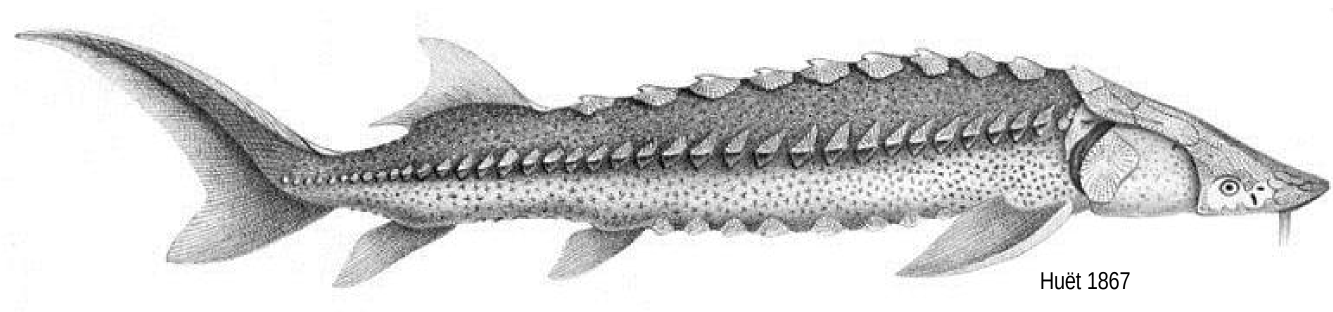
Rocky Reach Reservoir White Sturgeon Indexing and Monitoring Program 2016



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Final Report

19 October 2017

This report is a summary of the Public Utility District No. 1 of Chelan County *Rocky Reach Reservoir White Sturgeon Indexing and Monitoring* annual research studies that were conducted in 2016. This research project is currently being led by Blue Leaf Environmental, Inc. in collaboration with LGL Limited and Columbia Research Specialists. Presiding research scientists and contact information are listed below.

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P.U.D.
CHELAN COUNTY

Executive Summary

Chelan County Public Utility District is in its seventh year of a White Sturgeon (*Acipenser transmontanus*) hatchery supplementation program in the Rocky Reach Reservoir (Reservoir) on the Columbia River. The goal of the supplementation program is to promote White Sturgeon population growth to a level that is commensurate with available habitat in the Reservoir by 2039. To date, a total of 28,210 hatchery-reared juvenile sturgeon have been PIT tagged and released into the Reservoir including 2,273 in 2016. This report describes work done in 2016, the first year of Phase II of the program.

Acoustic telemetry was used to monitor sturgeon movements within and emigration out of the Reservoir. Since monitoring began in 2012, an array of acoustic receivers has been in place, and 219 sturgeon have been acoustically tagged and released. Although no acoustic tags were deployed in 2016, 109 tags remained active from previous deployments, of which 75 (69%) were detected on at least one receiver in 2016. As in past years, the highest numbers of detections and longest residence times were in the immediate tailrace of Wells Dam. Tracking in 2016 revealed that the 50 older (age 4-6) individuals (those recaptured and acoustic-tagged in 2015) behaved differently from the younger acoustic-tagged sturgeon (age 1) that were tracked in previous years. Half of the older fish never moved outside of the Wells tailrace, and the other half behaved more like adult sturgeon, making long-distance movements and in some cases multiple Reservoir transits. To date, ten acoustic-tagged fish have emigrated to areas downstream of the Reservoir, an overall weighted emigration proportion of 8.2% of all released sturgeon since 2012.

A PIT tag mark-recapture indexing study has been run since 2013. In each year, indexing occurred over several 5-10 day fishing sessions between mid-August and late-October. In 2016, all setlines were baited with pickled squid, and deployed for ~22 hours at randomized locations. Recapture data for the 2016 release cohort were not adequate for survival estimation, and the 2015 release group had not been in the Reservoir for long enough to permit estimation of its long-term survival rates. Regardless, results to date have shown decreasing survival with each additional supplementation group since 2012, suggesting possible density dependent effects. True short-term survival was estimated at: 37.6% (CI: 30.8-45.6%) for the fish released in 2011; 76.9% (CI: 51.7-95.0%) for the 2012 cohort; 58.6% (CI: 51.7-66.0%) for the 2013 cohort; 41.3% (CI: 34.1-49.8%) for the fish released in 2014; and 30.7% (CI: 24.4-38.6%) for the 2015 releases. True intermediate-term survival rates were estimated for the 2011-2015 cohorts as 45.2% (CI: 35.1-56.0%), 92.1% (CI: 52.6-99.2%), 78.5% (CI: 66.9-86.8%), 49.4% (CI: 39.3-59.6%), and 29.6% (CI: 21.4-39.2%), respectively. True annual long-term survival rates for the 2011-2014 cohorts were 73.4% (CI: 66.3-79.5%), 97.7% (CI: 79.1-99.8%), 94.2% (CI: 89.7-96.8%), and 81.6% (CI: 72.5-88.2%), respectively.

Median sturgeon growth rates (by fork length) were 54-187 mm/yr within the first half year following release, slowed over the next two years to 53-122 mm/yr, and slowed further after 3.5 years to 90-98 mm/yr. Condition of fish declined quickly after release: median relative weights ranged from 102-121% at the time of tagging, and dropped to 75-85% after a few months in the Reservoir. Median relative weights increased over time, either due to gradual improvements in general fish condition, or to selective demise of the fish in worst condition. Within the first half year following release, median rates of weight change ranged from -0.3 to +148 g/yr. After 1.5 years in the Reservoir, median rate of weight gain ranged from 71-238 g/yr,

and these rates continued to increase over time. Fish recaptured in the lower parts of the Reservoir had grown more than those recaptured in the upper reaches.

Acoustic-tracking and indexing are slated to continue through to 2020. The additional data will help resolve the results presented herein, and will provide valuable information about the success of the supplementation fish as they continue to persist in the Reservoir.

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Introduction

Prior to the Federal Energy Regulatory Commission (FERC) relicensing of Rocky Reach Hydroelectric Project, the *White Sturgeon Technical Group* was formed in 2004, comprising Chelan County Public Utility District (Chelan PUD) biologists, and stakeholders from state, federal, and tribal agencies. The role of the *White Sturgeon Technical Group* was to advise the Rocky Reach Fish Forum (RRFF) and coordinate the effort to develop the *Rocky Reach Comprehensive White Sturgeon Management Plan* (WSMP). The WSMP was completed in 2005, and has been adaptively implemented by the Rocky Reach Fish Forum since the new FERC license began in 2009.

Overall, the goal of the WSMP is to promote White Sturgeon population growth to a level commensurate with available habitat in the Rocky Reach Reservoir (Reservoir) by 2039. The following objectives are planned to assist in meeting this goal: 1) increase the White Sturgeon population in the Reservoir through supplementation, specifically to a level commensurate with available habitat, that will allow for an appropriate and reasonable future harvest; 2) determine the effectiveness of the supplementation program; 3) determine the carrying capacity of available habitat in the Reservoir; and 4) determine the natural reproduction potential in the Reservoir, with corresponding adjustments made to the WSMP supplementation program as needed.

Since 2010, Chelan PUD has been employing measures to fulfill the first objective, with the initiation and continuation of a supplementation program using captured wild adults for broodstock. To date, a total of 28,210 hatchery-reared juvenile sturgeon have been injected with Passive Integrated Transponder (PIT) tags, and released into the Reservoir.

Since 2012, Chelan PUD has been addressing the second objective of the WSMP, to measure the effectiveness of the supplementation program, by initiating: 1) a long-term indexing program; and 2) an acoustic telemetry study. The Initial Phase of the effectiveness monitoring ran from 2012 to 2015. The Initial Phase included a preliminary three-year indexing effort based on mark and recapture of PIT-tagged sturgeon. The indexing program included focused fishing effort in the Reservoir to recapture hatchery-produced juvenile sturgeon, such that survival and growth rates could be assessed, sturgeon distribution could be quantified, and habitat associations could be measured. The primary goal of the three-year acoustic telemetry study was to assess the downstream emigration rates of supplementation release groups over time, while also providing insight into the seasonal behavior and habitat use of sturgeon in the Reservoir. Details of the activities carried out in Phase I are in Robichaud et al. (2016).

Following the completion of Phase I, the RRFF determined that annual monitoring should be extended through 2020 to build on the information obtained over the first three years. Prior to the initiation of Phase II, index setline techniques were modified based on information gained during Phase I, and have now been standardized across the three Mid-Columbia PUD's (Chelan, Grant and Douglas) sturgeon supplement-ation programs. The telemetry portion was also extended with the aim of monitoring emigration of older sturgeon. In addition, an annual diet study was added to the program. The current report describes work done in 2016, the first year of Phase II of the program (Phase II runs until 2020). The data collected during

Phase II, including indexing, acoustic telemetry, and diet studies, will help identify potentially suitable rearing habitats, help to determine the carrying capacity of the Reservoir, and identify factors that may influence population size.

Methods

Study Site

The Reservoir on the Columbia River is formed by Rocky Reach Dam (river kilometer, RKM 762) and extends 67 km upstream to Wells Dam (RKM 829; Figure 1). Two tributaries enter the Reservoir from the west including the Entiat (RKM 778) and Chelan (RKM 810) rivers.

Habitat types transition from high water velocities and riverine conditions in the Wells Dam tailrace to low water velocities and reservoir-like conditions in the Rocky Reach Dam forebay. To reflect this transition, we divided the Reservoir into four zones of approximately equal length, delimited by natural topography. The zones were: 1) Upper Reservoir; 2) Mid-Reservoir North; 3) Mid-Reservoir South; and 4) Lower Reservoir. The Upper Reservoir zone extended from the Wells Dam to Beebe Bridge and was characterized by high velocities and riverine conditions. The Mid-Reservoir North (Beebe Bridge to Duck Tail Rock) and Mid-Reservoir South (Duck Tail Rock to Entiat River) zones were characterized by intermediate velocities and riverine/reservoir-like conditions, but with the latter zone having more reservoir-type habitat. The Lower Reservoir zone extended from the Entiat River to Rocky Reach Dam and was characterized by low water velocities and reservoir-like conditions.

Environmental Conditions

Over the past 10 years, discharge through the Reservoir has ranged from a mean monthly low of 1,700 m^3/s (60 kcfs) in autumn to a mean monthly high of 5,100 m^3/s (180 kcfs) in spring; and water temperatures have typically ranged from 4 to 19°C. The mean river flows during the study period (6 Nov 2015 – 12 Oct 2016) were slightly lower than the 10-year mean (Δ = -19 kcfs overall) and temperatures were slightly warmer than the 10-year mean (Δ = 0.3°C overall, Δ = 1.4°C summer). Runoff was earlier and summer flows were lower than normal (Figure 2).

PIT-Tag Releases

Chelan PUD staff released marked hatchery-reared juvenile sturgeon in each year from 2011 to 2016 (Table 1). Over the years, fish were raised at Marion Drain, Columbia Basin, and Chelan hatcheries. All released fish were PIT-tagged, scute-marked, and measured (fork length at the time of tagging); during 2011-2015 a subset of the individuals were weighed, and beginning in 2016 all fish were weighed. PIT-tagged fish were held prior to release to ensure recovery. Since 2013, the cohort of PIT-tagged fish were divided up and released at multiple locations in the Reservoir. Similarly, the 2016 cohort was released at three locations in approximately equal quantities (Table 2). Tagging and release dates, hold durations, and numbers of fish released are shown for each year in Table 1.

