016 were reprogrammed to save battery life to address premature battery failure encountered in Year 2, 4 receiver batteries failed before the conclusion of the monitoring period but covered the majority of the suspected spawning period.

Table 1: Summary of monitoring period of fixed acoustic receivers deployed in Kinbasket Reservoir (listed according to locations from North to South). Data were downloaded from May 9-13, 2017. Batteries of receivers highlighted in *italics* died before the end of the monitoring period.

Receiver ID	Location	Start of Monitoring	End of Monitoring	Number of Detections
125	Upper Canoe Reach	04-May-16	09-May-17	525
14	Lower Canoe Reach	02-May-16	09-May-17	556
124	Lower Canoe Reach	02-May-16	09-May-17	1105
12	South Wood River	01-May-16	09-May-17	25886
5	North Wood River	01-May-16	09-May-17	19889
15	West Columbia Reach	07-May-16	11-May-17	3055
112	Entrance Columbia Reach Mid	02-May-16	20-Mar-17	7442
113	*Kinbasket Lake Outlet*	*03-May-16*	*18-Mar-17*	*9591*
6	Kinbasket River	03-May-16	10-May-17	9053
08	Kinbasket Lake Inlet	04-May-16	10-May-17	2741
122	South Sullivan Arm	06-May-16	10-May-17	1964
4	Middle Sullivan Arm	03-May-16	10-May-17	2272
1	*North Sullivan Arm*	*01-May-16*	*09-May-17*	*1483*
11	Sullivan River	07-May-16	10-May-17	25598
115	*Surprise Rapids*	*06-May-16*	*21-Apr-17*	*5*
114	*Surprise Rapids*	*06-May-16*	*27-Mar-17*	*181*
13	Bush Arm	03-May-16	12-May-17	170
118	Esplanade Bay	09-May-16	13-May-17	386
117	Columbia River	07-May-16	12-May-17	71

Range tests conducted after receiver installation with a test tag indicated detection efficiency was high. Receivers detected the test tags during all drifts conducted between 100 and 750 m from receivers at a range of depths. Receivers also detected nearby receivers in narrowings where the reservoir was gated,

indicating that these areas had excellent coverage to detect movements of Burbot between reservoir areas.

Of 98 Burbot tagged in 2014 and 2015, 86 (88%) were detected by acoustic receivers. Detection rates for Burbot tagged in 2014 was 90% (43/48) while detection rates for BB tagged in 2015 was 84 % (42/50). A total of 24 Burbot were tracked during the Year 4 monitoring period. The Burbot with Acoustic Code 37200 tagged in 2015 was detected for the first time during Year 4.

Most movement detections occurred near the location of capture (Table 2; Appendix 1) with most detections occurring at receivers 12 (25%; Wood River), 5 (20%; Wood River), 11 (15%; Sullivan River), and 6 (6%; mouth of Kinbasket River). These locations also correspond to the locations of capture of 70% of the detected Burbot.

While the majority of detections were made at Wood River year-round (>40%), detections did vary seasonally (Figure 3): >25% of detections were made at Sullivan Arm/River during the suspected spawning period and Fall, as well as >20% of detections in Spring and Summer. Kinbasket River detections were also high (17, 23, 8% during Spring, Summer, Fall/Winter, respectively).

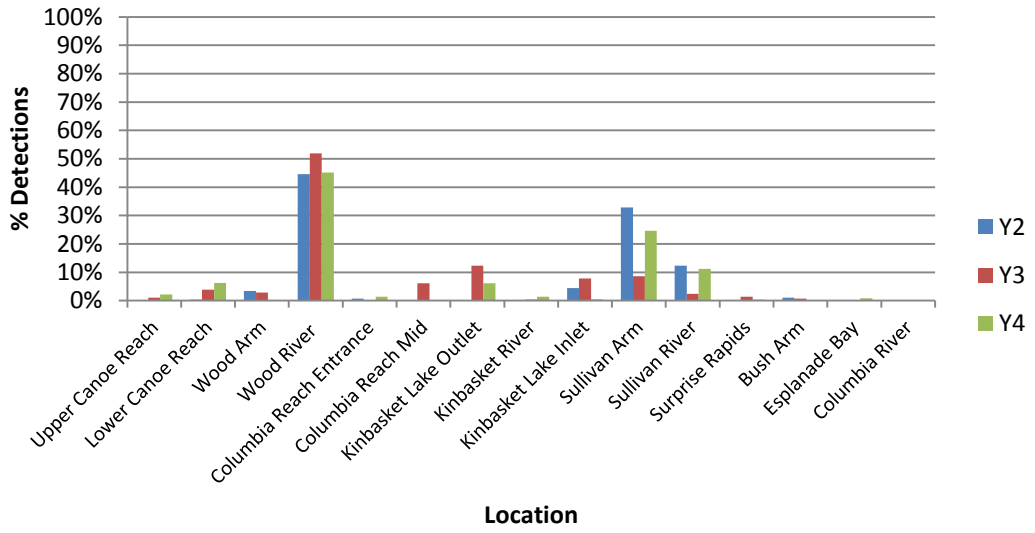
Table 2: Summary of locations of detection for each Burbot (listed left to right according to locations from North to South). Yellow circles = capture location; black checks = 2014-2015 detection; red checks = 2015-2016 detection; blue checks = 2016-2017 detection. Bolded acoustic codes represent Burbot that have not yet been detected during the study.

Acoustic Code	Upper Canoe Reach	Lower Canoe Reach	Wood Arm	Wood River	Columbia Reach Entrance	Columbia Reach Mid	Kinbasket Lake Outlet	Kinbasket River	Kinbasket Lake Inlet	Sullivan Arm	Sullivan River	Surprise Rapids	Bush Arm	Esplanade Bay	Columbia River
2014 IMPLANTS															
29500		✓	●	✓✓✓				✓							
29600		✓	●✓	✓	✓				✓	✓	✓				
29800		✓	●✓	✓	✓✓		✓	✓	✓✓	✓✓	✓✓				
29900			✓✓	✓✓	✓✓	●									
30100	✓	✓	●✓	✓✓✓	✓										
30200					✓✓	●✓✓									
30300							✓✓	●✓✓✓		✓✓	✓				
30400								●✓		✓	✓				
30500							✓			●✓✓✓	✓✓✓				
30600				✓				●✓		✓					
30700								✓		✓	●✓				
30800								✓		✓	●✓				
30900		✓	✓	✓					✓	✓	●✓				
31000											●✓✓				
31100								●✓	✓	✓	✓				
31200		✓		✓	✓			●✓		✓	✓				
31300								✓✓✓		✓✓	●✓				
31400									✓	✓	●✓				
31600				✓							●✓				
31700					✓				✓		●				
31900															
32000															
32200															
32300															
32500	✓	✓	●✓	✓✓											
32600			●✓	✓	✓										
32700															
33000					✓	●		✓	✓	✓	✓				
33100								●✓							
33200								✓		✓	●✓				
33300								✓✓		✓✓	●✓				
33400			●✓	✓											
33500	✓		●✓		✓				✓	✓					
33600					●				✓						
33700							✓	●		✓					
33900									✓			●			✓
34000										✓	●✓				

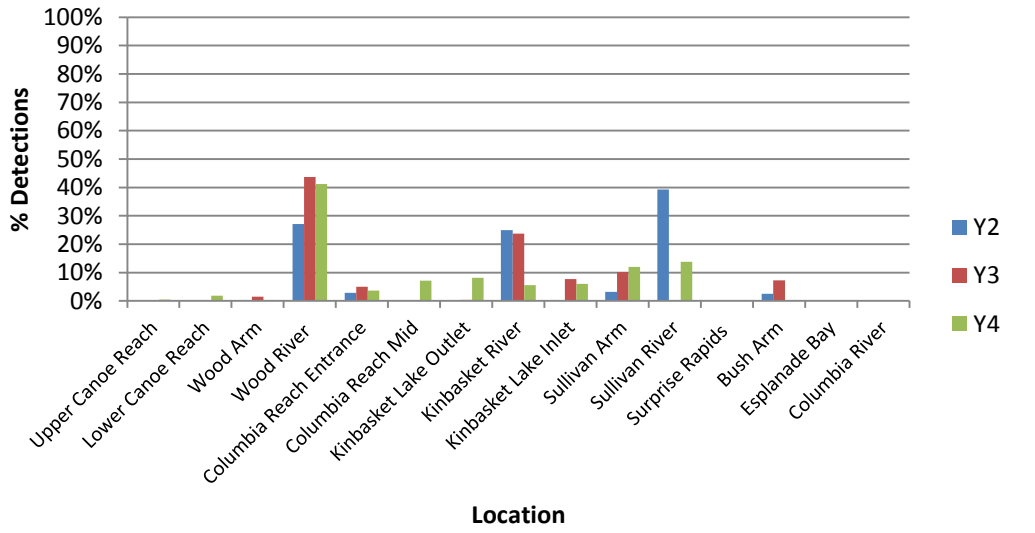
Acoustic Code	Upper Canoe Reach	Lower Canoe Reach	Wood Arm	Wood River	Columbia Reach Entrance	Columbia Reach Mid	Kinbasket Lake Outlet	Kinbasket River	Kinbasket Lake Inlet	Sullivan Arm	Sullivan River	Surprise Rapids	Bush Arm	Esplanade Bay	Columbia River
34100					✓	●									
34200		✓	●	✓✓											
34300			●	✓			✓		✓	✓					
34400								●✓✓	✓						
34500					✓	●									
2015 IMPLANTS															
34 600					✓		✓	✓	✓✓	✓✓	●	✓✓	✓	✓✓	
34 700										✓✓	●✓✓				
34 800															
34 900															
35 000	✓	✓		✓	✓	✓	✓✓		✓	●✓	✓	✓			
35 100								✓		●	✓				
35 200							✓✓	●✓✓	✓	✓✓	✓				
35 300							✓✓	●✓✓		✓	✓				
35 400										✓	●✓				
35 500										✓	●✓				
35 600											●✓				
35 700											●✓				
35 800		✓	✓	●✓✓	✓										
35 900								●✓							
36 000								●✓							
36 100									✓	✓	●✓				
36 200	✓✓	✓✓	●✓	✓✓											
36 300	✓	✓		●✓✓											
36 400			●	✓											
36 500		✓	✓	●✓✓	✓✓										
36 600	✓✓	✓✓	●✓	✓✓✓											
36 700					✓	●	✓								
36 800			●✓												
36 900			✓	●✓	✓										
37 200												✓			
37 300							✓✓	●							
37 400															
37 600												●✓✓			
37 700															
37 800										✓	●✓				
37 900					●				✓			✓			
38 000															
38 100					●				✓✓						
38 200										✓	●✓✓				
38 300									✓	✓	●✓	✓		✓✓	✓
38 400							✓			●					

Acoustic Code	Upper Canoe Reach	Lower Canoe Reach	Wood Arm	Wood River	Columbia Reach Entrance	Columbia Reach Mid	Kinbasket Lake Outlet	Kinbasket River	Kinbasket Lake Inlet	Sullivan Arm	Sullivan River	Surprise Rapids	Bush Arm	Esplanade Bay	Columbia River
38 600															
38 700							●	✓							
38 800															
38 900				●✓											
39 000							✓	●✓	✓	✓✓	✓✓				
39 100		✓			●✓										
39 200			✓	●✓✓											
39 300	✓✓	✓	●✓	✓											

Spawn-ing (Jan-Apr)



Spring



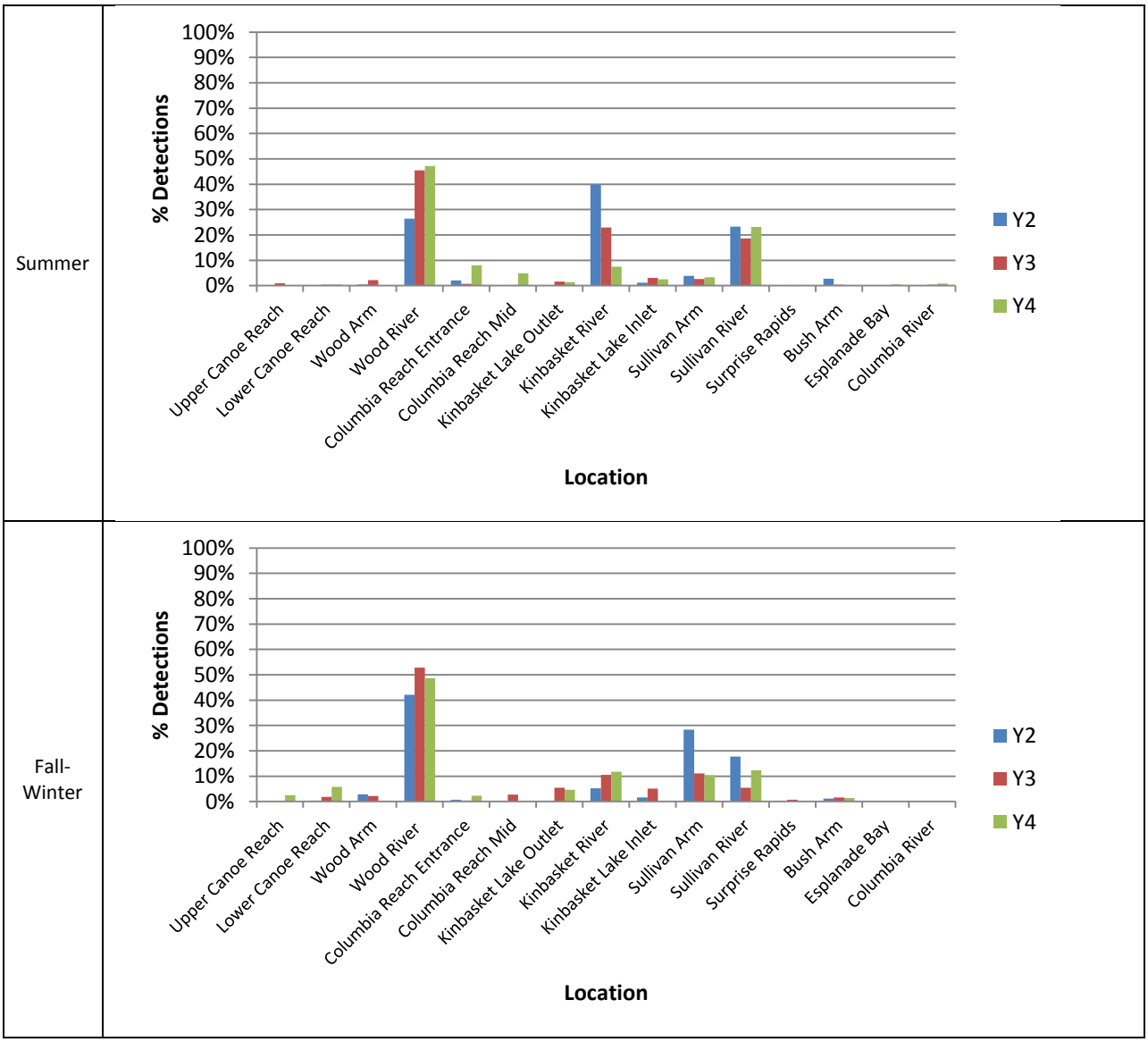


Figure 3: Summary of proportion of seasonal detections of Burbot at receiver locations (listed left to right according to locations from North to South) in Kinbasket Reservoir. The spawning period is expected to occur from January to April.

Mean depth of Burbot in Year 4 (2016-2017, excluding data collected by unrecovered receivers 7, 10, 76, and 121) was 16.0 ±7.50 m, with most Burbot distributed in the depth range of 11.0 to 20.0 m (Figure 4).

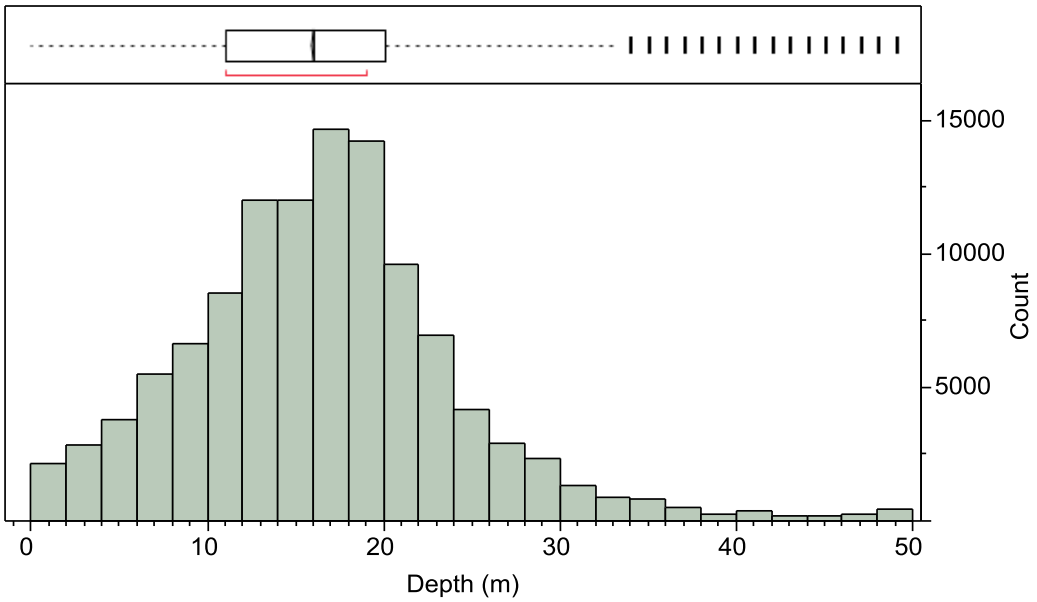


Figure 4: Distribution (histogram and box plot) of depth (m) for Burbot detected by acoustic tracking (n = 24) in Kinbasket Reservoir during 2016-2017. Boxes represent interquartile range, diamonds represent the sample mean and 95% confidence interval, while the middle line in the box is the median sample value. Whiskers represent observations outside of the interquartile range, with outlier data points. The red line indicates the densest 50% of the observations.

Burbot occupied lower elevations on average during the 2014-2015 monitoring period than during the 2015-2016 and 2016-2017 monitoring period (Figure 5; median depths: 2014-2015 = 19.0 m; 2015-2016 = 14.0 m; 2016-2017: 16.0 m; $p<0.0001$; df = 501964). Depths occupied in both years were shallower than that reported by Harrison et al. (2013; day-time and night-time mean depths ± SE were 37.09 ± 1.30 m and 25.9 ± 1.52 m, respectively), which might reflect general differences in depths of receivers between studies. Burbot are benthic (Fischer 2000a, 2000b) and depth detections likely reflect their behaviour.

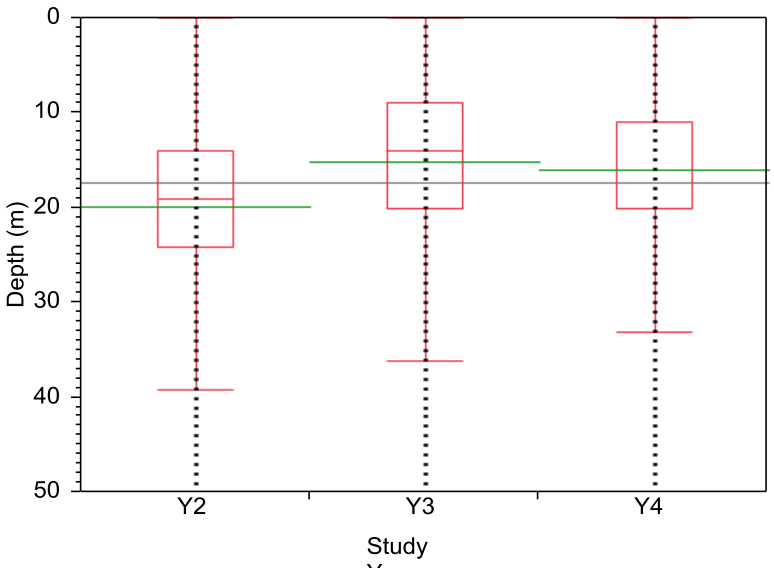


Figure 5: Mean depth (m) of Burbot for each study year (Year 2: 2014-2015, n= 206,505, Year 3:2015-2016, n = 183,653, and Year 4:2016-2017, n = 111,809). Boxes represent interquartile range with the middle line representing the median sample value. Green diamonds represent the 95% confidence interval with the middle line representing the mean. Whiskers represent observations outside of the interquartile range, with outlier data points. Data from June 2014 to May 2017.

Depth profiles illustrate the variability in depth occupation among Burbot, with individuals occupying a range of depths (Appendix 2). However, some general trends are apparent such as shifts from shallow to deeper areas from June/July to November/December and subsequent shifts to shallower depths from January to April-May (movements are discussed further below). Diel vertical migration (DVM) is illustrated by the vertical pattern of multiple points within a day. Of the 70 detected and living Burbot, 39% of individuals appeared to move into areas deeper than the receiver range limit of 50 m, as illustrated by numerous data points along the 50 m mark (Appendix 2).

During the Year 4 monitoring period, depths occupied by Burbot during the suspected spawning period (i.e., January to April, mean ± SE = 13.41 ± 0.046 m, n=24,230) was significantly shallower than other seasons (Spring: May to June, mean ± SE = 14.71 ± 0.039, n=32,409; Summer: July to September, mean ± SE = 16.34 ± 0.041, n=30,203; Fall/Winter: October to December, mean ± SE = 19.61 ± 0.045, n=24967; Tukey post-hoc tests all $p < 0.00001$; Figure 6). Depth occupation data from all years will be evaluated against elevation data in the Year 5 report.

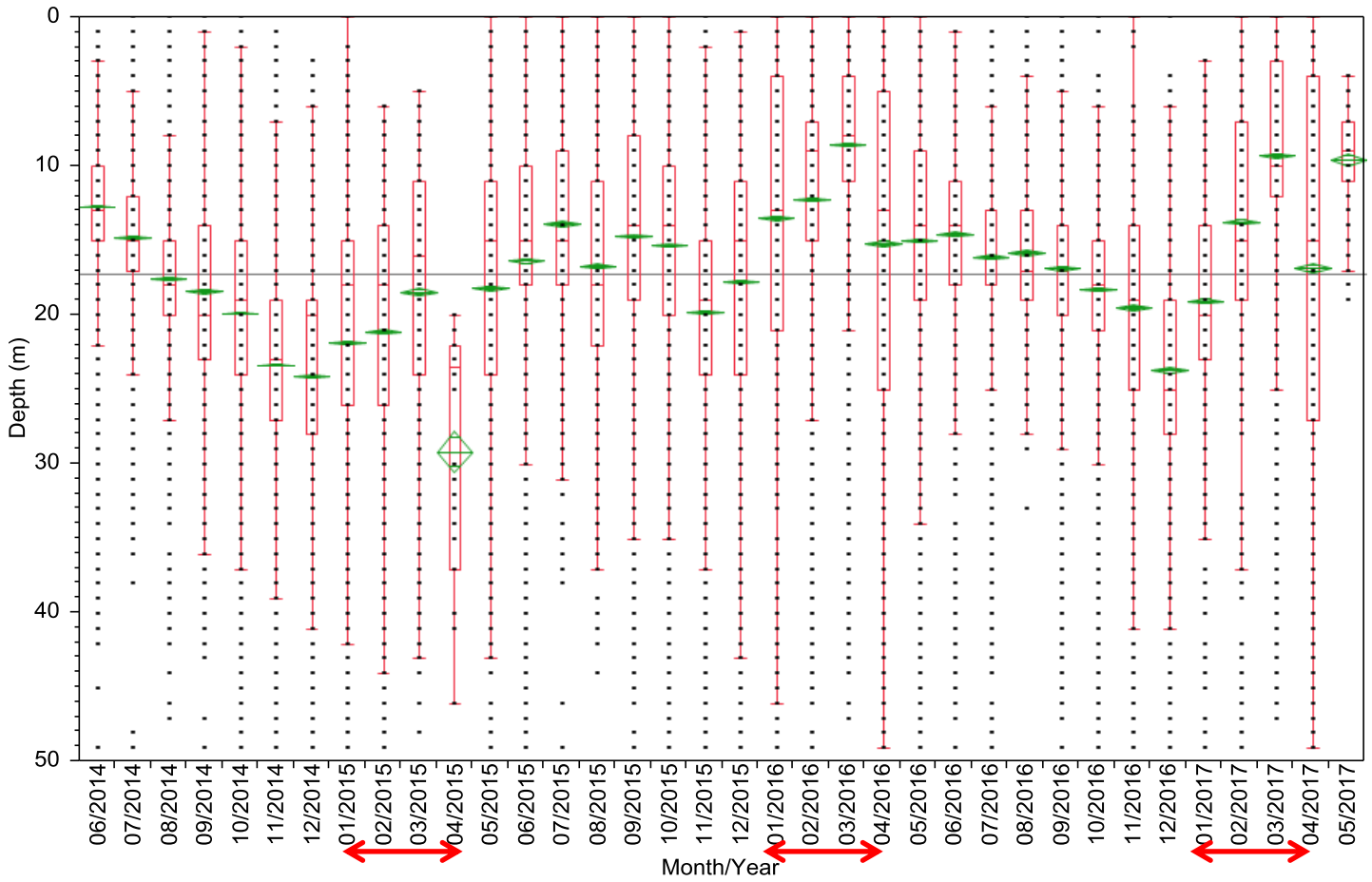


Figure 6: Mean daily depth (m) of Burbot detected each month of the year in all monitoring periods. Boxes represent interquartile range with the middle line representing the median sample value. Diamonds represent the 95% confidence interval with the middle line representing the mean. Whiskers represent observations outside of the interquartile range, with outlier data points. Red double arrows mark the expected spawning periods. Data from June 2014 to May 2017.

Burbot Mortality

Fifteen Burbot were either suspected (n=13) or confirmed dead (n=2) by the end of the fourth year of study (Table 3), including the five Burbot mortalities reported in the Year 3 report (Kang et al., 2016). Data collected in Year 4 indicated 3 additional Burbot (Acoustic Codes 35500, 37600, 38200) have either died or expelled their tags based on repeated patterns of detection at the same depth over a number of days (Table 3; similarly for Burbot with Acoustic Codes 29700, 30000, 31800, 32900, 37000, 37200, 37500, and 38500). The Burbot with acoustic tag 32800 was found by a trapper who found the tag on a rock ledge 1m above the water level on Aug. 23, 2015. Teeth marks (possibly from an otter) on the broken tag indicated that the Burbot had died from predation. The Burbot with acoustic tag 30800 died from harvesting on Jul. 30, 2014 by a fisherman who returned the tag.

Table 3: Summary of suspected or confirmed mortality of tagged Burbot in Kinbasket Reservoir. Mortalities of Burbot with Acoustic Codes highlighted in bold are have not been identified previously.