In addition to the hatchery releases, PIT tags were also applied *in situ* to recaptured scute-marked sturgeon (scute marks indicate hatchery origin) whose original PIT tags had failed or been shed.

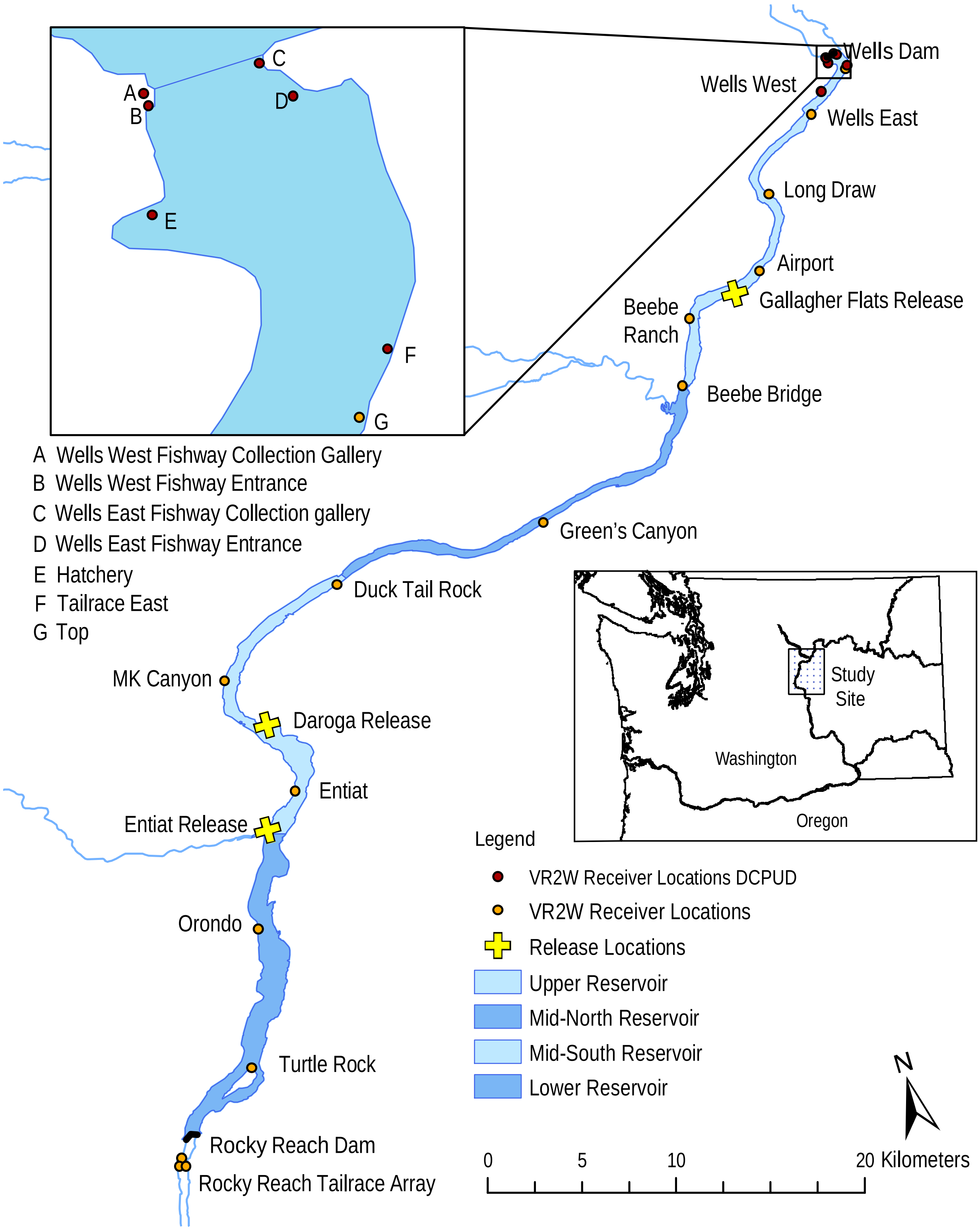

Figure 1. Overview of Rocky Reach Reservoir study area with locations of Vemco VR2W receiver deployment locations in 2016. Reservoir zones are indicated using alternating shades of blue.

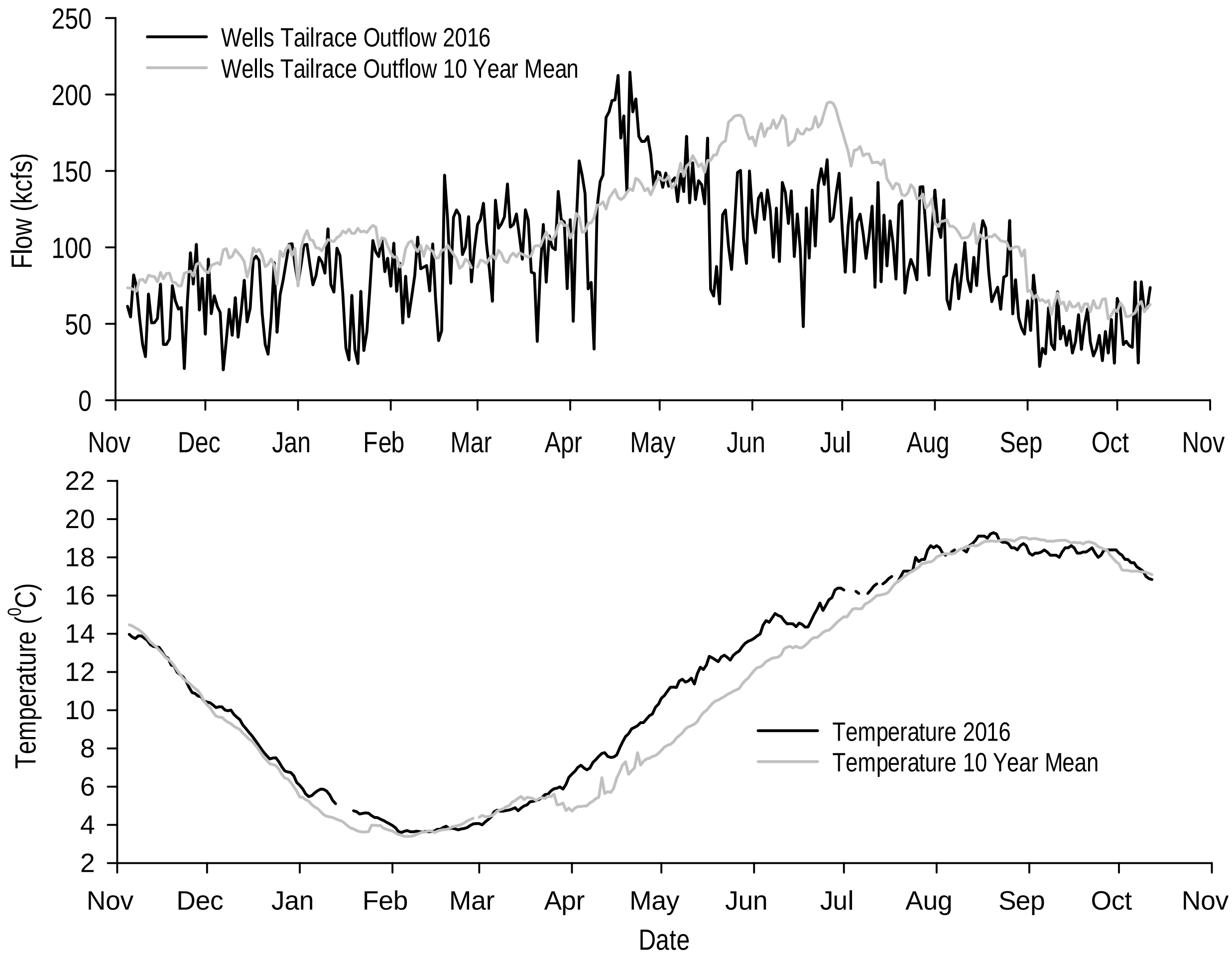

Figure 2. River flow (top) and temperature (bottom) including the 10-year mean measured at the Wells Dam tailrace water quality site in 2016 (data source: http://www.cbr.washington.edu/dart/river.html).

Acoustic Tagging and Tracking

Acoustic Tags

The primary purpose of past acoustic tagging was to estimate emigration rates from the Reservoir and to understand movements and habitat use. In 2016, no new acoustic tags were applied to sturgeon, however the manufacturer's estimated expiration dates suggested that 109 acoustic tags from previous years were still active during the 2016 season (Table 3). In 2015, 50 longer-life (Vemco Model V13) tags had been applied to large-sized recaptured sturgeon for the expressed purpose of allowing continued tracking data beyond age-3. Information regarding the original release locations and movements prior to November 2015 can be found in Robichaud et al. (2016).

Table 1. Details of Chelan PUD's spring releases of juvenile sturgeon by year, including source hatcheries, number and average size of fish, tagging dates, release dates, and holding durations. All fish were PIT-tagged.

Release Year	Source Hatchery *	Number Released	Average Fork Length (mm)	PIT Tagging Dates	Acoustic Tagging Dates	Release Dates	Hold Duration (days)
2011	Ch, MD	6,376	244.9	8-15 Mar	-	20-21 Apr	36-44
2012	Ch	137	189.1	29 Mar	11-13 Sep	16 May	48
2013	Ch, Co	7,975	251.7	12-22 Mar	24-25 Apr	20-23 May	59-72
2014	Ch, Co	4,962	246.0	3-24 Mar	14-16 Apr	8-15 May	45-73
2015	Ch, Co	6,487	263.9 †	23 Mar - 23 Apr	-	27-30 Apr & 8 May	8-38
2016	Ch, Co	2,273	310.2	25-28 Apr	-	10-12 May	12-17

* Ch = Chelan Hatchery; Co = Columbia Basin Hatchery; MD = Marion Drain Hatchery.

† Distribution was bimodal, with peaks for each hatchery (mean 183.7 mm at Chelan, and 316.5 mm at Columbia Basin)

Table 2. Numbers of White Sturgeon released in 2016, by release location. All fish were PIT-tagged.

Location	RKM	Release Date	Number of Fish Released
Gallagher Flats	817	10-11 May 2016	757
Daroga Boat Launch	785	10-11 May 2016	758
Entiat	778	10,12 May 2016	758
		2016 Totals	2,273

Table 3. Number of acoustic tags in juvenile sturgeon that were expected to be active during 2016, and estimated battery-expiration dates.

Vemco Tag Model *	Qty	Est. Expiration Dates/Years
V9P-2L	5	1 Jun 2016
V13P-1L	1	26 Dec 2016
V9-2L	50	2017
V13-1L	3	2017
V13-1L	50	2020
Total	109	

*Models with P indicate depth sensor

Receiver Locations

In order to monitor the movements of acoustically-tagged juvenile sturgeon, 15 Vemco Model VR2W (hereafter VR2W) receivers were deployed throughout the Reservoir and in the Rocky Reach Dam tailrace in spring of 2012. Details on deployment are found in Robichaud et al. (2016).