Acoustic Code	Tag Year	Location tagged	Date mortality determined	Location of mortality	UTM E	UTM N	Cause of mortality	Method used to determine mortality	Mortality Confirmed?
29700	2014	Wood Arm	5-Jun-14	Wood Arm	419541	5780798	Unknown	Depth data	No
30000	2014	Surprise Rapids	25-Jul-15	Surprise Rapids	451616	5737839	Unknown	Depth data	No
30800	2014	Kinbasket River confluence	30-Jul-14	Kinbasket River confluence	436934	5756668	Angler harvest	Angler return of tag	Yes
31500	2014	Sullivan River confluence	22-Mar-15	Mica Dam tailrace	390817	5767174	Entrainment	Sensor data from aerial tracking	No
31800	2014	Columbia Reach	13-Jun-15	Kinbasket Lake inlet	443248	5743798	Unknown	Depth data	No
32400	2014	Columbia Reach south	18-Apr-15	Columbia Reach south; surprise rapids	453133	5735739	Unknown	Sensor data from aerial tracking	No
32800	2015	Kinbasket River confluence	23-Aug-15	Kinbasket River confluence	431480	5757714	Predator	Tag found with teeth marks	Yes
32900	2015	Wood River confluence	15-May-15	Wood River confluence	420315	5782027	Unknown	Depth data	No
35500	**2015**	**Sullivan River confluence**	**04-May-16**	**Sullivan River**	**436576**	**5756745**	**Unknown**	**Depth data**	**No**
37000	2015	Surprise Rapids	25-Jul-15	Surprise Rapids	451724	5737999	Unknown	Depth data	No
37200	2015	Surprise Rapids	25-Jul-15	Surprise Rapids	449108	5739467	Unknown	Depth data	No
37500	2015	Sullivan River confluence	18-May-15	Kinbasket Lake inlet	437063	5756831	Unknown	Depth data	No
37600	**2015**	**Surprise Rapids**	**25-Jul-15**	**Surprise Rapids**	**452559**	**5735868**	**Unknown**	**Depth data**	**No**
38200	**2015**	**Sullivan River confluence**	**04-May-16**	**Sullivan River**	**436576**	**5756745**	**Unknown**	**Depth data**	**No**
38500	2015	Sullivan River confluence	23-Jul-15	Sullivan River	438673	5756887	Unknown	Depth data	No

CONCLUSIONS

Mobile and fixed receiver tracking

The fixed acoustic tracking information from Year 4 (2016-2017) showed clear seasonal patterns in depth occupation, as has been corroborated by information collected in Year 2 (2014-2015) and Year 3 (2015-2016). Receiver settings were modified in Year 3 and 4 so that battery life could be maximized, and the sample sizes of detections in the late winter period (i.e., February to April) supported more robust statistical tests during this time of year. While data indicated variability in the depths occupied by Burbot, they generally occupied relatively shallow areas during the suspected spawning period and deeper areas in Fall/Winter (Figure 6 and Appendix 2). The timing in occupation of the shallowest depths (March 2017 mean ± SE depth = 9.3 ± 0.51 m) is associated with a generalized time period that could coincide with spawning (Harrison et al., 2013). This may reflect true movement to shallower depths during the suspected period for spawning, some other activity, or it may indicate occupation of shallower depths at this time of year due to the reservoir operations. In a concurrent study on Kinbasket Reservoir (CLBMON-6), adult Burbot were captured in nearshore fyke nets set during April in the Canoe Reach of (Kang and Warnock, 2017) and during May at Encampment Creek (Kang and Warnock, 2018). These were the only observations of Burbot made during bi-weekly and monthly sampling sessions which concluded in August. All Burbot that were assumed to be alive during tracking displayed distinct behavioural patterns of diel vertical migration.

Aerial radio tracking conducted from February to April 2015 indicated that Burbot use shallow water habitat during these months in the reservoir, with the greatest number of detections on March 22, 2015 (Kang et al., 2015). There were also several observations of river habitat occupation from radio tracking data during this time period (Kang et al., 2015). These fish were detected at the Sullivan River (identified by local anglers as a historic location for large Burbot capture; Prince, 2001) and made limited movements (<2 km) upriver. It is hypothesized that this behaviour is indicative of a segment of the population that engages in an adfluvial life history, undertaking limited movements up large spawning tributaries. Time of spawning in March is further corroborated by patterns of detection collected from acoustic tracking and observations of 4 ripe fish captured during tagging in April (Kang et al., 2015).

The occurrence of Burbot in shallow areas in Spring suggests that Burbot may occupy shallow areas during the post-spawn period (Harrison et al., 2013). Incorporation of data from 2017-2018 will provide further elucidation of the distribution, migratory behaviour, and depth use during the spawning season. Information on the depths occupied by Burbot will be used to determine if these depths are at risk of dewatering with reservoir operations.

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APPENDIX 1: Summary of locations of capture/detection and depth statistics for Burbot (n = 72) in Kinbasket Reservoir (capture locations listed from North to South). Depth sensor maximum to 50 m and detections were made to the nearest meter.

Acoustic Code	Radio Code	Frequency	Length (mm)	Weight (kg)	Capture Location	Receivers	Detection Location	Mean Depth (m)	SD Depth (m)	Min Depth (m)	Max Depth (m)
39100	24	150.3	610	0.9	Encampment Creek	124	Lower Canoe Reach	22.8	10.37	15	38
29500	1	150.25	742	1.6	Wood Arm	5, 12, 124	Wood River, Lower Canoe Reach	21.8	7.3	3	45
29600	2	150.25	715	2	Wood Arm	7, 11, 14	Sullivan Arm, Sullivan River, Lower Canoe Reach	21.3	10.85	4	49
29800	4	150.25	770	2.4	Wood Arm	1, 4, 6, 7, 8, 11, 13, 14, 15, 121	Lower Canoe Reach, Columbia Reach Entrance, Kinbasket River, Kinbasket Lake Inlet, Sullivan Arm, Sullivan River	21	8.37	3	49
30100	7	150.25	795	2.5	Wood Arm	5, 10, 12, 13, 15	Columbia Reach Entrance, Wood Arm, Wood River	17.2	7.81	0	41
32500	5	150.3	747	1.8	Wood Arm	5, 12, 124	Lower Canoe Reach, Wood River	16.6	6.28	0	36
32600	6	150.3	660	1.5	Wood Arm	13, 15	Columbia Reach Entrance	15.5	3.78	4	39
33400	14	150.3	570	1	Wood Arm	5, 6, 9, 10, 12	Wood Arm, Wood River, Kinbasket River	21.3	10.28	6	49
33500	15	150.3	656	1.2	Wood Arm	7, 125	Upper Canoe Reach, Sullivan Arm	21.1	8.21	10	49
34200	22	150.3	683	1.4	Wood Arm	5, 12, 14	Lower Canoe	17	6.2	2	30

Acoustic Code	Radio Code	Frequency	Length (mm)	Weight (kg)	Capture Location	Receivers	Detection Location	Mean Depth (m)	SD Depth (m)	Min Depth (m)	Max Depth (m)
							Reach, Wood River				
34300	23	150.3	642	1.4	Wood Arm	8, 113	Kinbasket Lake Outlet, Kinbasket Lake Inlet	18.9	5.18	4	37
36200	17	150.27	700	1.72	Wood Arm	5, 10, 12, 124, 125	Upper Canoe Reach, Lower Canoe Reach, Wood Arm, Wood River	13.9	6.15	0	49
36400	19	150.27	723	1.8	Wood Arm	5, 12	Wood River	6.9	1.45	5	9
36600	21	150.27	746	1.66	Wood Arm	5, 10, 12, 124	Lower Canoe Reach, Wood Arm, Wood River	14.7	5.28	5	49
36800	23	150.27	697	1.58	Wood Arm	10	Wood Arm	15.8	1.64	13	21
39300	26	150.3	625	1.26	Wood Arm	5, 10, 12, 124, 125	Upper Canoe Reach, Lower Canoe Reach, Wood Arm, Wood River	19.7	6.86	7	49
35800	13	150.27	770	2.06	Wood River	5, 10, 12	Wood Arm, Wood River	8.9	4.26	0	38
36300	18	150.27	804	2.41	Wood River	5, 12, 124, 125	Upper Canoe Reach, Lower Canoe Reach, Wood River	14.2	5.93	3	33
36500	20	150.27	776	1.96	Wood River	5, 10, 12, 13	Wood Arm, Wood River, Columbia Reach Entrance	14	5.54	2	49
36900	24	150.27	715	1.86	Wood River	5, 10, 12, 13, 15	Wood Arm, Wood River, Columbia	14.7	4.3	3	21

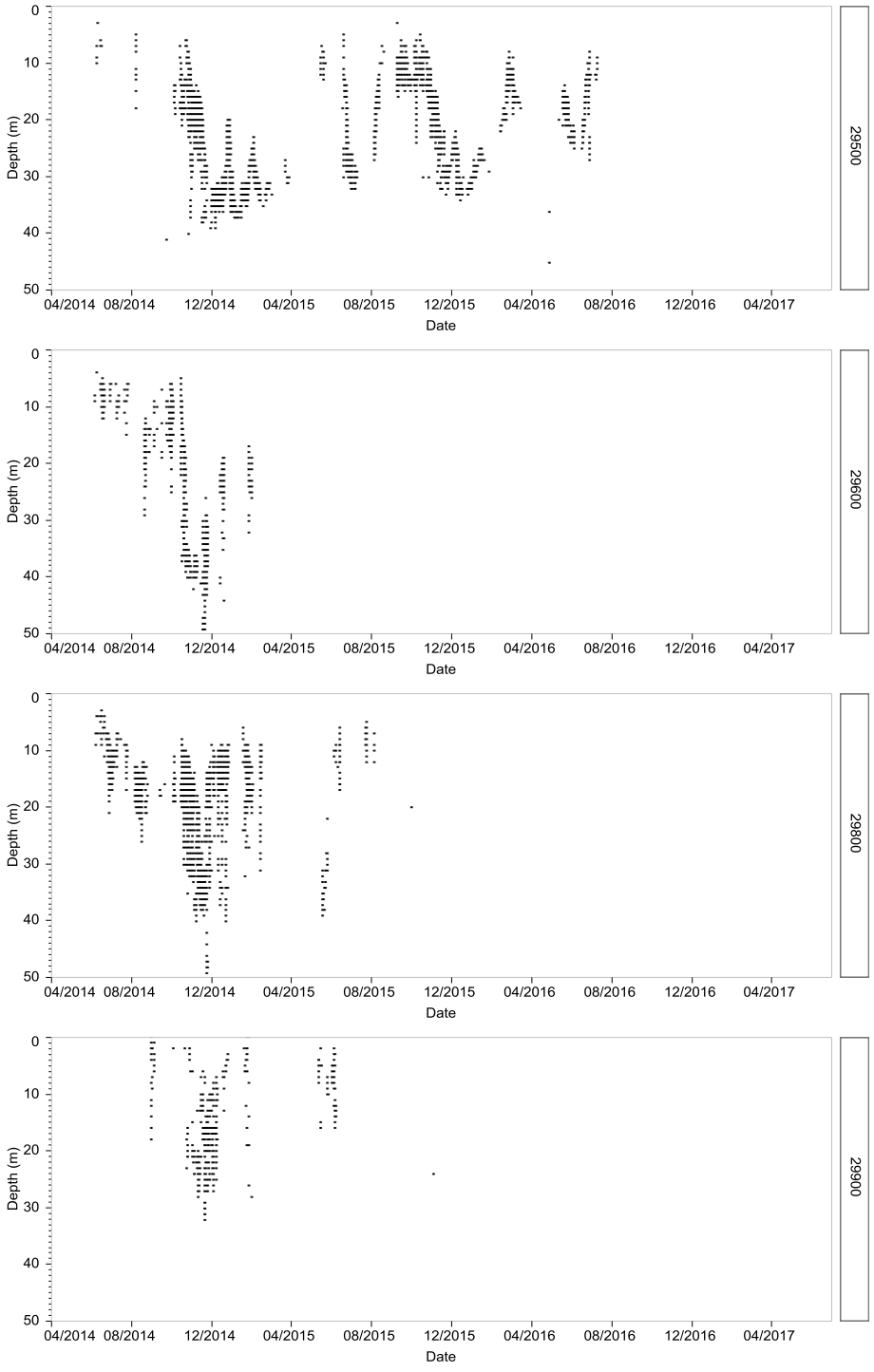
Acoustic Code	Radio Code	Frequency	Length (mm)	Weight (kg)	Capture Location	Receivers	Detection Location	Mean Depth (m)	SD Depth (m)	Min Depth (m)	Max Depth (m)
							Reach Entrance				
38900	22	150.3	697	1.36	Wood River	5, 12	Wood River	12.1	6.17	0	25
39200	25	150.3	600	1.18	Wood River	5, 10, 12	Wood Arm, Wood River	16.6	6.26	0	32
33600	16	150.3	574	1.1	Columbia Reach	8	Kinbasket Lake Inlet	29.5	5.99	14	49
37900	18	150.3	790	2.41	Columbia Reach	8, 115	Kinbasket Lake Inlet, Surprise Rapids	11.5	4.57	6	18
38100	2	150.3	595	1.08	Columbia Reach	8	Kinbasket Lake Inlet	14.5	9.56	0	46
36700	22	150.27	736	1.81	Cummins Creek	13, 15, 113	Columbia Reach Entrance, Kinbasket Lake Outlet	27.9	17.47	0	49
34100	21	150.3	685	1.3	Cummins River	13, 15	Columbia Reach Entrance	14.6	9.37	0	34
34500	25	150.3	592	0.9	Cummins River	15	Columbia Reach Entrance	26		26	26
29900	5	150.25	904	3.4	Goosegrass Creek (across from Cummins River)	10, 12, 13	Wood Arm, Wood River, Columbia Reach Entrance	16.3	6.01	0	32
30200	8	150.25	642	1.5	Goosegrass Creek (across from Cummins River)	13, 15, 112	Columbia Reach Entrance, Columbia Reach Mid	8.4	5.43	0	39
33000	10	150.3	810	2.7	Goosegrass Creek (across from Cummins River)	7, 11	Sullivan Arm, Sullivan River	25.4	13.32	0	49
38700	20	150.3	667	1.26	Kinbasket Lake Outlet	6	Kinbasket River	34	14.89	10	46
30300	9	150.25	720	1.8	Kinbasket River	1, 6, 7, 11, 113	Kinbasket Lake Outlet, Kinbasket River, Sullivan Arm, Sullivan River	28.4	10.32	5	49
30400	10	150.25	668	1.6	Kinbasket River	7, 11	Sullivan Arm, Sullivan River	12.6	2.79	4	41
30600	12	150.25	655	1.5	Kinbasket	7	Sullivan	16.9	7.17	0	49

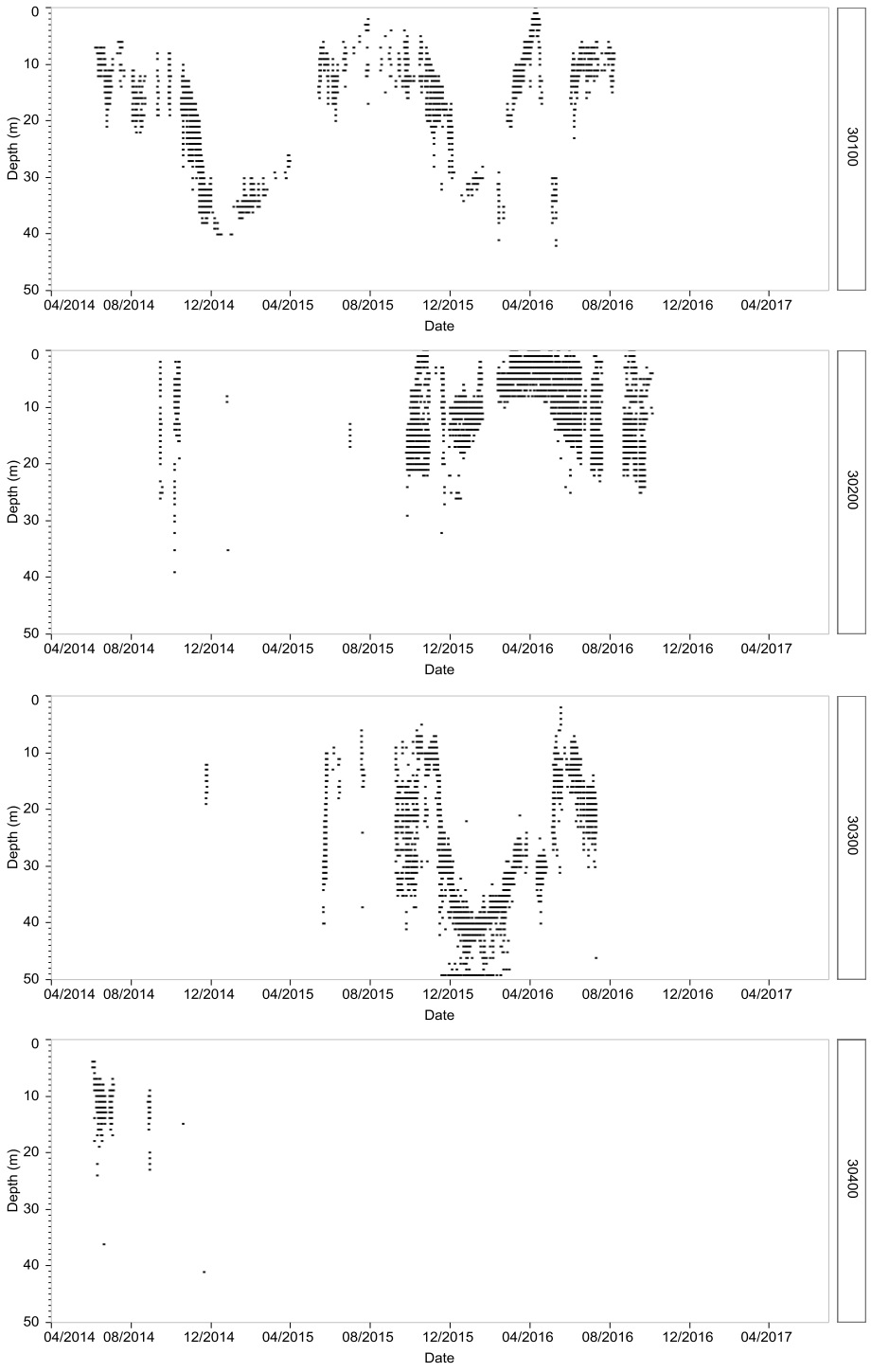
Acoustic Code	Radio Code	Frequency	Length (mm)	Weight (kg)	Capture Location	Receivers	Detection Location	Mean Depth (m)	SD Depth (m)	Min Depth (m)	Max Depth (m)
31100	17	150.25	950	4.6	River Kinbasket River	7, 8, 11	Arm Kinbasket Lake Inlet, Sullivan Arm, Sullivan River	19.2	5.74	0	49
31200	18	150.25	710	1.9	Kinbasket River	7, 11. 13, 15, 124	Lower Canoe Reach, Columbia Reach Entrance, Sullivan Arm, Sullivan River	16.9	7.25	1	45
33100	11	150.3		1.1	Kinbasket River	6	Kinbasket River	16.9	3.5	6	25
33700	7	150.3	645	1.24	Kinbasket River	4, 113	Kinbasket Lake Outlet, Sullivan Arm	38.9	5.3	27	42
34400	24	150.3	592	1	Kinbasket River	6, 8	Kinbasket River, Kinbasket Lake Inlet	16.6	6.17	0	47
35200	7	150.27	739	1.62	Kinbasket River	1, 4, 6, 113, 122	Kinbasket Lake Outlet, Kinbasket River, Sullivan Arm, Sullivan River	23.1	7.24	4	49
35300	8	150.27	859	2.66	Kinbasket River	6, 113	Kinbasket Lake Outlet, Kinbasket River	18.3	8.61	2	49
35900	14	150.27	864	3.06	Kinbasket River	6	Kinbasket River	16.1	5.99	3	28
36000	15	150.27	788	2.26	Kinbasket River	6	Kinbasket River	9	4.67	0	23
37300	12	150.3	756	1.86	Kinbasket River	113	Kinbasket Lake Outlet	2.1	3.4	0	14
39000	23	150.3	587	1.28	Kinbasket River	1, 4, 6, 8, 113, 121, 122	Kinbasket Lake Outlet, Kinbasket River, Kinbasket Lake Inlet, Sullivan Arm, Sullivan River	15.1	10.97	0	49
30500	11	150.25	735	2	Sullivan	1, 4, 7,	Kinbasket	18.1	7.31	0	49

Acoustic Code	Radio Code	Frequency	Length (mm)	Weight (kg)	Capture Location	Receivers	Detection Location	Mean Depth (m)	SD Depth (m)	Min Depth (m)	Max Depth (m)
					River	11, 113, 121, 122	Lake Outlet, Sullivan Arm, Sullivan River				
30700	13	150.25	742	1.8	Sullivan River	7, 11	Sullivan Arm, Sullivan River	18.8	1.81	4	26
30900	15	150.25	768	2.4	Sullivan River	5, 7, 10, 11, 12, 124	Lower Canoe Reach, Wood Arm, Wood River, Sullivan River	24.3	11.4	0	49
31000	16	150.25	794	2.25	Sullivan River	11, 12	Wood River, Sullivan River	5.9	2.8	3	47
31300	19	150.25	731	2.1	Sullivan River	1, 4, 6, 7, 11	Kinbasket River, Sullivan Arm, Sullivan River	26.8	13.54	4	49
31400	20	150.25	744	2.1	Sullivan River	7, 11	Sullivan Arm, Sullivan River	17.2	5.63	5	49
31600	22	150.25	784	2.4	Sullivan River	11	Sullivan River	10.1	2.35	5	21
31700	23	150.25	674	1.6	Sullivan River	11	Sullivan River	14	3.67	9	44
33200	12	150.3	647	1.4	Sullivan River	7, 11	Sullivan Arm, Sullivan River	20.6	6.58	4	36
33300	13	150.3	653	1.3	Sullivan River	1, 4, 6, 7, 11	Kinbasket River, Sullivan Arm, Sullivan River	22.7	6.86	3	49
34000	20	150.3	665	1.4	Sullivan River	7, 11	Sullivan Arm, Sullivan River	15.3	4.67	3	29
34600	1	150.3	723	1.9	Sullivan River	1, 4, 8, 114, 115, 116, 118, 122	Kinbasket Lake Inlet, Sullivan Arm, Surprise Rapids, Bush Arm, Esplanade Bay	16.9	10.28	2	41
34700	2	150.27	715	1.6	Sullivan	1, 4, 121,	Sullivan	5.1	4.39	0	32

Acoustic Code	Radio Code	Frequency	Length (mm)	Weight (kg)	Capture Location	Receivers	Detection Location	Mean Depth (m)	SD Depth (m)	Min Depth (m)	Max Depth (m)
					River	122	Arm, Sullivan River				
35400	9	150.27	700	1.7	Sullivan River	1, 4, 5, 121, 122	Wood River, Sullivan Arm, Sullivan River	9.1	5.19	0	32
35500	10	150.27	760	1.91	Sullivan River	1, 4	Sullivan Arm	11.2	5.81	7	24
35600	11	150.27	760	1.96	Sullivan River	121	Sullivan River	6.8	1.3	0	10
35700	12	150.27	939	3.96	Sullivan River	121	Sullivan River	6.4	1.8	0	10
36100	16	150.27	792	2.24	Sullivan River	1, 4, 8, 121	Kinbasket Lake Inlet, Sullivan Arm, Sullivan River	6.6	2.94	2	23
37800	17	150.3	727	1.6	Sullivan River	4	Sullivan Arm	18		18	18
38200	3	150.3	650	1.04	Sullivan River	4, 121	Sullivan Arm, Sullivan River	7.6	2.51	4	20
38300	4	150.3	669	1.3	Sullivan River	1, 4, 8, 114, 115, 118, 121, 122	Kinbasket Lake Inlet, Sullivan Arm, Sullivan River, Surprise Rapids, Esplanade Bay	18.8	9.01	2	35
35000	5	150.27	893	2.96	Windy Creek	1, 4, 8, 113, 115, 121, 122	Kinbasket Lake Outlet, Kinbasket Lake Inlet, Sullivan Arm, Sullivan River, Surprise Rapids	16.1	9.15	0	47
35100	6	150.27	713	1.73	Windy Creek	6	Kinbasket River	1		1	1
38400	5	150.3	588	0.84	Windy Creek	113	Kinbasket Lake Outlet	32.7	12.75	20	49
33900	19	150.3	620	1.3	Surprise Rapids	117	Columbia River	22.1	12.63	0	45
37600	15	150.3	818	2.7	Surprise Rapids	114	Surprise Rapids	0	0	0	0

APPENDIX 2: Mean daily depths of each Burbot during all monitoring periods (June 2014 to May 2017) in Kinbasket Reservoir (n=84, includes depth profiles of 15 Burbot suspected or confirmed to be dead). Spawning is expected to occur January (01/2015 or 01/2016) to April (04/2015 or 04/2016).