On 3-4 November 2015, the VR2W receivers were redistributed from their prior 'paired' positions (with mean separation of 12 km, see Robichaud et al. 2016) to new positions, deployed singly, with a mean separation of 6 km (Figure 1). This redistribution was done to gain finer-scale resolution on movements, while minimally sacrificing detection efficiency (based on analysis of the 2012-2015 acoustic data set, single receivers were determined to have good detection efficiency). Additionally, in the spring of 2015 Douglas County Public Utility District (DCPUD) installed two VR2W receivers in the tailrace of Wells Dam and then four more at or inside the Wells fishway entrances. With the combined Chelan and Douglas PUD receivers there were 22 VR2W's in the Reservoir (including the Wells fishways) in 2016 (Figure 1).

Receiver Detection Data Analysis

Receivers were pulled to the surface, inspected, and downloaded quarterly. Data were downloaded to a field laptop running Vemco VUE software and then subsequently transferred to a SQL Server database for processing and analysis. Detections of acoustic tags were filtered for invalid data including non-study tags, false detections and detections before release. Movement was defined as sequential detections between different stationary receivers. Due to overlapping detections on the closer-proximity receivers located above Beebe Bridge, all receivers in the Wells tailrace were combined into one 'Wells Tailrace' detection array. Similarly, the Airport, Beebe Ranch and Beebe Bridge receivers were combined into a single 'Beebe' detection array. Residence times were calculated by grouping detections of individual fish on each unique receiver (i.e., not grouped arrays) that occurred within twenty minutes of each other, and assigning a first and last detection date and time. If a fish was absent from a receiver for more than twenty minutes, a new residence period was assigned.

Mobile Tracking

To obtain additional fine scale distribution information on acoustic tagged sturgeon three mobile tracking sessions were performed during 2016, one each in March, June and October. Each session lasted two days, comprised a single continuous transect down the center of the Reservoir, and was performed using a mobile-tracking receiver (Vemco Model VR100) and an omni-directional hydrophone (Vemco Model VH165). The position (latitude and longitude) of the boat was logged as tags were detected within the range of the receiver. Detection range was variable as flow conditions, wind, and other sources of noise varied over the Reservoir and between sessions. Full coverage of the Reservoir was not expected.

Population Indexing

Population indexing efforts produced robust distribution data, sturgeon recaptures for mark recapture survival estimation, and fish biometrics for growth analyses.

The first standardized population indexing survey was performed in 2013. Prior to this, sturgeon recaptures had been documented in both 2011 and 2012 as part of the *Northern Pikeminnow (Ptychocheilus* *oregonensis) Removal Program* or during efforts to capture sturgeon for acoustic tag implantation. In each year during Phase I of the population indexing survey (from 2013 to 2015), sampling occurred over 45-50 days, spread over five sessions from mid-August to late-October. The index fishing methods evolved over time, and consisted of setlines deployed at a combination of random and targeted locations, two hook types, several hook sizes, and two bait types. See Robichaud et al. (2016) for details.

The setline gear has changed over the course of this monitoring program. During Phase I, setlines were 76 m in length (250 ft), with 80 circle or treble hooks (details in Robichaud et al. 2016). Starting in 2016, the Phase II setline fishing gear was modified so that all mid-Columbia River PUDs (Chelan, Douglas and Grant) were using standardized gear in their respective sturgeon monitoring programs: gear that more closely resembled that used in other FERC sturgeon stock assessment efforts. Starting in 2016, setlines were 122 m (400 ft) long, with 40 circle hooks (20 each of 2.0 and 4.0 gauge) evenly spaced along the line, and baited with pickled squid (Gilmore Tackle Company, Pelsor, AR). Setlines were deployed and recovered by Columbia Research Specialists.

All 2016 setlines were deployed in randomly-determined locations. ArcGIS software (Environmental Systems Research Institute, Inc., Redlands, CA) was used to select random coordinates within the reservoir, without stratification, excluding areas within 20 m of the shoreline vector, and with a minimum distance of 50 m between points. Before each sampling session, all randomly-determined locations were selected simultaneously. Over the course of the sampling session, the crew worked the locations in a systematic order, starting at one end of the Reservoir (picked randomly) and working toward the other end, doing on average eight sets per day. In 2016, a total of 357 setlines were retrieved over 45 days (Table 4). Each setline was fished overnight, for an average of 21.4 hours (fishing duration ranged from 17 to 32 hours). For each setline, the date, time, latitude, longitude, and depth of the line were recorded. Using a field laptop, all indexing field data (setline and recaptured sturgeon data, including dates, times, locations, tag IDs, lengths, weights, etc.) were entered directly into a *Microsoft Access* database developed specifically for this study by Blue Leaf.

Table 4. Spatial and temporal distribution of setline sampling effort in the Rocky Reach Reservoir in 2016.

		Setlines Retrieved per Reservoir Zone			
Session	Dates	Upper	Mid North	Mid South	Lower
1	28 Aug - 7 Sep	15	21	12	30
2	11-21 Sep	14	19	20	26
3	25 Sep - 5 Oct	10	15	20	36
4	9-19 Oct	16	19	18	26
5	23-28 Oct	9	4	13	14
	Totals	64	78	83	132

Fish Capture

Each captured sturgeon was scanned for a PIT tag (BioMark Model 601 Reader) and measured for fork length (mm), girth (mm), and weight (g). Girth was measured directly behind the pectoral fins. Each fish was examined for removed scutes (indicating hatchery origin), and the location and pattern of removed scutes were documented. All sturgeon captured without a PIT tag were implanted with a new tag (BioMark Model HPT12) on the left dorsal side, just posterior of the head. All injuries or abnormalities (e.g., stunted or missing fins) were documented. Sturgeon were released near their capture location immediately after measurements were completed. Catch Per Unit Effort (CPUE) was expressed in terms of catch counts (numbers of sturgeon) per setline. Bycatch was identified by species and enumerated.

Sturgeon recapture data were used for analyses of growth rates (change in length or weight over time; DeVries and Frie 1996), changes in condition (relative weight, based on White Sturgeon standard weight equation, see Beamesderfer 1993), and survival (see below). For fish caught more than once in a given year, data from the first recapture was used in analyses of growth and condition factor.

Recaptures of Unknown Origin

Recaptured scute-marked sturgeon without readable PIT tags were measured, re-tagged and released. These fish were not included in analyses of growth rate or survival. These capture events were used to estimate PIT tag loss rates.

Survival Estimation

Survival of the hatchery-released juvenile sturgeon was assessed using a Cormack-Jolly-Seber (CJS) framework and the commonly accepted CJS formulation (see Lebreton et al. 1992). The CJS framework considers as separate processes the probability of capturing an individual during sampling events (p) and the apparent survival (Φ) between sampling events.

Analyses combined data from all available years to maximize statistical power of survival estimates. In order to combine all available years, capture models were developed to accommodate changes in methodology that occurred both between and within some years. *A priori*, different sampling methods (i.e., unique combinations of setline lengths, hook types, and sampling techniques) would be expected to have different capture efficiencies (therefore affecting capture probabilities) within a given survey session. Furthermore, because different sampling methods also had different efficiencies, the total effort spent using a particular set of sampling methodologies within a sampling session would further affect capture probabilities within that session. If left unmodelled, heterogeneity would be introduced into the capture probabilities, which could result in over-dispersion, model misfit, and potentially biased estimates.

To accommodate methodological changes, each year was broken down into multiple bouts depending on the survey session and the exact methodology employed (Table 5). The term “bout” was used to indicate a unique set of sampling methodologies applied within a survey session. For instances when multiple methodologies were deployed within the same survey session, pseudo-bouts were created to allow each methodology type to be modelled independently. It was assumed that no time occurred between the primary bout and associated pseudo-bouts (i.e., no mortality was assumed to occur) and as such, pseudo-

Table 5. Unique sampling bouts used in the survival analyses.

Year	Bout ID	Bout Type	Bout Start	Bout End	Time Interval†	Pseudo-bout	Setline Length & Hook Type‡	Sampling Type	Effort	Effort Type
2011	R1	Release	Apr 20	Apr 20	–	No	–	–	–	–
2011	C1	Recapture	Apr 07	Nov 11	0.263	No	Short-Treble	Incidental	219	Days
2012	R2	Release	May 16	May 16	0.810	No	–	–	–	–
2012	C2	Recapture	Jun 21	Sep 08	0.205	No	Short-Treble	Incidental	80	Days
2012	C3	Recapture	Sep 09	Sep 13	0.117	No	Short-Treble	Incidental	5	Days
2012	C4	Recapture	Sep 14	Oct 13	0.046	No	Short-Treble	Incidental	30	Days
2012	C5	Recapture	Oct 24	Oct 27	0.074	No	Short-Treble	Incidental	4	Days
2013	R3	Release	May 20	May 20	0.567	No	–	–	–	–
2013	C6	Recapture	Aug 19	Aug 28	0.259	No	Short-Treble	Random	56	Setlines
2013	C7	Recapture	Aug 19	Aug 28	0.001	Yes	Short-Treble	Targeted	28	Setlines
2013	C8	Recapture	Sep 02	Sep 11	0.037	No	Short-Treble	Random	55	Setlines
2013	C9	Recapture	Sep 02	Sep 11	0.001	Yes	Short-Treble	Targeted	25	Setlines
2013	C10	Recapture	Sep 16	Sep 25	0.037	No	Short-Treble	Random	53	Setlines
2013	C11	Recapture	Sep 16	Sep 25	0.001	Yes	Short-Treble	Targeted	28	Setlines
2013	C12	Recapture	Sep 30	Oct 09	0.037	No	Short-Treble	Targeted	65	Setlines
2013	C13	Recapture	Sep 30	Oct 09	0.001	Yes	Short-Circle	Targeted	13	Setlines
2013	C14	Recapture	Oct 14	Oct 23	0.037	No	Short-Treble	Targeted	14	Setlines
2013	C15	Recapture	Oct 14	Oct 23	0.001	Yes	Short-Circle	Targeted	63	Setlines
2014	R4	Release	May 08	May 08	0.553	No	–	–	–	–
2014	C16	Recapture	Aug 12	Aug 20	0.271	No	Short-Treble	Random	27	Setlines
2014	C17	Recapture	Aug 12	Aug 20	0.001	Yes	Short-Circle	Random	27	Setlines
2014	C18	Recapture	Aug 12	Aug 20	0.001	Yes	Short-Treble	Targeted	17	Setlines
2014	C19	Recapture	Aug 12	Aug 20	0.001	Yes	Short-Circle	Targeted	18	Setlines
2014	C20	Recapture	Aug 25	Sep 03	0.033	No	Short-Treble	Random	28	Setlines
2014	C21	Recapture	Aug 25	Sep 03	0.001	Yes	Short-Circle	Random	27	Setlines
2014	C22	Recapture	Aug 25	Sep 03	0.001	Yes	Short-Treble	Targeted	18	Setlines
2014	C23	Recapture	Aug 25	Sep 03	0.001	Yes	Short-Circle	Targeted	20	Setlines
2014	C24	Recapture	Sep 08	Sep 17	0.035	No	Short-Treble	Random	28	Setlines
2014	C25	Recapture	Sep 08	Sep 17	0.001	Yes	Short-Circle	Random	28	Setlines
2014	C26	Recapture	Sep 08	Sep 17	0.001	Yes	Short-Treble	Targeted	20	Setlines
2014	C27	Recapture	Sep 08	Sep 17	0.001	Yes	Short-Circle	Targeted	18	Setlines
2014	C28	Recapture	Sep 22	Oct 01	0.037	No	Short-Treble	Targeted	23	Setlines
2014	C29	Recapture	Sep 22	Oct 01	0.001	Yes	Short-Circle	Targeted	63	Setlines
2014	C30	Recapture	Oct 19	Oct 23	0.068	No	Short-Circle	Targeted	50	Setlines
2015	R5	Release	Apr 27	Apr 27	0.515	No	–	–	–	–
2015	C31	Recapture	Aug 10	Aug 19	0.296	No	Short-Treble	Random	25	Setlines
2015	C32	Recapture	Aug 10	Aug 19	0.001	Yes	Short-Circle	Random	26	Setlines

Year	Bout ID	Bout Type	Bout Start	Bout End	Time Interval†	Pseudo-bout	Setline Length & Hook Type‡	Sampling Type	Effort	Effort Type
2015	C33	Recapture	Aug 10	Aug 19	0.001	Yes	Short-Treble	Targeted	9	Setlines
2015	C34	Recapture	Aug 10	Aug 19	0.001	Yes	Short-Circle	Targeted	9	Setlines
2015	C35	Recapture	Aug 24	Sep 02	0.035	No	Short-Treble	Random	27	Setlines
2015	C36	Recapture	Aug 24	Sep 02	0.001	Yes	Short-Circle	Random	28	Setlines
2015	C37	Recapture	Aug 24	Sep 02	0.001	Yes	Short-Treble	Targeted	9	Setlines
2015	C38	Recapture	Aug 24	Sep 02	0.001	Yes	Short-Circle	Targeted	21	Setlines
2015	C39	Recapture	Sep 07	Sep 16	0.035	No	Short-Treble	Random	27	Setlines
2015	C40	Recapture	Sep 07	Sep 16	0.001	Yes	Short-Circle	Random	29	Setlines
2015	C41	Recapture	Sep 07	Sep 16	0.001	Yes	Short-Treble	Targeted	18	Setlines
2015	C42	Recapture	Sep 07	Sep 16	0.001	Yes	Short-Circle	Targeted	19	Setlines
2015	C43	Recapture	Sep 21	Sep 25	0.033	No	Short-Circle	Targeted	41	Setlines
2015	C44	Recapture	Oct 12	Oct 21	0.063	No	Short-Circle	Targeted	80	Setlines
2016	R6	Release	May 10	May 12	0.566	No	-	-	-	-
2016	C45	Recapture	Aug 28	Sep 07	0.314	No	Long-Circle	Random	78	Setlines
2016	C46	Recapture	Sep 11	Sep 21	0.038	No	Long-Circle	Random	79	Setlines
2016	C47	Recapture	Sep 25	Oct 05	0.038	No	Long-Circle	Random	81	Setlines
2016	C48	Recapture	Oct 09	Oct 19	0.038	No	Long-Circle	Random	79	Setlines
2016	C49	Recapture	Oct 23	Oct 28	0.030	No	Long-Circle	Random	40	Setlines

Note: Sampling bouts reflect unique release and recapture sessions and any unique methodological combinations within a recapture session. Recapture sessions were broken up into pseudo-bouts when more than one methodology type was used within a survey session. A unique pseudo-bout was created for each unique combination of gear.

† Time intervals indicate the elapsed time from the previous bout to the current bout, and are measured in units of years.

‡ "Short-Treble" refers to 76 m setlines with 80 treble hooks; "Short-Circle" refers to 76 m setlines with 80 circle hooks; "Long-Circle" refers to 122 m setlines with 40 circle hooks.

bouts are viewed as being akin to 'secondary sampling sessions' in Pollock's (1982) robust design (which is a sampling design constructed to allow the assumptions of equal catchability to be relaxed). The creation of bouts and pseudo-bouts allowed for detection models to be developed that could accommodate for:

1. use of three different sampling techniques (i.e., incidental[1], targeted, and random);
2. use of three different setline configurations (i.e., short setlines with 80 treble hooks; short setlines with 80 circle hooks; and long setlines with 40 circle hooks);
3. differing amounts of effort associated with each combination of (1) and (2); and
4. no recaptures attempted during release events.

Survival was, by definition, estimated as a rate (e.g., survival per year); because the time interval between analysis bouts varied (see Table 5), the interval between bout midpoints was used when modeling survival

[1] Herein we refer to "incidental" surveys as captures occurring during the 2011-2012 Northern Pikeminnow Removal Program sampling, or during 2012 efforts to capture fish for acoustic tagging (i.e., recapture bouts C1-C5; Table 5).

between bouts. As such, reported survival estimates are presented on a *per year* basis, unless otherwise indicated. For pseudo-bouts, the time interval was effectively set to zero.

Survey effort under a given methodology was also considered, by developing an effort metric. Where possible, the number of setlines deployed using a given sampling method within a bout was used. However, this was not possible for bouts relying on incidental captures (i.e., C1-C5; Table 5), so an alternative effort metric (i.e., sampling days) was used in its place. Whenever 'effort' was included as a model parameter, a separate parameter value was estimated for each of the effort metric types, thereby accommodating the differing effort type measurements used in earlier (C1-C5) sampling sessions.

Where possible, survival analyses employed a multi-model inference approach using model ranking, which was performed using the small-sample-size corrected version of Akaike's Information Criterion (AICc; see Burnham and Anderson 2002). AICc, a measure of model support, attempts to find a balance between model fit (i.e., minimizing the information loss) and the number of modelling parameters (i.e., avoiding over-fitting). Model ranking is determined by ordering the AICc scores from smallest to largest, with the top-supported model having the lowest AICc score in the candidate model set. A derivative measure, Delta AICc (ΔAICc) shows the distance (in AICc units) between the top model and all other models in the candidate set. Models with a ΔAICc score between 0 and 2 are generally considered to have equal support. Delta AICc scores between 2 and 5 are considered plausible, while models with ΔAICc scores higher than 7 are considered to have minimal support (see Cooch and White 2013).

Survival estimates generated from a CJS model do not make any distinction between individuals that died and those that permanently emigrated from the study area or suffered tag loss. Both types of violations were known to occur in this study, hence the term "apparent survival" was used to describe these outputs. To better understand the impact of these violations, select results were adjusted for emigration and tag loss by re-running analyses after setting losses on captures to equal estimated emigration and tag loss rates (these were derived from the acoustic tagging and indexing programs, respectively). Emigration losses were assumed to have occurred immediately after release and after each fall sampling session, and were only set for individuals that were never observed again. Tag losses were assumed to occur immediately after release in a manner that was independent from emigration losses. Adjusted survival estimates were presented using the term "true survival."

All survival analyses were carried out using the R computing environment (R Core Team 2016) using the RMark package (Laake 2013) to construct and fit models in Program MARK (White and Burnham 1999).

<u>Data Inclusion</u>

By design, analyses of survival were restricted to fish that were PIT tagged as part of the Chelan PUD hatchery supplementation releases. In total there were six distinct release groups (i.e., one per year from 2011 to 2016) and 49 recapture bouts (Table 5). Of the 49 recapture bouts, 24 were pseudo-bouts used to accommodate different sampling methodologies within the same survey session.

All incidental recaptures after 2012 were excluded from the analyses due to limited numbers. Captures associated with re-tagged sturgeon (i.e., the original PIT tag was lost and a new PIT tag was injected) were excluded because the fish's original release location and overall recapture history were unknown. The impacts of tag-loss and emigration were considered in the "True Survival Rates" section.

Emigration Rates

One of the goals of the acoustic tracking was to study emigration patterns such that the mark-recapture survival model could be adjusted to account for tags that permanently departed from the study area. Since the survival model was based on several time-steps (dictated by the timing of the indexing surveys), it made sense to estimate emigration probabilities over the same intervals. Thus, the acoustic telemetry data were used to determine: a) the portion of tags that emigrated within the first few months after release (these tags would already be out of the study area by the time the annual indexing survey occurred); and b) the portion of tags that emigrated between each subsequent set of indexing surveys.

To estimate emigration, we divided the number of observed emigrants by the number of active tags that were available to be detected. For each acoustic tag, we noted when its battery would expire, and how long since its original release date (i.e., release as age 1 from hatchery) did it emigrate (if at all). For each time interval of interest, we then determined the average number of active tags and the total number of emigration events, and then calculated the percent emigration for that interval.

To match the time intervals of the survival model, emigration rates were calculated for:

- The period between release from the hatchery and the subsequent indexing survey (duration of several months);
- The one-year period between the first post-release indexing survey and the second post-release indexing survey;
- The one-year period between the second post-release indexing survey and the third post-release indexing survey; and
- Any time after the third post-release indexing survey.

Age-Structured Abundance of Supplementation Fish

The age-structured abundance of hatchery-produced White Sturgeon in the Reservoir can be estimated using release numbers, true survival rates, and emigration proportions. Since true survival rates take both emigration and tag shedding into account, they are effectively estimates of the survival of fish that are present in the Reservoir, regardless of whether or not it has shed its tag, and not counting emigrants as 'death'. However, the emigrants are not in fact present in the Reservoir, so to calculate an abundance time-series, we must both remove emigrants from the Reservoir *and* use true survival rates. That is, we must know the true survival of the fish in the Reservoir, but we must also allow emigration to remove fish from the population.

To estimate age-structured abundance, we calculated abundance for each release cohort separately, and generated one abundance estimate per year, corresponding to the time of the indexing survey. For the first indexing survey, a few months post-release, we calculated abundance as the number released, multiplied by both the short term retention rate (i.e., 1 minus emigration) and the cohort-specific short-term true survival rate. The estimated abundance during this first survey was then used as the starting point for the next year's calculation. The abundance for the following year was calculated by multiplying the previous abundance by the second-year retention rate, and by the intermediate-term survival rate. The abundance for each subsequent year was calculated by multiplying the previous abundance by the period-specific retention rate, and by the cohort-specific annual long-term survival rate. Once all the estimates were calculated, they were organized into a table showing abundance by calendar year, which allowed for the cohorts to be lined-up and summed into an age-structured overall abundance.

Diet study

In order to begin to understand the types of prey utilized by hatchery-released White Sturgeon, a pilot diet study using a nonlethal method of gastric lavage was implemented in 2016. Methods for gastric lavage were modified from Haley (1998), Brosse et al. (2002), and Wanner (2006). Nine days of fishing were spread throughout the year (3 days in each of April, July and October) to detect seasonal variations in diet composition. An attempt to divide fishing effort evenly throughout the Reservoir was made but due to the pilot nature of this first year and difficulty capturing sturgeon in the lower Reservoir, disproportional effort was expended in the upper Reservoir in order to obtain a sufficient number of diet samples. Hook and line angling was used as the capture method so that sturgeon could be quickly landed and the gut contents preserved. Medium-heavy action rods with bait casting reels, 60 kg (130 pound) test braided line, lead weight and circle hooks were used. Pickled squid and salmon were both used as bait. Once fish were brought to the boat they were held in 156 L coolers with river water and aeration before gastric lavage was performed.