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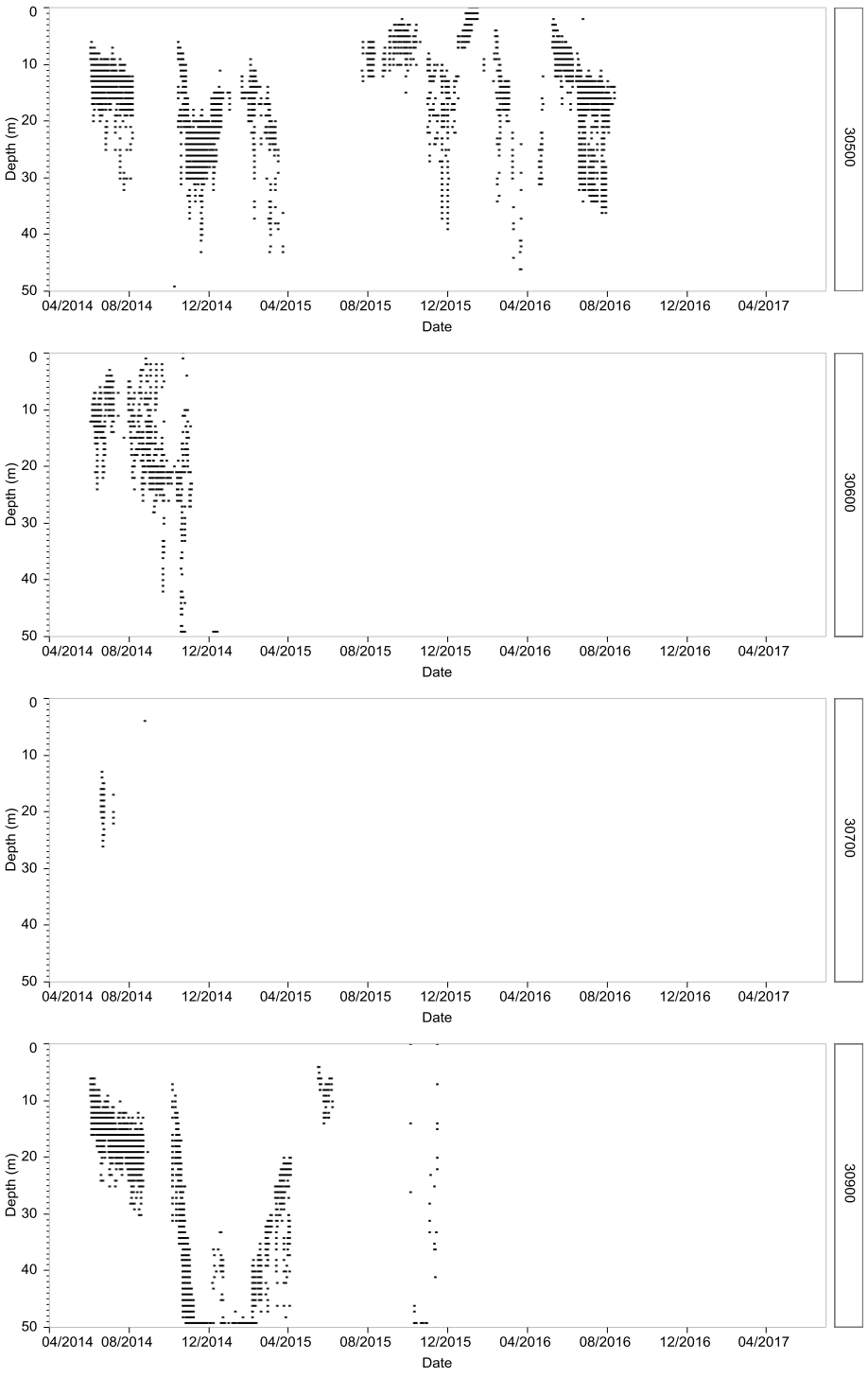
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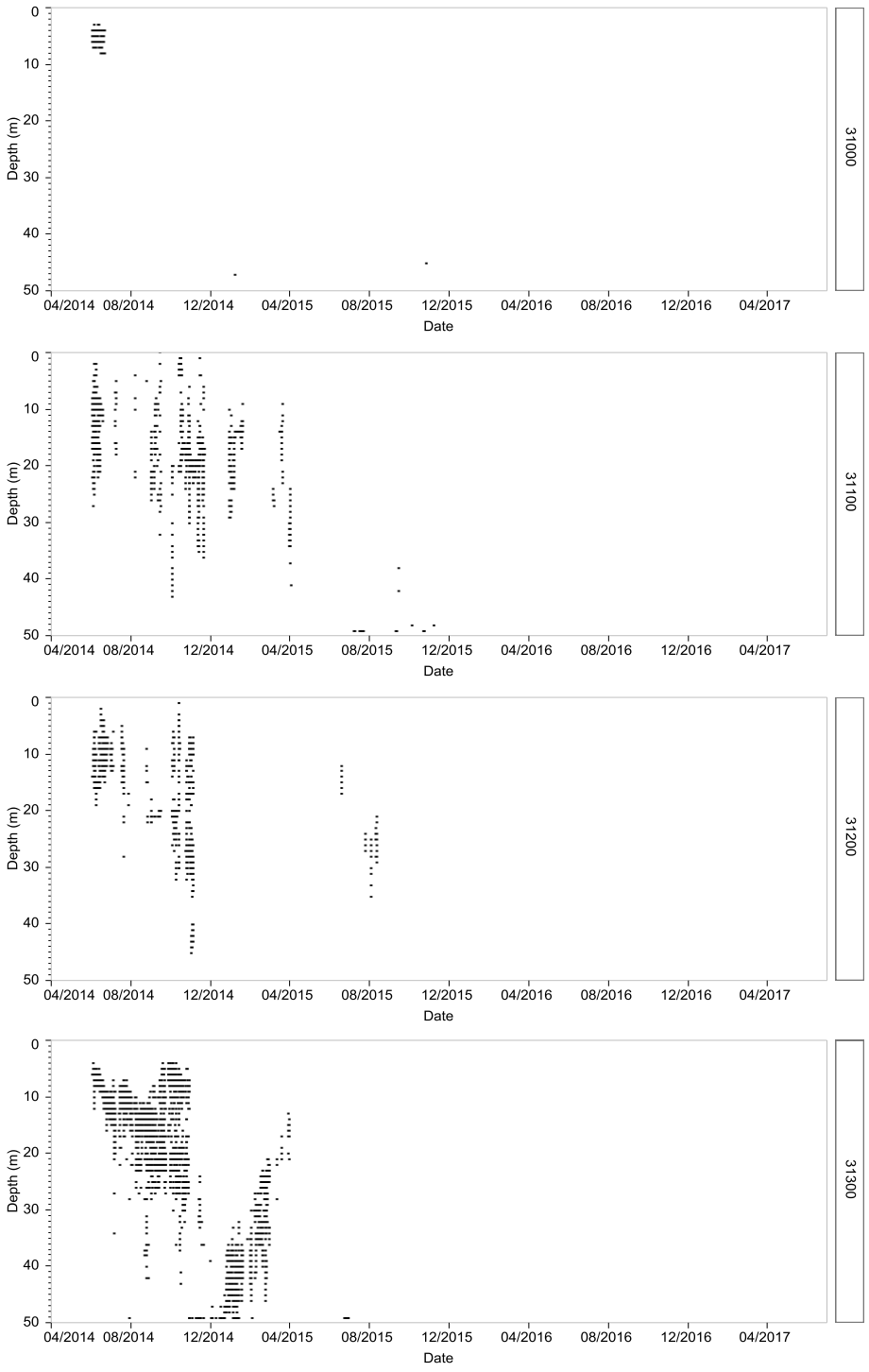
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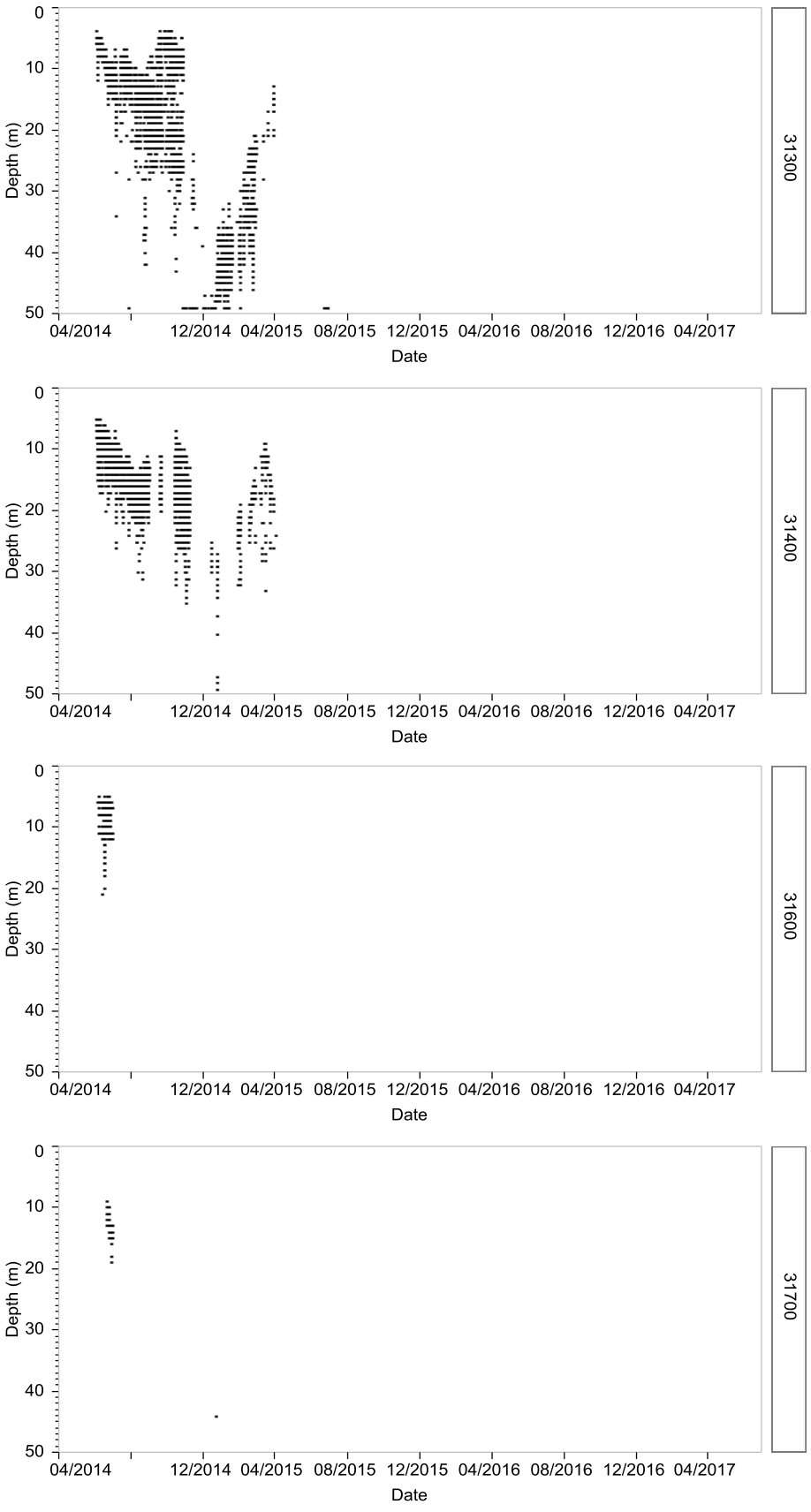
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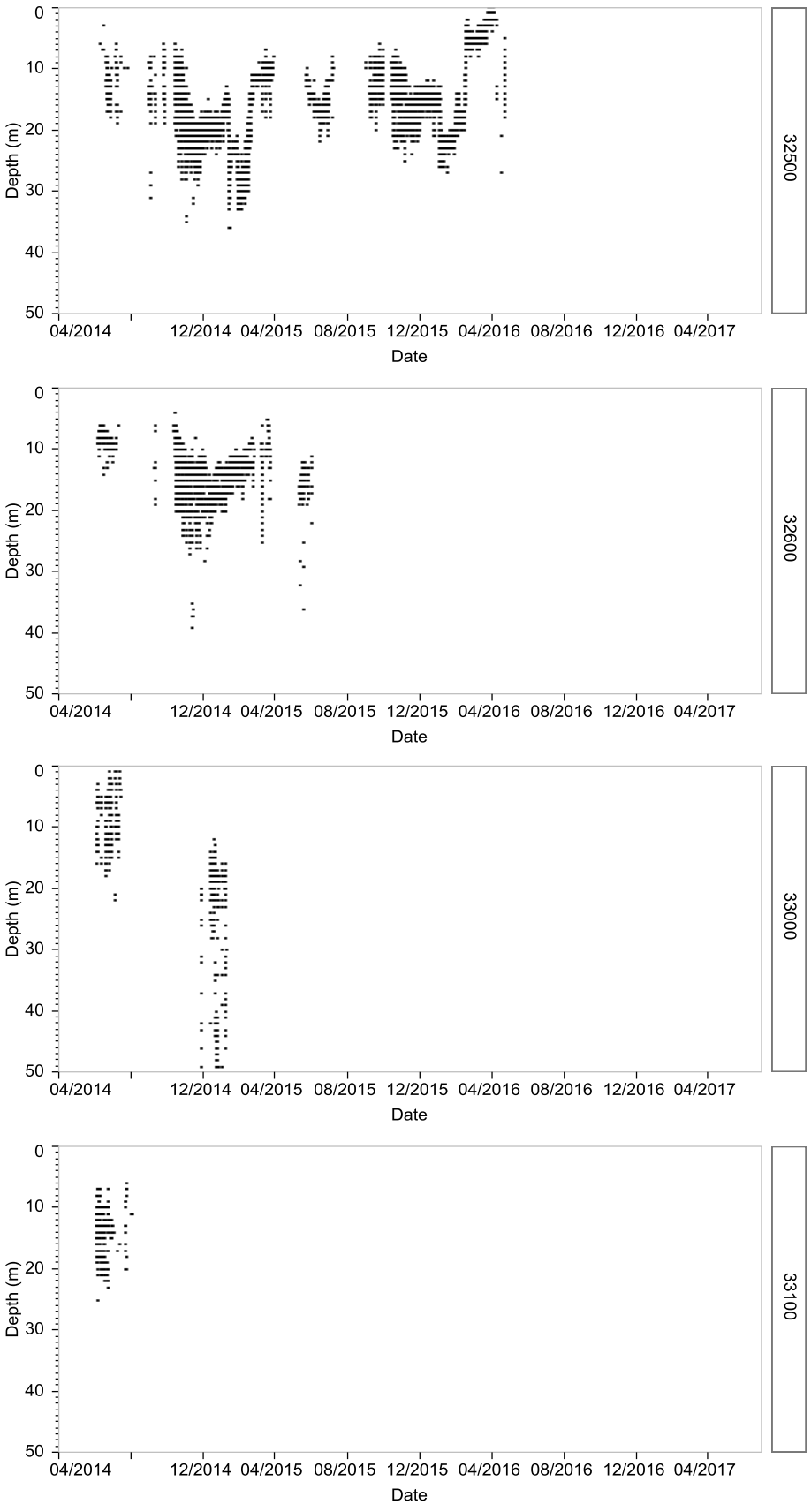