Before gastric lavage was performed, sturgeon were anesthetized with clove oil (40-60 mg/L) for 4-6 minutes until equilibrium was lost. Sturgeon were then weighed, measured and scanned for PIT tags. For lavage, sturgeon were placed ventral side up and head down in a tray at an approximate 45 degree angle. A 6 mm external diameter PVC tube was inserted into the sturgeon's digestive track to the first bend in the stomach. Pressurized river water not exceeding 200 kPa (29 psi) was pumped into the digestive track while the ventral area was massaged to help dislodge food items. Additionally, the tube was moved back and forth and water pulsed to aid in dislodging food items. All water and food items expelled from the sturgeon were filtered through a 500 μm sieve to separate food items from water. No more than 4 L of water, taking approximately 5 min, was used on each sturgeon to dislodge food items. Diet samples for each sturgeon were preserved in 200 proof denatured ethanol, were immediately placed under dry ice, and were transferred to a freezer once off the boat.

Sturgeon diet samples were sent to Washington Department of Fish and Wildlife (WDFW) Region 3 District Office for processing in their lab. Contents were identified to the lowest possible taxonomic level using standard identification keys (Hansel et al. 1988, Pennak 1989, Merrit and Cummins 1996, Frost 2000, Parrish et al. 2006). Samples were weighed using a blotted wet weight.

Results

Acoustic Telemetry

A total of 1,849,277 detections were added to the acoustic tag database in 2016 (6 Nov 2015 – 12 Oct 2016; Table 6). This brings the total number of unique detections recorded on VR2W receivers since the beginning of the study (in May of 2012) to 4,315,290. Over the five years of the acoustic tagging study (2012-2016), 219 sturgeon were tagged, of which 212 (97%) have been detected on at least one receiver.

Table 6. Number of individual White Sturgeon detected at each receiver, and total detections by receiver in 2016 (6 November 2015 through 12 October 2016).

Detection Location	RKM	Individual tags detected in 2016	Detections in 2016
Wells West Fishway Entrance *	830	26	2,459
Wells West Fishway Mid *	830	16	292
Wells East Fishway Entrance *	830	14	56
Fish Point East Bank *	829.8	29	98,787
Hatchery *	829.6	38	740,916
Tailrace East *	829.2	28	5,993
Top	829	34	4,732
Wells West *	827.9	25	6,949
Wells East	826.7	26	367,257
Long Draw	822	22	15,146
Airport	817.8	23	146,728
Beebe Ranch	814.7	23	122,218
Beebe Bridge	811.2	22	2,044
Green's Canyon	802.3	24	57,373
Duck Tail Rock	793.8	23	13,657
MK Canyon	787.8	20	21,905
Entiat	780.7	18	160,605
Orondo	773.5	17	52,806
Turtle Rock	766.3	11	29,301
Rocky Reach Tailrace 1	761.8	1	19
Rocky Reach Tailrace 2	761.2	1	21
Rocky Reach Tailrace 3	761.2	1	13
	Totals	75	1,849,277

* VR2W's installed and maintained by DCPUD

During 2016, the majority of detections were in the upper Reservoir with 66.4% in the top 3 km of the Reservoir and 46.1% in the top 1 km or the immediate tailrace of Wells Dam (Table 6). There were seven DCPUD VR2W receivers added to the Wells tailrace area in 2016 (Figure 1), which is a contributing factor to the high number of detections in that area. However, when corrected for the number of receivers present, there were on average 3.7 times the number of detections per receiver above Beebe Bridge (136,382) versus below (37,300). Certain receivers were located in areas of very high residence, such as the 'Hatchery' receiver (located just downstream of Wells Dam) which recorded 40.1% of all detections in 2016. Also, the Wells East location, located ~3 km from Wells Dam, recorded 19.9% of all detections. The 'Entiat' receiver, located in the lower Reservoir, had the third-highest number of detections, having recorded 8.7% of all detections (Table 6). Detection proportions were very low at the bottom of the Reservoir, where only 1.6% of all detections were recorded at Turtle Rock or in the Rocky Reach Tailrace (Table 6). A total of 75 individual sturgeon were detected on at least one receiver in 2016, 69% of the 109 remaining active tags. The number of individual sturgeon detected on each receiver ranged from 1 below Rocky Reach Dam to 38 at the Hatchery receiver (mean = 20.1).

Distributions and Movements

Over the 2016 study period, at the scale of our receiver deployments, there were 212 upstream movements and 221 downstream movements. The mean number of movements per sturgeon was 1.9 upstream and 2.0 downstream (Table 7). The mean distances traveled per sturgeon were 13.5 km upstream (range 1.1-226.3 km), 14.6 km downstream (range 0.2-165.9 km), and 28.2 km regardless of direction (range 0-392.2 km). A total of 38 individuals (35% of all active tags, 51% of 2016-detected tags) moved greater than 6 km (the mean separation between receivers). Of the 75 sturgeon with detections in 2016, 34 (45%) were only detected on one receiver or array, 27 (36%) moved between receivers or arrays but less than 100 km, and 14 (19%) moved 100 km or greater (Figure 3). Regardless of direction, 78% of all movements between receivers were from the 50 larger (older) sturgeon (25 release year 2011 and 25 release year 2013) that were recaptured and tagged in the fall of 2015. These fish made up slightly less than half of the 109 active acoustic tags at large in 2016. Of the 50 fish acoustic-tagged in 2015, 39 (78%) were captured, tagged and released in the upper Reservoir within 5 km of Wells Dam, and 25 of the 39 (64%) stayed in the upper Reservoir (they did not move from the receivers in the immediate tailrace of Wells Dam). Of the 50 fish acoustic-tagged in 2015, 11 (22%) were captured, tagged and released in the lower half of the Reservoir: all moved at least 10 km, and many made extensive Reservoir-wide movements. Detection histories for all acoustic tagged fish are given in Appendix A.

Individual receivers with the highest residence times were in the upper Reservoir within 3 km of Wells Dam. In particular, the 'Hatchery' receiver immediately below Wells Dam had 3,329 days of residence time from 38 individual sturgeon, or 43% of all residence time within detection range of a receiver for the entire 2016 study year (Figure 4). Outside of the upper Reservoir, the 'Entiat' receiver had the highest residence time. As seen in prior study years, adjacent receiver's residence times vary widely and certain receivers seem to be in areas of high sturgeon residence while others only detect passing migrants.

Table 7. Number of active tags by their last know location (prior to 6 November 2015) with detections in 2016 including movements up and downstream between receivers and total distance covered. 'Upstream' and 'downstream' abbreviated as "US" and "DS".

Last Known Location (as of 6 November 2015)	Total	Detected	# US Moves	Mean US Moves	Total km US	Mean US km	# DS Moves	Mean DS Moves	Total km DS	Mean DS km	Net Moves†	Total km Moved	Mean km Moved
Wells Tailrace	45	34	34	0.8	232.1	5.2	55	1.2	422.2	9.4	-190.1	654.3	14.5
Boat Release* (upper Res.)	3	3	10	3.3	61.3	20.4	7	2.3	57.4	19.1	3.9	118.7	39.6
Long Draw	1	1											
Beebe	26	17	35	1.3	214	8.2	39	1.5	255.3	9.8	-41.3	469.3	18.1
Greens Canyon	1	1	9	9.0	69.3	69.3	9	9.0	69.3	69.3	0.0	138.6	138.6
Duck Tail	10	5	30	3.0	215.1	21.5	30	3.0	204.3	20.4	10.8	419.4	41.9
MK Canyon	1	1											
Daroga Boat Launch	1												
Entiat	10	6	32	3.2	235.3	23.5	30	3.0	220.9	22.1	14.4	456.2	45.6
Orondo	6	6	31	5.2	222.2	37.0	28	4.7	197.9	33.0	24.3	420.1	70.0
Turtle Rock	2	1	31	15.5	226.3	113.2	23	11.5	165.9	83.0	60.4	392.2	196.1
Rocky Reach Tailrace	3												
Totals	109	75	212	1.9	1475.6	13.5	221	2.0	1593.2	14.6	-117.6	3068.8	28.2

* "Boat releases" are released at various locations, currently all boat releases are within 7 km downstream of Wells Dam.

† Net movements in the upstream direction are shown as positive values, and net downstream movements as negative values.

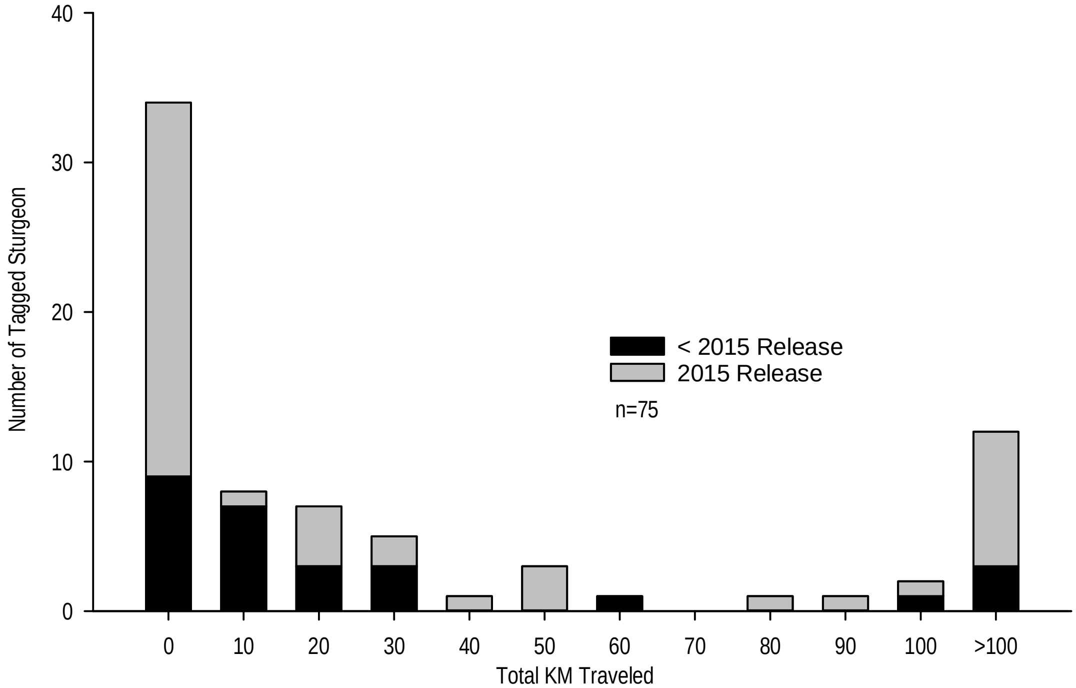

Figure 3. Histogram of the total distance traveled by acoustic tagged sturgeon in 2016. Black bars are releases prior to 2015 and grey bars are 2015-released fish.