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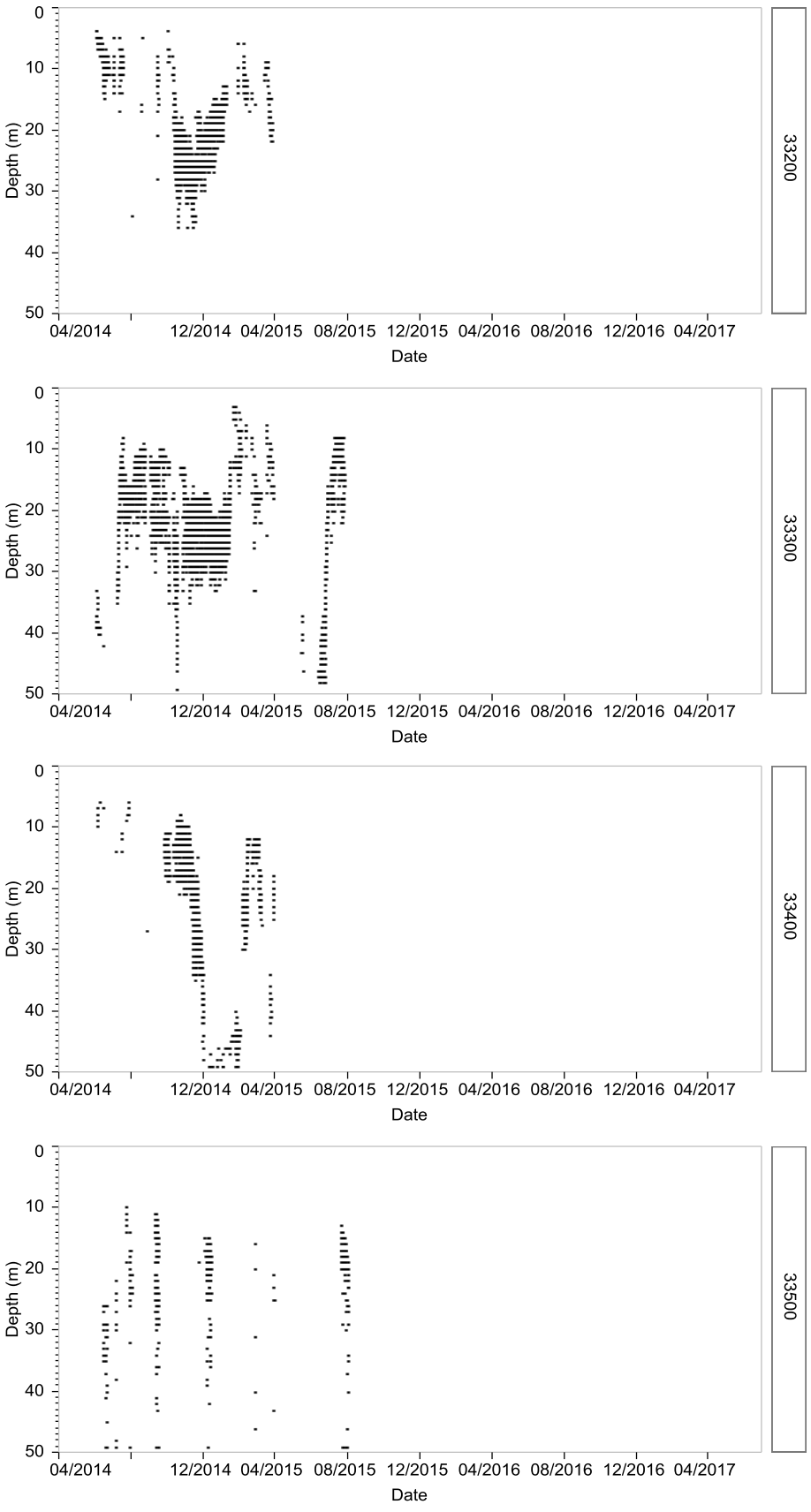
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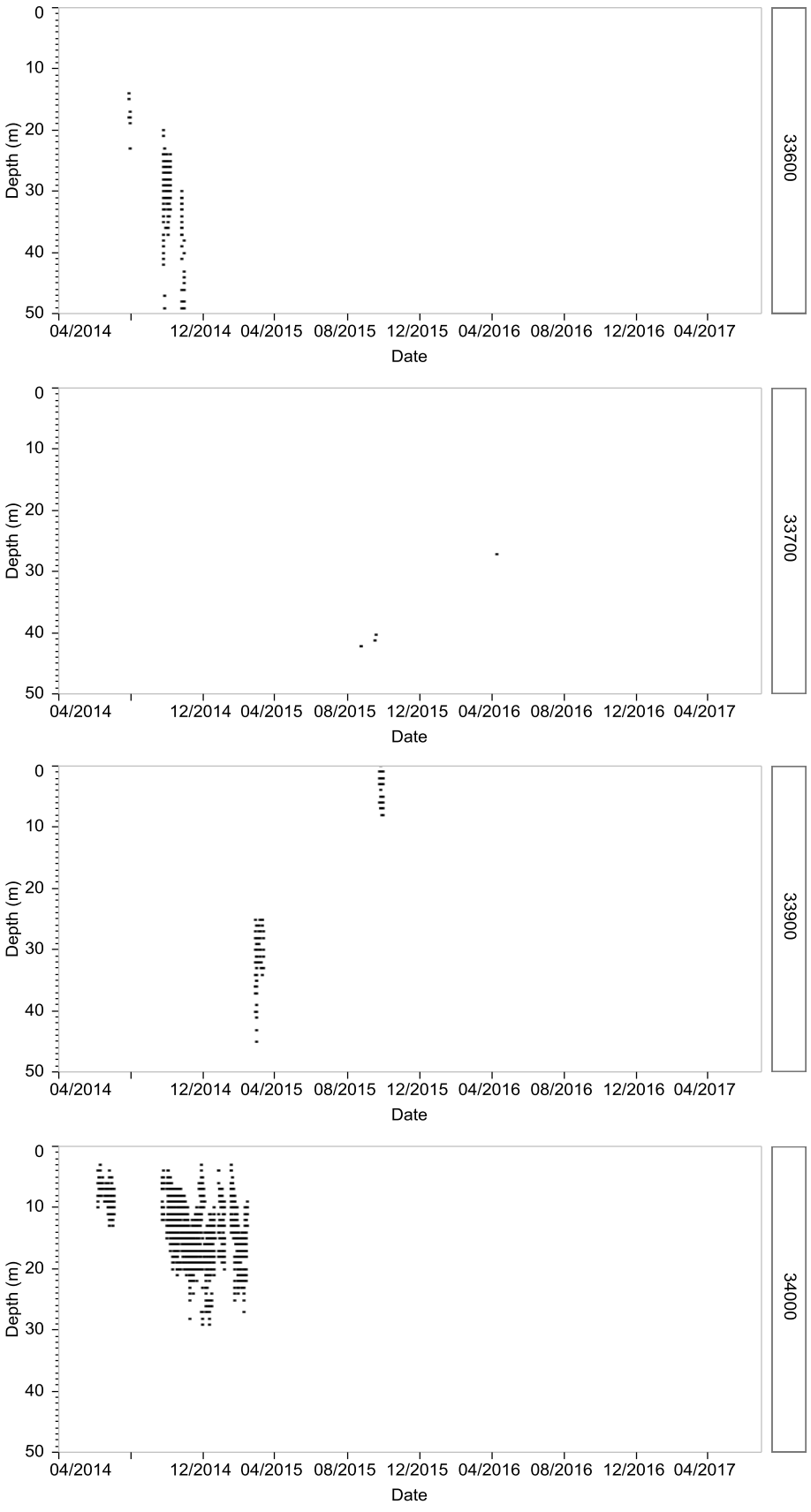
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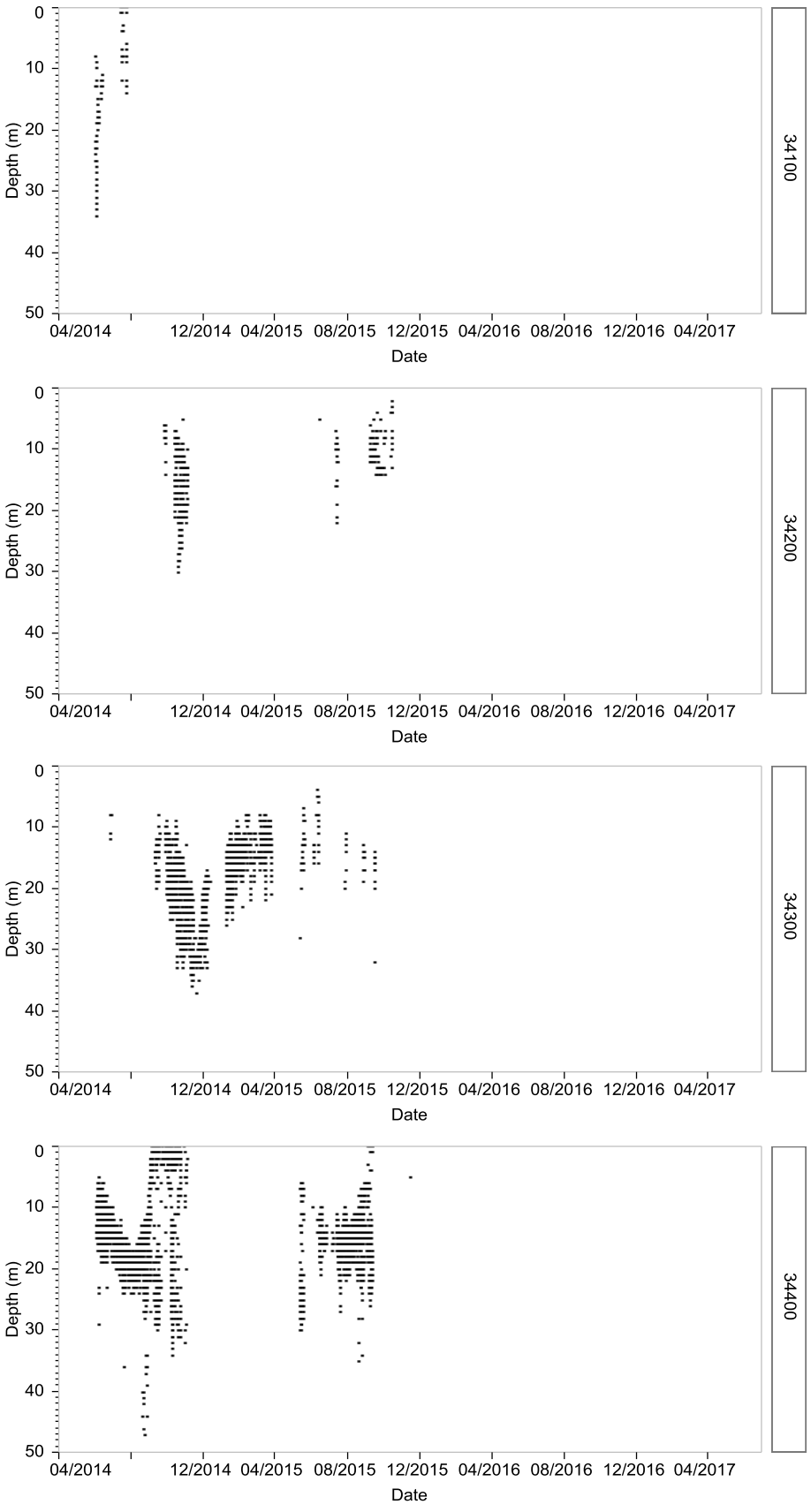
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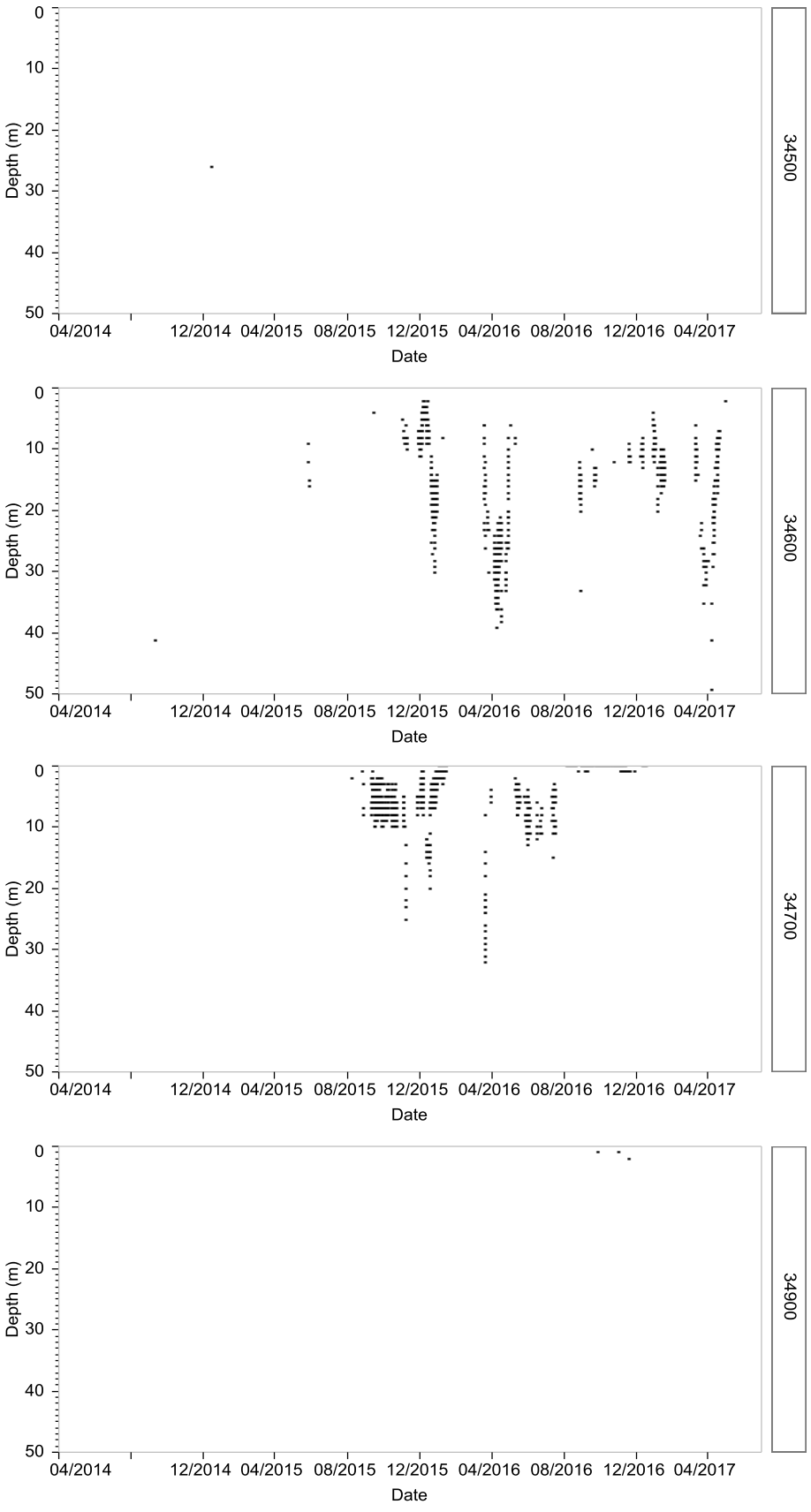
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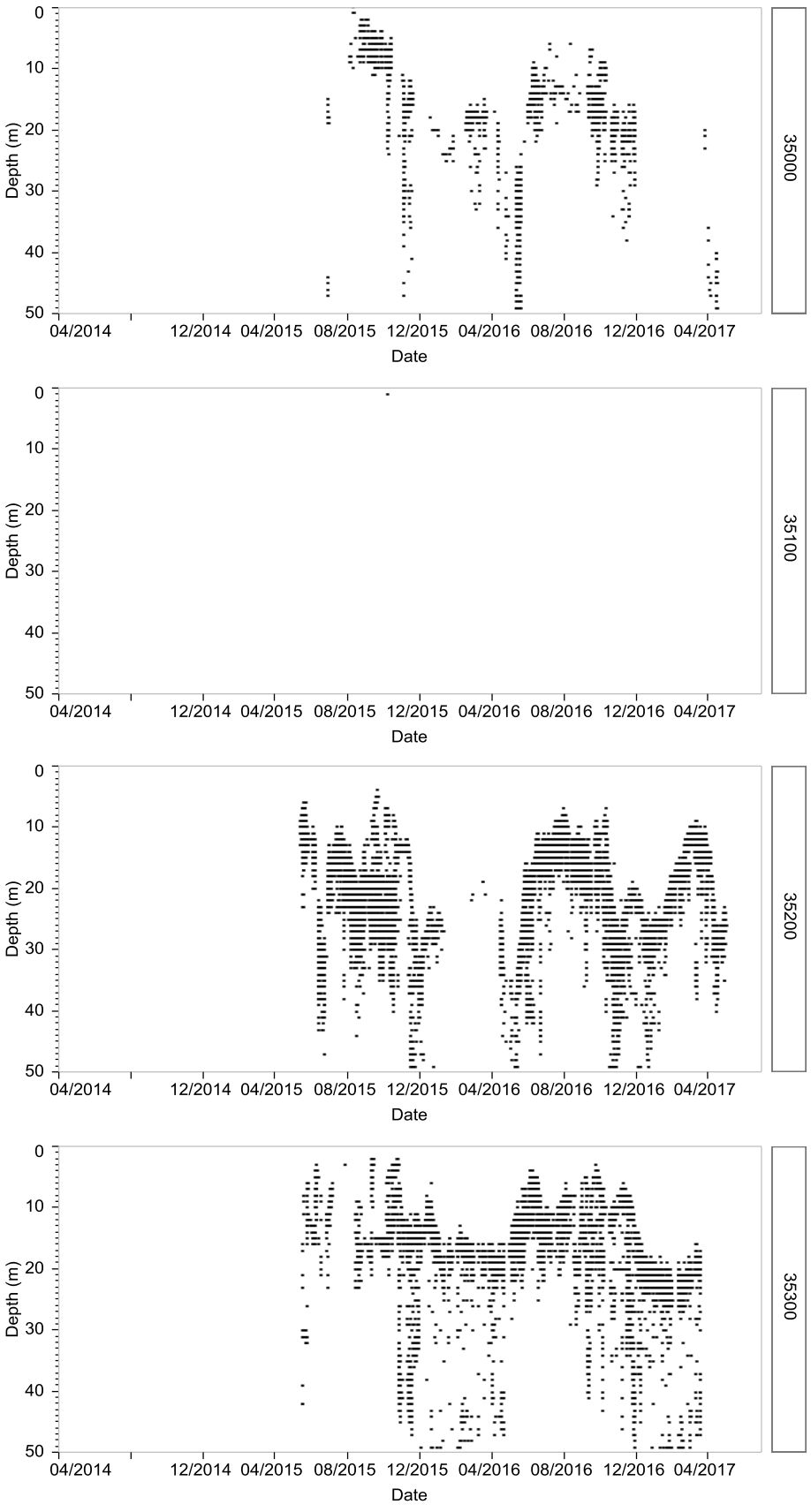
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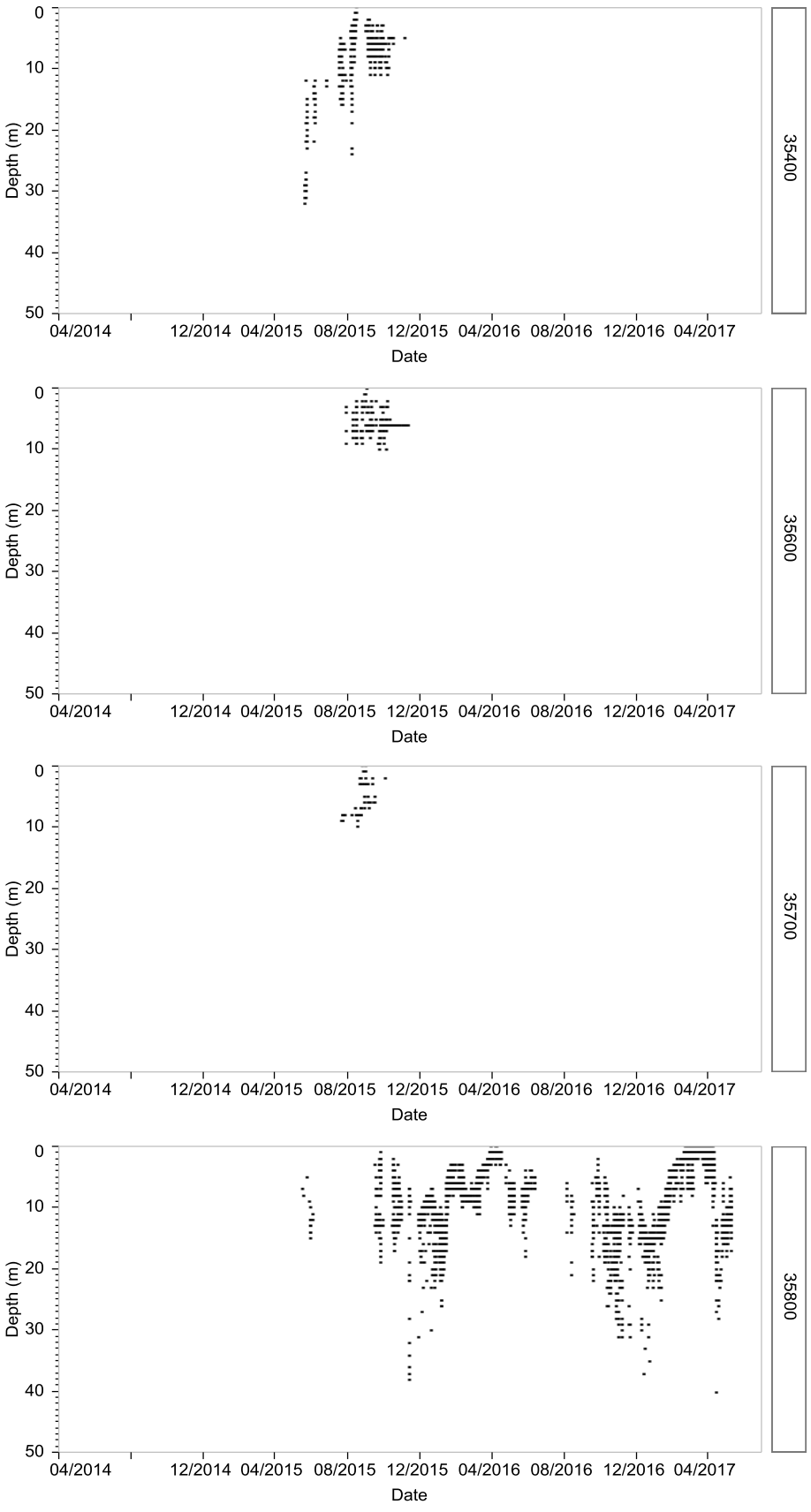
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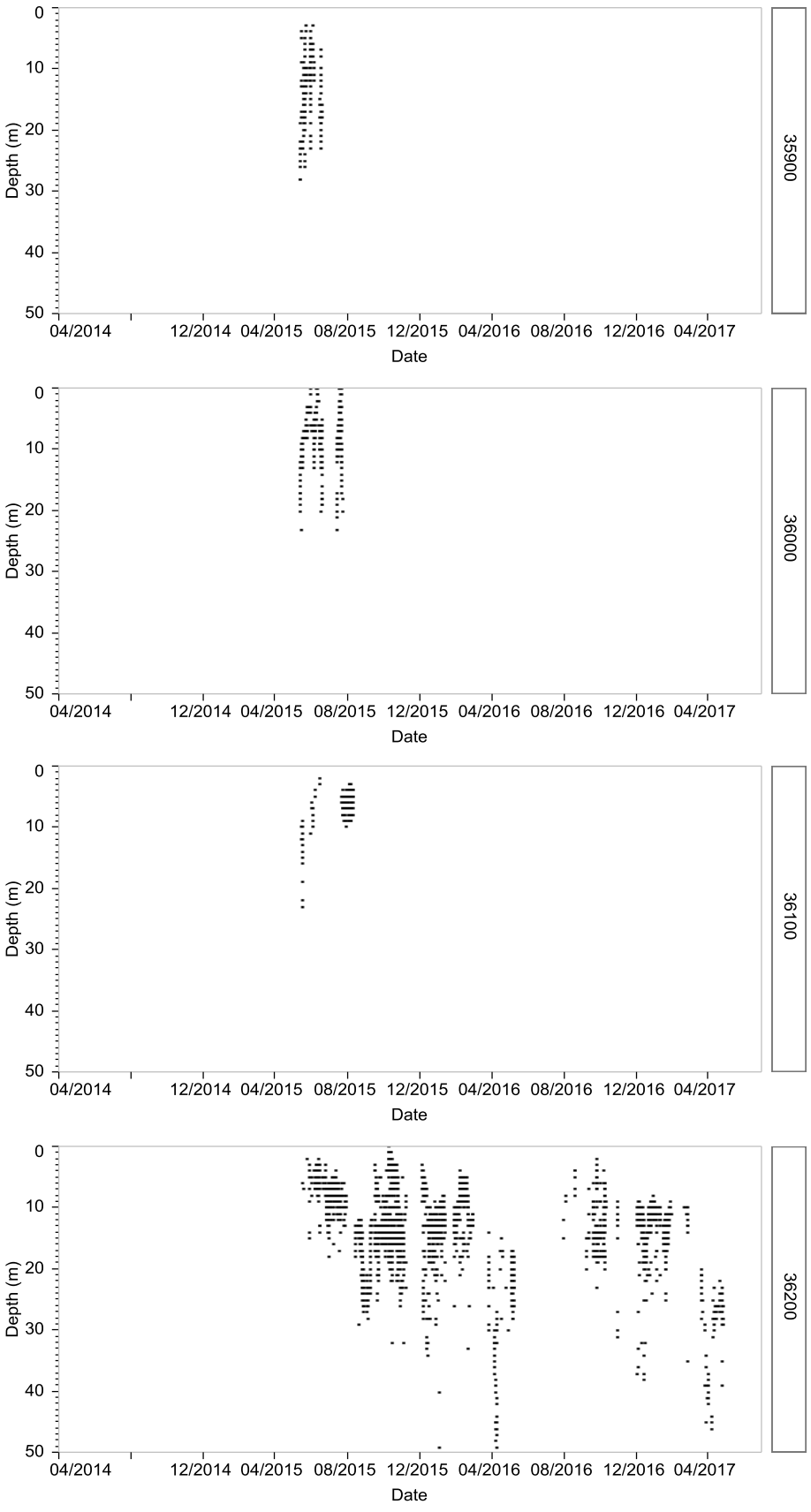
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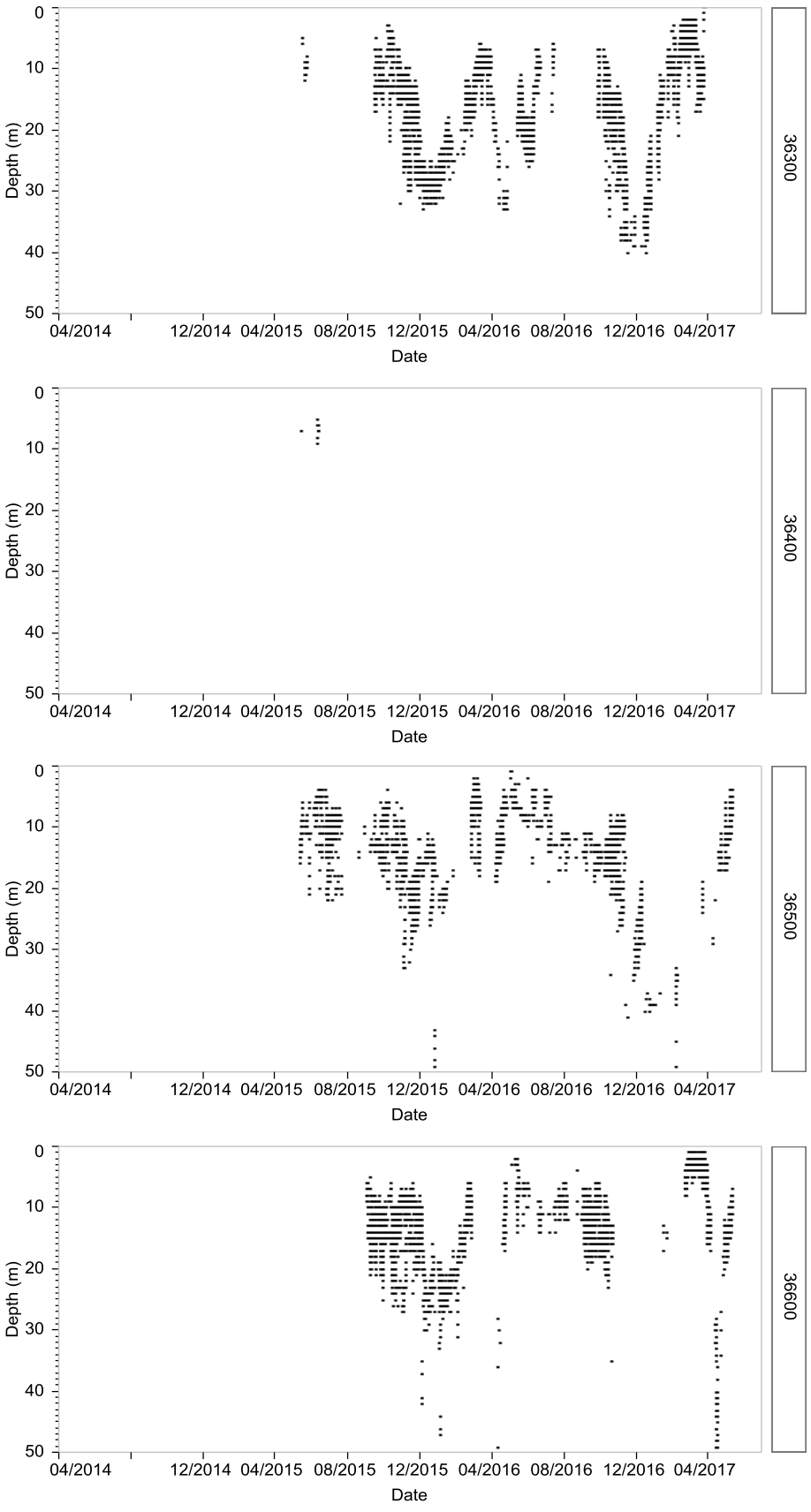