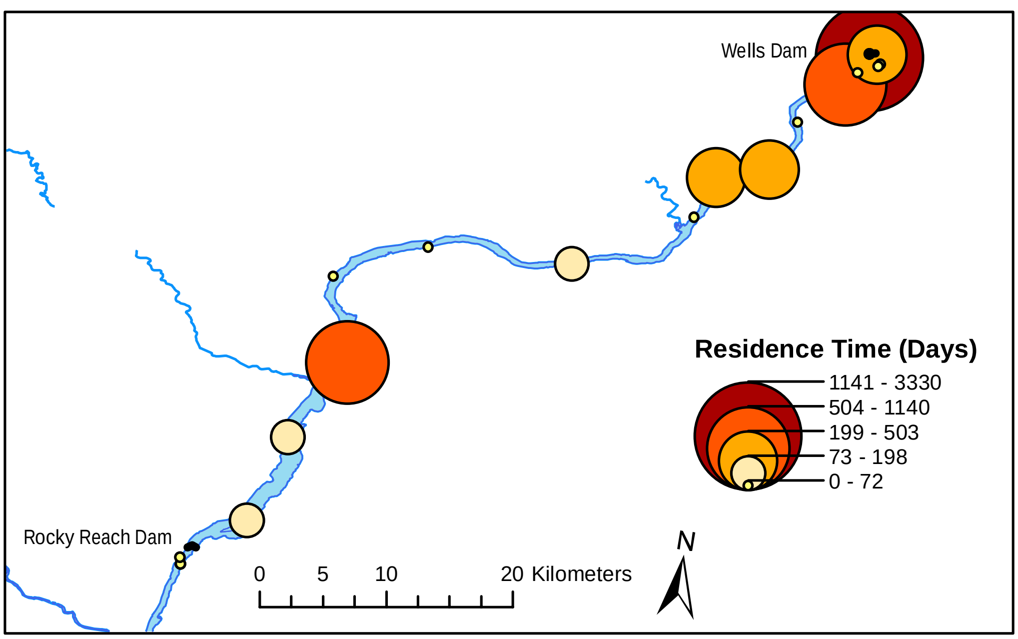

Figure 4. Residence time in days of all tagged sturgeon at each receiver throughout the study area during 2016. Data are grouped into varying size classifications by the Jenks natural breaks method, used due to the strongly skewed data distribution.

Seasonal movement patterns differed somewhat from the dominant pattern of past study years (Figure 5). Movements after release had typically been in the upstream direction, and were generally followed by decreases in movement over time (Robichaud et al. 2016). However, the older sturgeon that were tagged

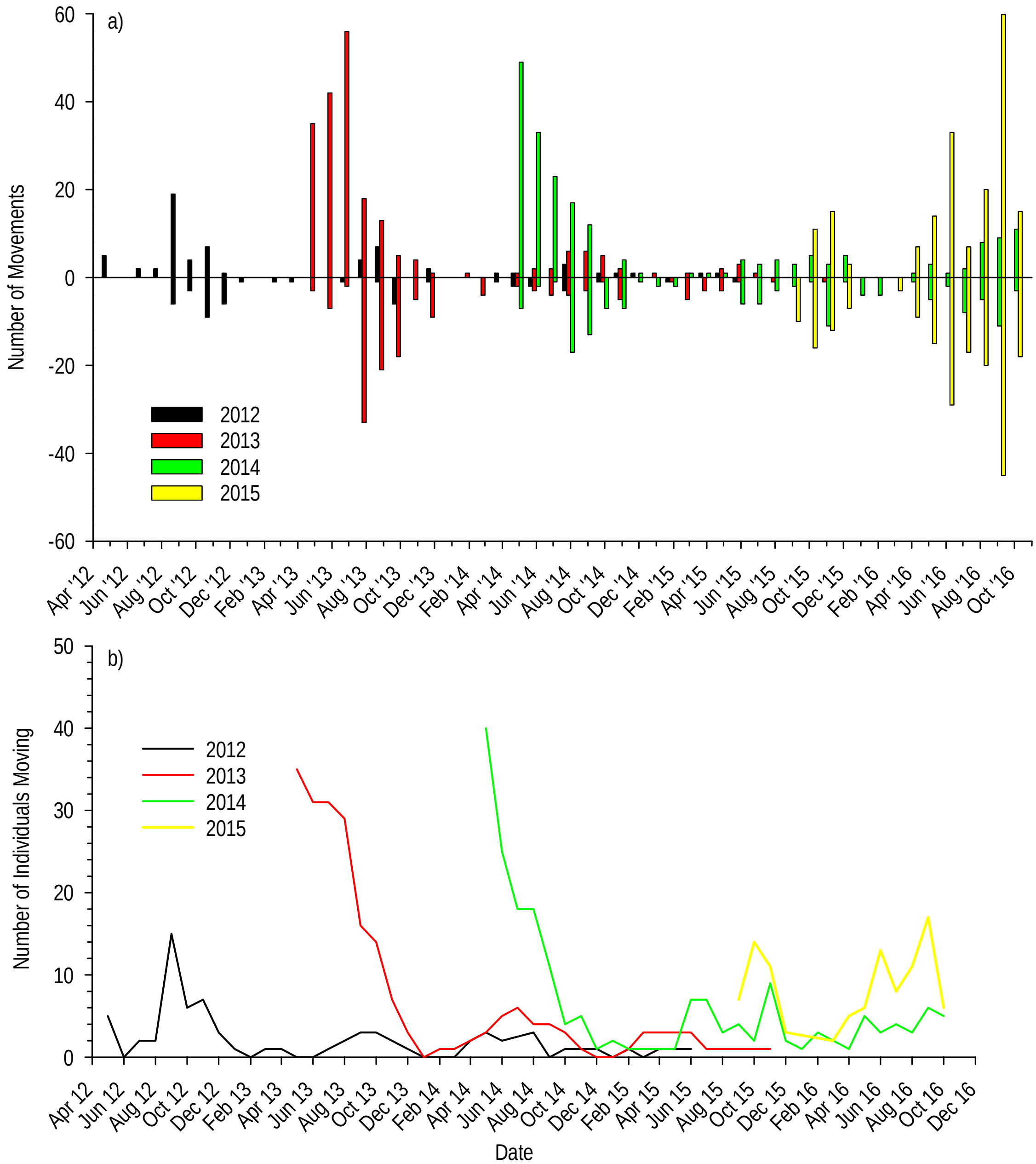

Figure 5. Seasonal movement information for all acoustically-tagged sturgeon, by month and year of release. Top panel: the number of movements upstream (positive movement counts) and downstream (negative movement counts) over time. Bottom panel: the total number of individual fish moving.

in the fall of 2015 were mostly released in the upper Reservoir (78%) and thus had limited opportunity to move further upstream. Nevertheless, the 2015 fish exhibited more movements (both up and downstream) in the year following their initial acoustic tagging than has been seen in the past (Figure 5). Other dominant seasonal patterns were maintained by the 2015 releases: winter movements were limited; and post-release-year movements peaked in the late summer and fall. The number of individual sturgeon moving by month in the year(s) following their initial release was higher (range= 6-17 fish) for fish released in 2015 than for any other year (range= 1-6 fish).

Mobile Tracking

During 2016 we performed three mobile-tracking sessions, and detected 63 out of the 109 (58%) active tags, including 39 in Session One, and 44 in each of Sessions Two and Three (Figure 6). Sturgeon were dispersed throughout the Reservoir, though areas of aggregation and sparsity were identified. Sturgeon distributions were fairly consistent between sessions, where the few exceptions could be attributed to the effects of environmental conditions on tag detections. Release location didn't seem to play a major role in where fish were detected: sturgeon from all release locations were widely distributed within the Reservoir (Figure 7). For example, many fish released at Gallagher Flats (in the upper third of the Reservoir) were detected in the lower Reservoir just upstream of Turtle Rock (Figure 7).

Emigration

Emigration Events

From 2012-2016, a total of ten acoustically-tagged sturgeon are known to have emigrated out of the Reservoir (Table 8). This equates to an overall emigration proportion of 4.6% (or 10 of 219 tags).

Of the sturgeon originally released in 2011, a total of 25 were acoustic-tagged in 2012 upon recapture. To date, two of these fish (8%) emigrated from the Reservoir. The first one, ID 29544, emigrated at the end of November 2012, 586 days after initial release and approximately one month after being acoustic-tagged. It moved 58 km from the 'Airport 2' receiver to the Rocky Reach tailrace receivers in 78 hours (Appendix A). The second fish to emigrate in 2012, ID 29819, was detected on the Wells tailrace receivers 23 days after being acoustic-tagged and released into the Wells Dam tailrace. It then slowly moved downstream and out of the Reservoir over the next 22 days, before being detected in the Rocky Reach Dam tailrace on 9 December 2012 (598 days after initial release).

For the 2012 Chelan PUD supplementation release, ten sturgeon were tagged with acoustic tags on 16 May and none emigrated over their six month battery life.

A total of 65 acoustic-tagged fish were part of the 2013 supplementation release (20-23 May), of which four fish (6.2%) emigrated. One fish (ID 28075) released at Entiat was detected downstream of Rocky Reach Dam within three days following release, and then remained in the Rocky Reach tailrace within detection range for 19 days until 6 June (Appendix A). The second fish (ID 28051) was released at Gallagher Flats, moved up into the Wells Dam tailrace, remained in the upper reservoir for the entire summer, left the Airport array on 21 September, moved downstream over ten days, and was first detected in the Rocky

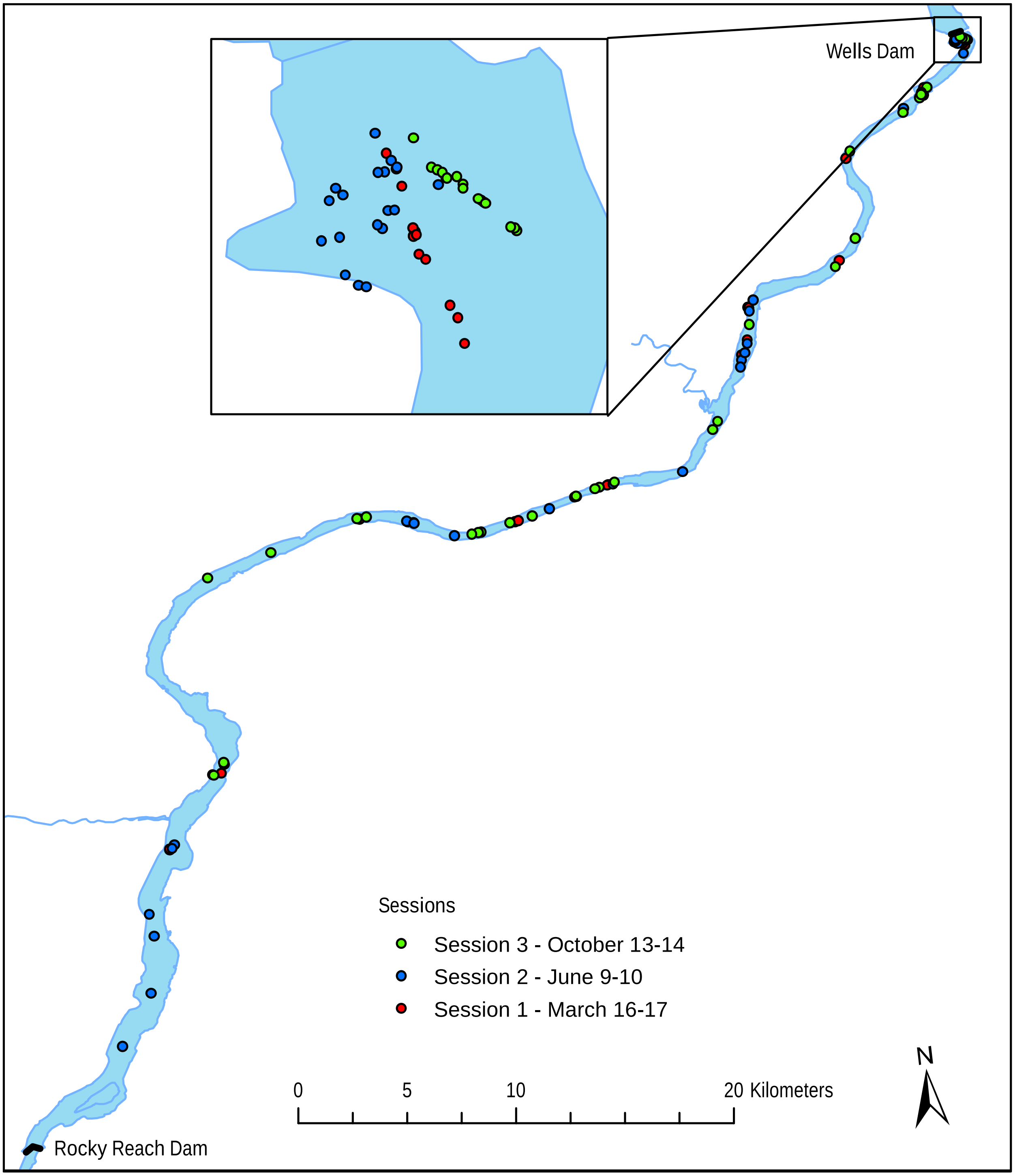

Figure 6. Mobile tracking detections during three sessions in 2016. A single dot, colored by session, is used to depict where individuals were detected along the transect, regardless of the number of detections.

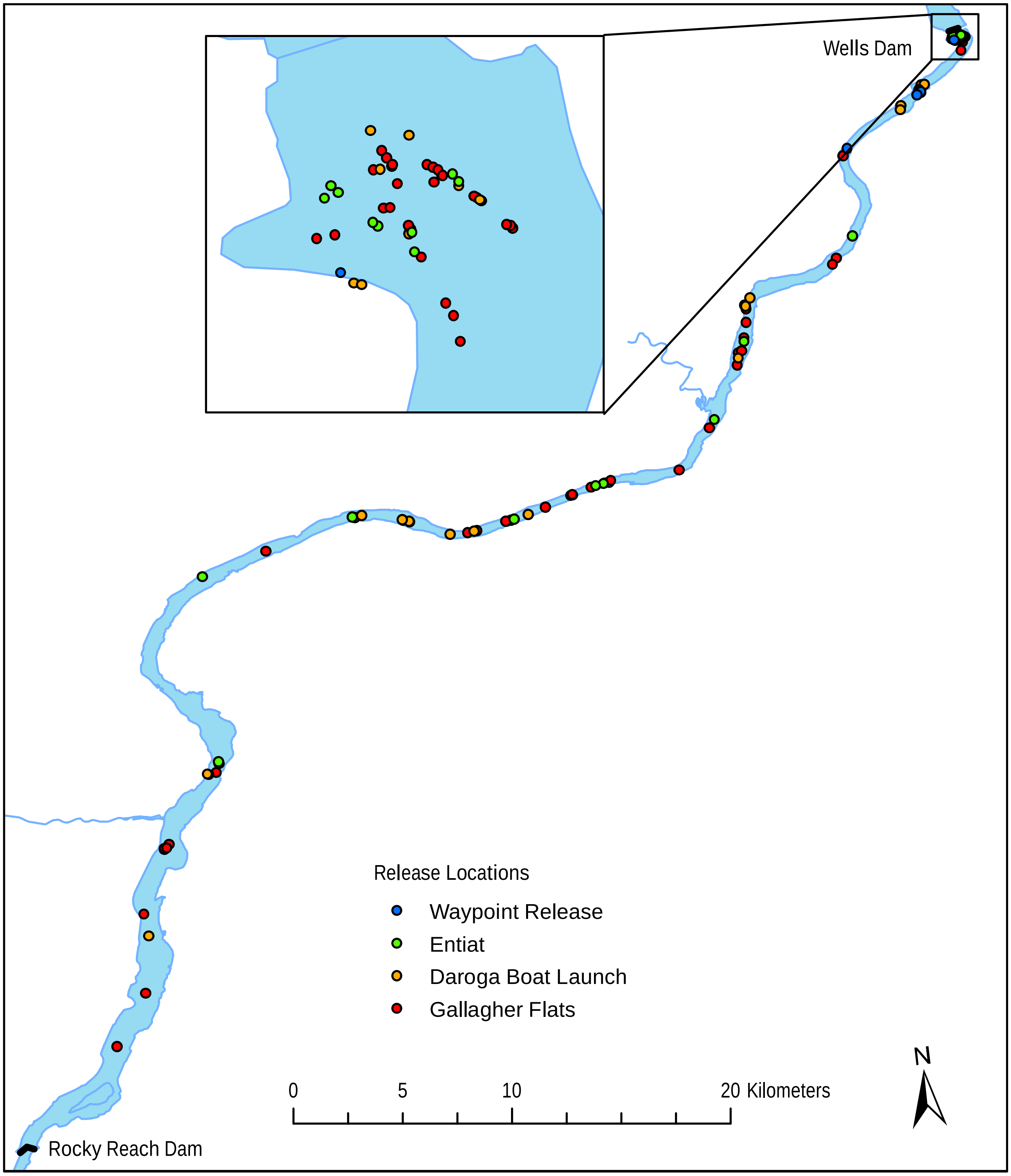

Figure 7. Mobile tracking detections during three sessions in 2016 classified by original release location. A single dot is used to depict where individuals were detected along the transect, regardless of the number of detections. The term "Waypoint Release" is used for fish that were recaptured in the Reservoir and acoustic-tagged *in situ* (as opposed to the fish acoustic-tagged in the hatcheries, which were released in bulk at one of three locations).

Table 8. Details of emigrated acoustic-tagged fish, showing date of release from the hatchery, date of acoustic-tagging, date of emigration, days between release and emigration, and age at emigration.

Tag Code	Hatchery Release Date	Acoustic Release Date	Emigration Date	Days Between Hatchery Release And Emigration	Age At Emigration
29544	20 Apr 2011	27 Oct 2012	26 Nov 2012	586	2
29819	21 Apr 2011	25 Oct 2012	9 Dec 2012	598	2
28075	20 May 2013	20 May 2013	23 May 2013	3	1
28051	22 May 2013	22 May 2013	1 Oct 2013	132	1
9585	21 May 2013	21 May 2013	12 Oct 2013	144	1
27171	20 Apr 2011	22 Oct 2013	8 Dec 2013	963	3
24884	14 May 2014	14 May 2014	21 May 2014	7	1
24900	14 May 2014	14 May 2014	1 Oct 2014	140	1
28082	20 May 2013	20 May 2013	7 Mar 2015	656	3
24882	8 May 2014	8 May 2014	6 Sep 2016	852	3

Reach tailrace on 1 October (132 days, or about five months after release). The third fish (ID 9585, a V7 tag), released at Daroga, moved as far upstream as Beebe Bridge during August and then began movement downstream on 5 October (five months after release) and was detected in the Rocky Reach tailrace seven days later on 12 October (144 days after release). The fourth fish (ID 28082) emigrated on 7 March 2015 (656 days, or almost two years, after release) after residing in the upper Reservoir at or above its release site for 648 days. On 27 February 2015 it was detected at Beebe Bridge and then moved downstream and out of the Reservoir over 8 days.

Four additional recaptured release-year 2011 sturgeon were tagged in October of 2013 with long-life V13 tags, and one (25%) emigrated out of the Reservoir. This fish (ID 27171) had been recaptured and tagged during the indexing fishing effort on 22 October 2013, two and a half years (963 days) after its initial release into the Reservoir. Following acoustic-tagging, it slowly moved downstream over 47 days before exiting the Reservoir on 8 December 2013.

To date, three of the 65 (4.6%) fish released as part of the 2014 supplementation release have emigrated. The first fish (ID 24884) quickly left the Reservoir on 21 May, seven days following release at Entiat on 14 May. This fish was sporadically detected in the tailrace of Rocky Reach Dam throughout 2014 (i.e., through to the last download on 3-4 November 2015), spending a total of 63 days residing within the detection range of the tailrace receivers. The second fish (ID 24900) was released at Daroga on 14 May and initially made its way upstream as far as the Wells tailrace on 31 July before heading downstream over two months, emigrating out of the Reservoir on 1 October (140 days after release). The third fish (ID 24882) was released at Entiat on 8 May and moved between Duck Tail Rock and Turtle Rock from September 2014 until its last detection in the Reservoir at Turtle Rock on 5 June 2016; it was detected in the tailrace three months later on 6 September 2016 (852 days after release).

In 2015, 50 fish (25 each from the 2011 and 2013 release cohorts) were captured and acoustic-tagged from August to September, and none have emigrated to date.

PIT tag detection rates are low, thus PIT detections are not appropriate for estimation of emigration rates. Nevertheless, there were two PIT-tag detections that were of particular interest. Two individual juvenile sturgeon (one released in 2013 and the other released in 2014) have been recaptured in setlines in the Wells Reservoir (one individual was captured twice), apparently having emigrated out of the Rocky Reach Reservoir in an upstream direction. Despite not being detected on Wells Dam fishway antennas, the fishways are the only volitional option for upstream passage at Wells Dam and are the most likely route. Though it is possible that anglers moved fish between reservoirs, it is unclear what would motivate them to do so.

Emigration Rates

The first step in calculating emigration rates was to determine the timing of the emigration events from the acoustic-tracking data, and determine how long after release they occurred. To date, we have observed a total of ten emigration events, including two in the first three months, another three in the year that followed (4-15 months after release), three in the subsequent year (16-27 months after release), and two after 28 or more months.

The next step was to determine the number of active tags during each of these time intervals. Given the mix of different tag models deployed (each with different specified tag life), and the varied timing in which they were deployed (some were deployed long after the fish was released from the hatchery), the number of active tags varied widely over time (Figure 8). The average number of tags that were active during each of the periods of interest ranged from 137.5 to 95.1 (Table 9).

Based on the above steps, we saw a clear decline in emigration rate over time. During the first three months after release, 1.45% of the available tags emigrated (Table 9), equating to an annual emigration rate of 5.82% per year. In the following three years, the annual emigration rate was half as much: 2.54% of the remaining fish were estimated to have emigrated during the year that followed, 2.35% during the year after that, and 2.10% thereafter.