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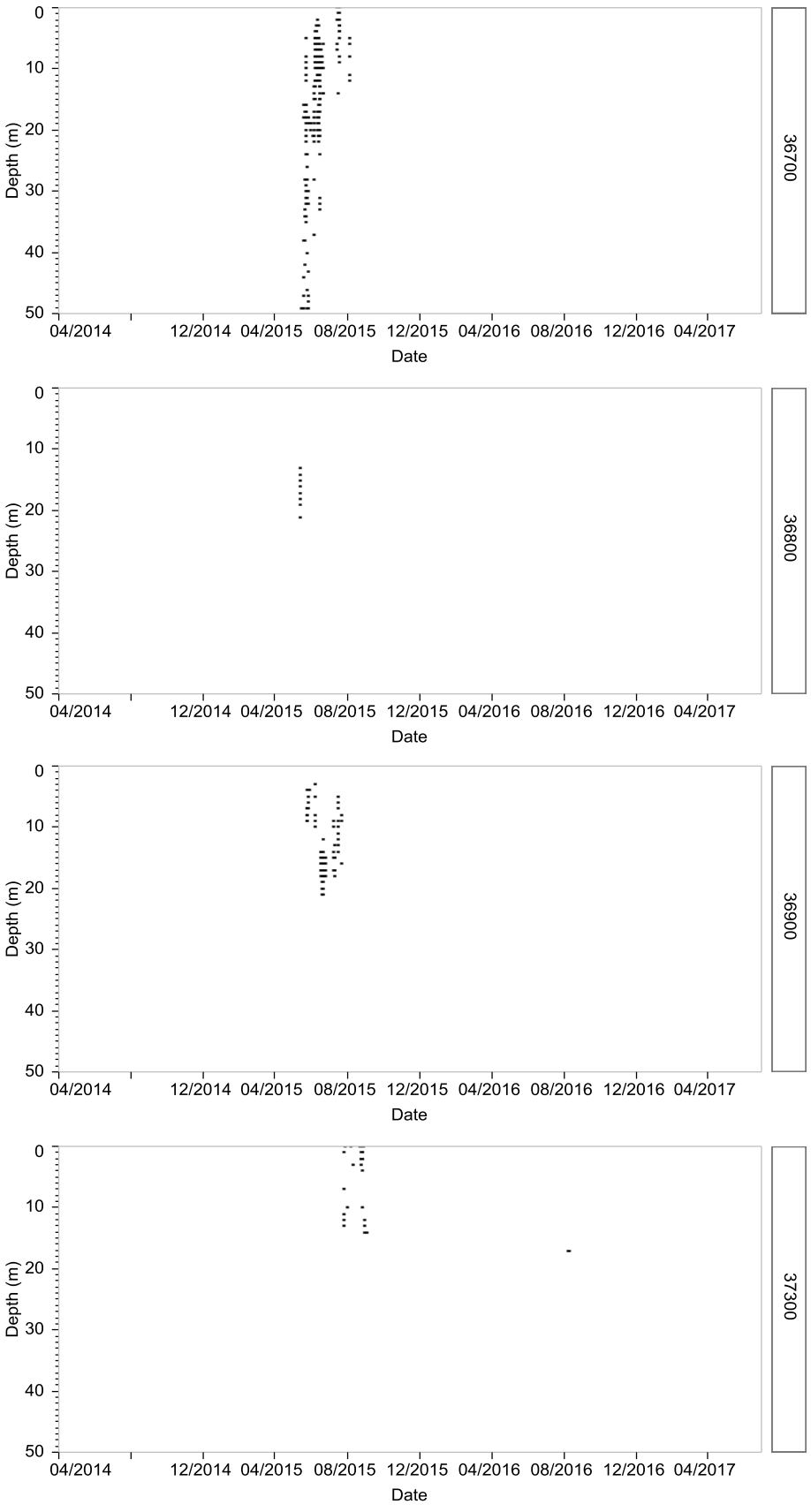
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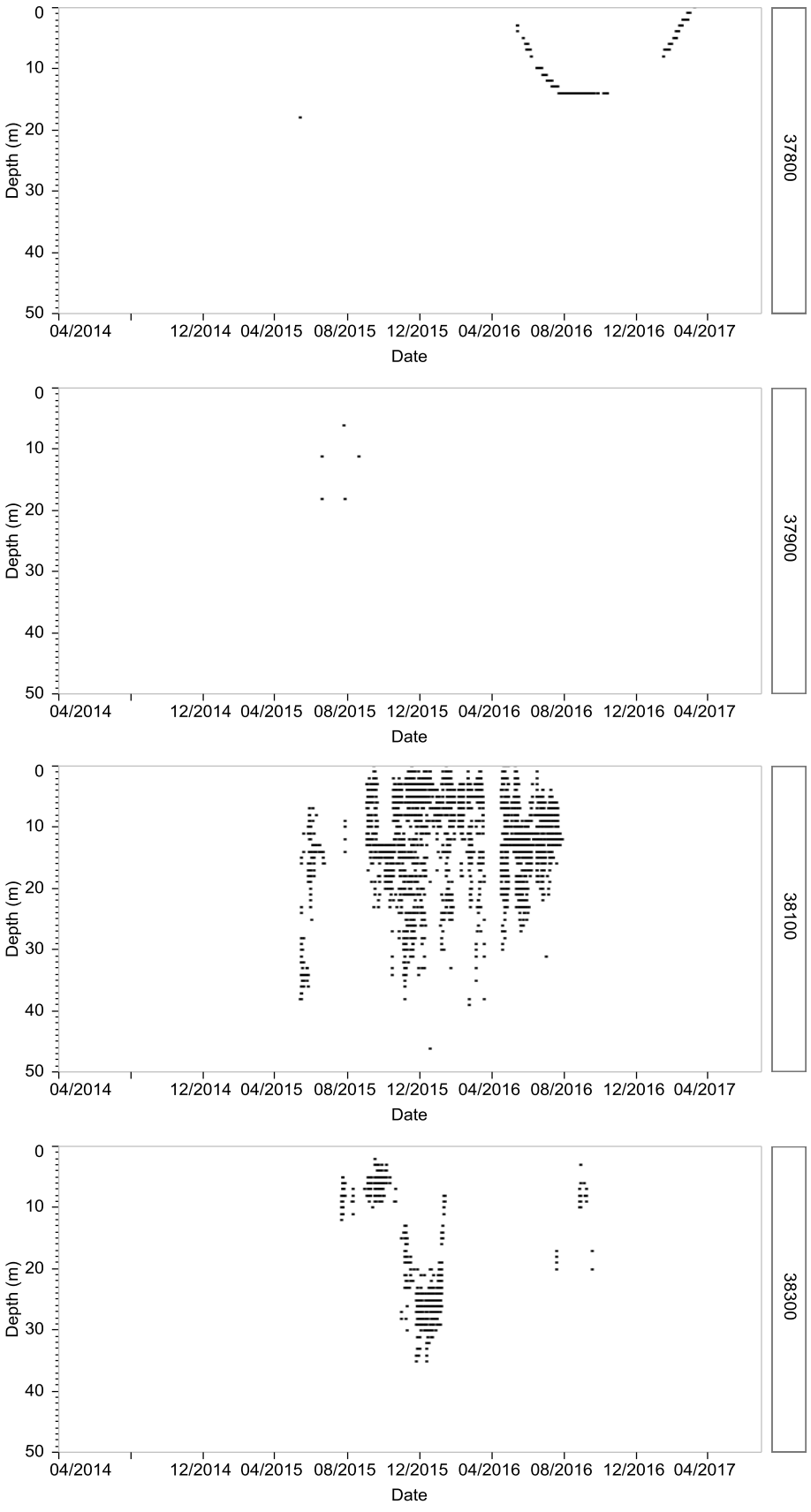
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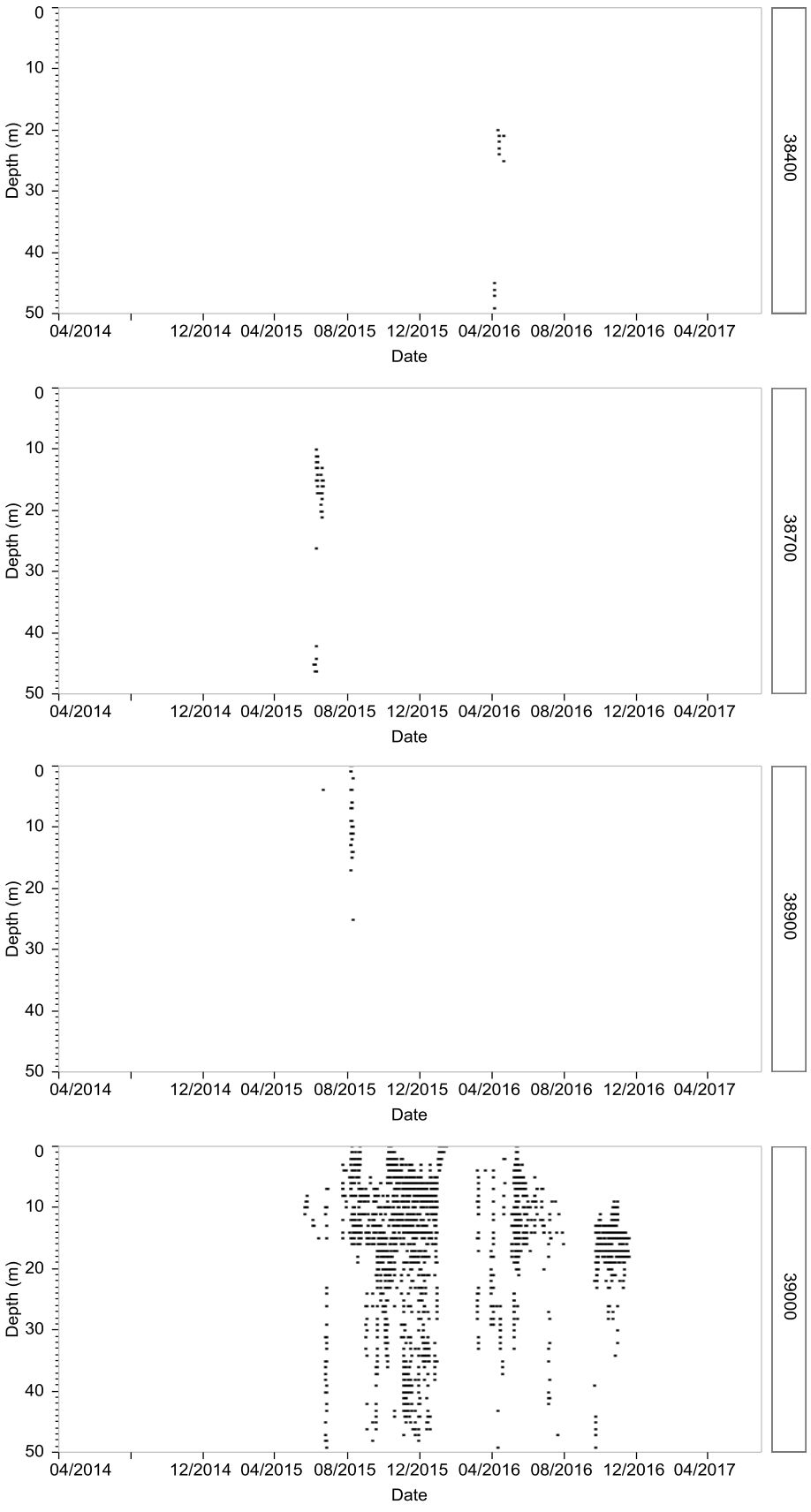
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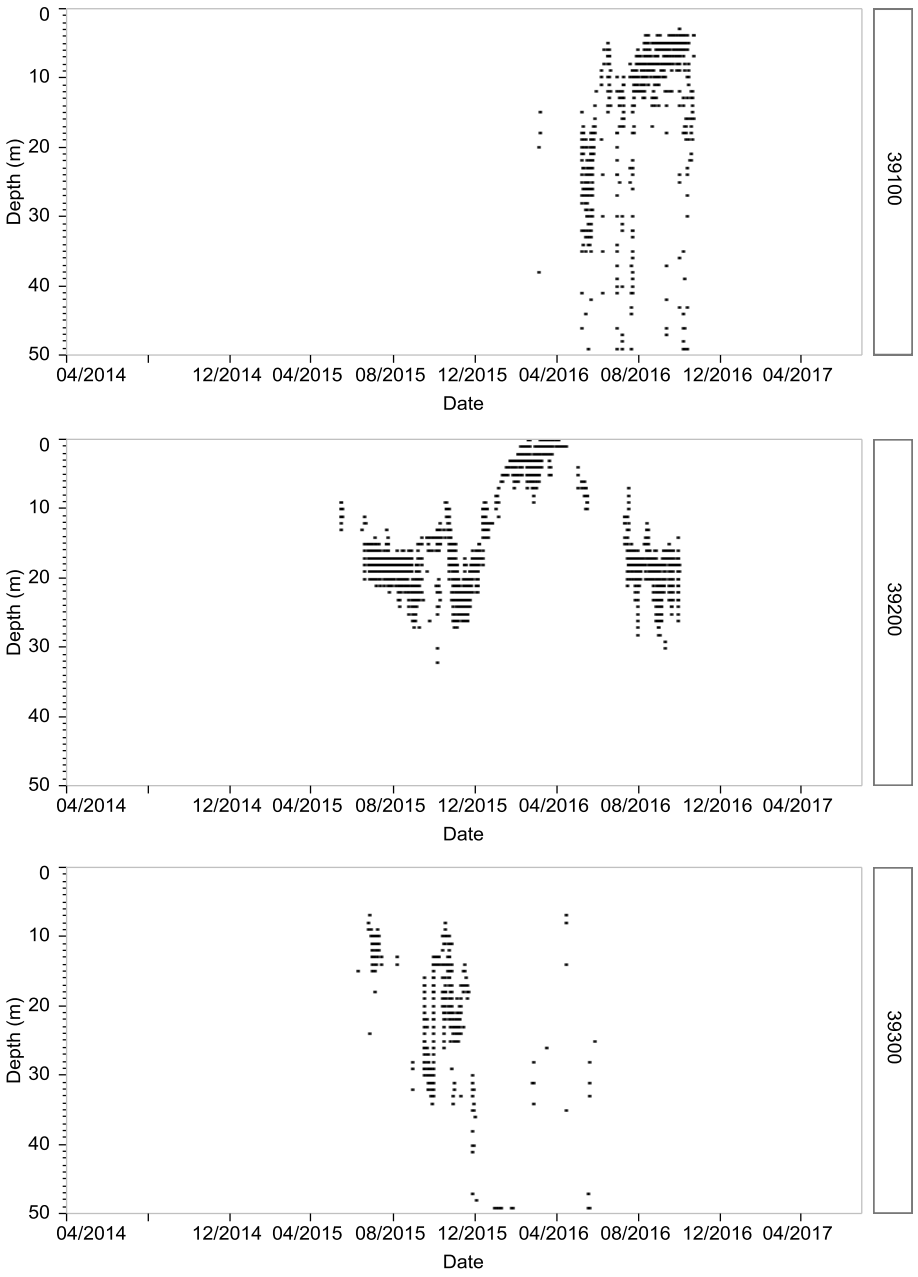
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