Given the declining emigration rate over time, it is inappropriate to calculate and average annual rate, but an overall proportion of fish released from 2011-2016 of 8.2% could be calculated from the emigration numbers. This value can be derived using a hypothetical 10,000 fish released (Table 9). During the first interval, 1.45% are expected to emigrate, leaving 9,855 'fish' in the Reservoir. In the next period, another 2.54% of the 9,855 'fish' are expected to emigrate, leaving 9,605 'fish' remaining in the Reservoir. Stepping through all four of the intervals leaves 9,182 'fish' remaining, and a total of 818 emigrated 'fish' out of

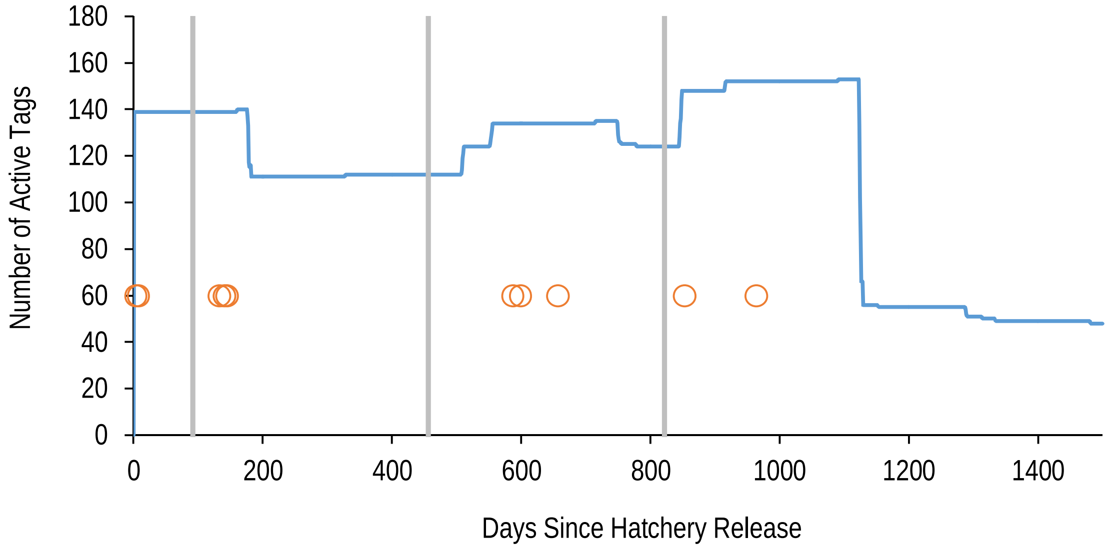

Figure 8. The number of active acoustic tags, by day, relative to the original hatchery release date for each of the 219 acoustic-tagged sturgeon in the Rocky Reach Reservoir. Orange circles indicate days on which emigration events occurred (Y positions are meaningless). Grey bars delimit the intervals used in Table 9.

Table 9. Average numbers of active tags, and total numbers of observed emigration events in each time interval. Time intervals match the steps used in the mark-recapture survival model. On the right is a hypothetical 10,000 fish population that shows how emigration steps can be compounded over time to calculate an overall emigration proportion of 8.2%.

Time Interval	Months After Release from Hatchery	Average Number of Active Tags	Total # of Emigration Events	Emigration Proportion	Equivalent Emigration Rate (% per year)	*Hypothetical: 10,000 Fish Released*	
						Emigrated	*Remained*
Before 1st index	1-3	137.5	2	1.45%	5.82%	*145*	*9,855*
1st - 2nd index	5-15	118.0	3	2.54%	2.54%	*250*	*9,605*
2nd - 3rd index	16-27	127.8	3	2.35%	2.35%	*226*	*9,379*
After 3rd index	28+	95.1	2	2.10%	2.10%	*197*	*9,182*
TOTAL			10			*818 of 10,000 (8.2%)*	

10,000, or 8.2%. The value of 8.2% is higher than the 'raw observed' proportion of 4.6% (10 of 219), because the raw value does not account for tag life (it assumes all tags were available to be detected at all times, and that all tags were released instantaneously at the start of the tracking period).

PIT-Tag Recaptures

Recaptures of Unknown Origin (Tag Loss)

Since 2013, 153 individual sturgeon have been captured without functioning PIT tags, representing 4.3% of the total number of White Sturgeon examined (3,532) during indexing surveys. It is assumed that all of these had tags that failed or were shed. This 4.3% tag-loss proportion was used to adjust survival estimates, since these failed tags were not available for recapture in the mark-recapture model (see "True Survival Rates" section, below).

All of the captured sturgeon that lacked functioning PIT tags were small enough to have been released between 2011 and 2016 as part of the Chelan PUD supplementation effort (no fish tagged in 2002-03 have been captured to date, see Golder Associates 2003). Yet six of the fish did not have scute-marks, possibly indicating wild-origin. To determine if they were hatchery fish that were accidentally released without scute-marks, DNA samples were collected (n = 5; the samples have not yet been processed).

Recaptures of PIT tags in 2016

During the 2016 indexing efforts, a total of 1351 recapture events were recorded (Figure 9) that included 1241 unique fish (Table 10). In 2016, 79 sturgeon were captured that had no detectable PIT tag, presumably due to tag loss (shed or failed tags). These were re-tagged and released. Eight other PIT-

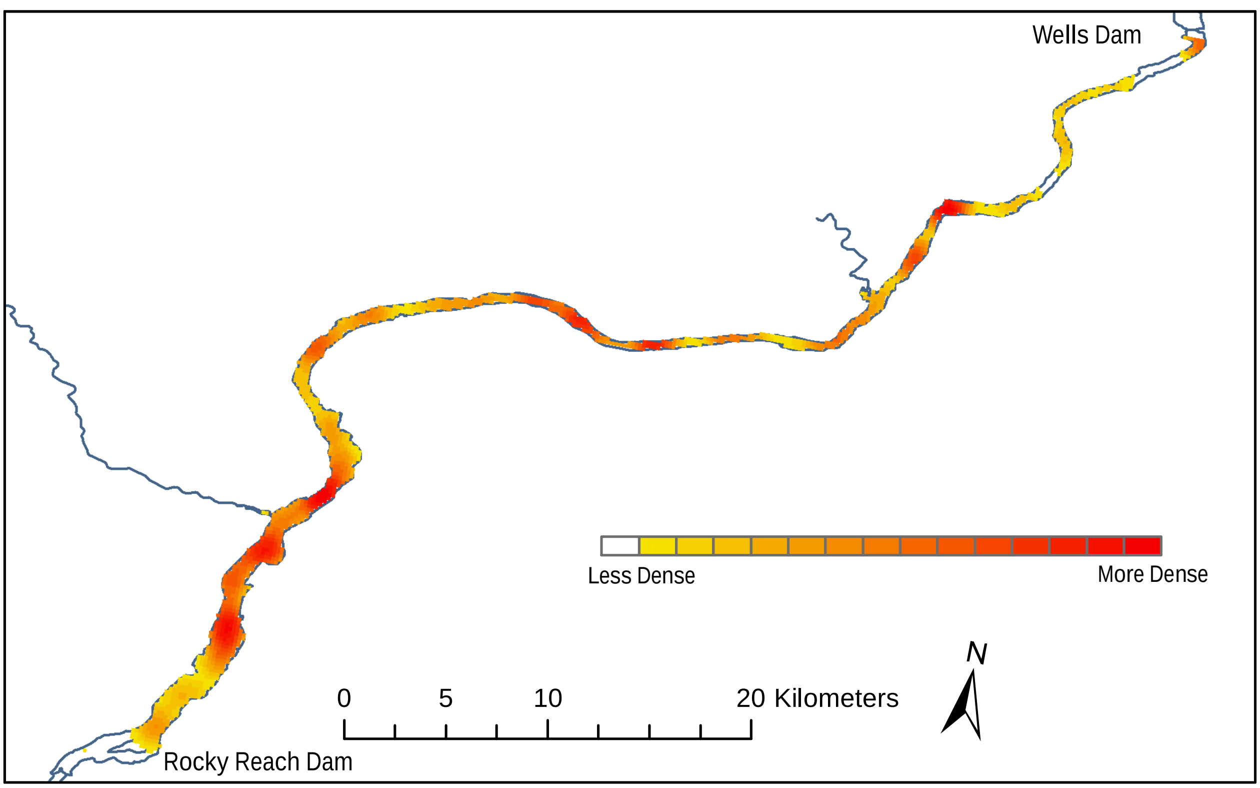

Figure 9. Density of sturgeon recaptures in the Reservoir in 2016 (29 August – 28 October).

Table 10. Number of White Sturgeon recaptured in 2016, by release year.

Release Year	Recaptures
2011	45
2012	9
2013	673
2014	220
2015	176
2016	31
Unknown (tag present)	8
Unknown (tag lost)	79

tagged sturgeon caught in 2016 were of unknown origin: they had been PIT-tagged when previously recaptured (all in 2015) because their original PIT tags had failed. Details of the PIT-tag recaptures from 2011-2015 are in Robichaud et al. (2016).

Indexing Catch Per Unit Effort

In all, seven of the 1351 recapture events were excluded because the setline on which they were caught was not completely recovered. The remaining 1344 fish were caught most readily in the Mid-North Zone (CPUE = 5.6 fish per setline), followed by the Upper Reservoir (4 fish per setline), Mid-South Zone (3.72 fish per setline), and the Lower Reservoir (2.59 fish per setline; Table 11). A generalized linear model (GLM) with negative binomial error structure found a statistically significant effect of Zone (Dev = 21.7; df = 3, $P < 0.0001$). Tukey tests showed that the CPUE in the Lower Reservoir was significantly lower than in the Mid-North Zone, and that no other among-zone differences were significant.

Negative binomial GLM found that CPUE differed significantly among cohorts (Dev = 887.8; df = 5, $P < 0.0001$). CPUE was significantly higher for the hatchery fish released in 2013 (2.09 fish per setline) than for any other cohort. CPUE for the 2014 (0.67 fish per setline) and 2015 (0.51 fish per setline) cohorts were significantly greater than for the 2011, 2012 and 2016 cohorts; and CPUE for the 2011 (0.13 fish per setline) and 2016 (0.09 fish per setline) cohorts was significantly greater than for 2012 (0.03 fish per setline; Table 11). Results from the 2013-2015 indexing surveys are presented in Robichaud et al. (2016).

Table 11. Sampling effort, catch and CPUE by reservoir zone and release year for juvenile White Sturgeon in the Rocky Reach Reservoir in 2016. The Rocky Reach Reservoir was divided into four Zones (see text). Hatchery-origin fish that were recaptured without functioning PIT tags had unknown release years.

		Release Year							
Zone	Setlines	2011	2012	2013	2014	2015	2016	Unk	Total
		Catch							
Upper	64	16	4	176	24	14	9	13	256
Mid-North	78	15	5	261	71	39	7	39	437
Mid-South	83	5	0	127	68	80	9	20	309
Lower	132	9	1	181	76	49	6	20	342
TOTAL	357	45	10	745	239	182	31	92	1344
		CPUE							
Upper		0.25	0.06	2.75	0.38	0.22	0.14	0.20	4.00
Mid-North		0.19	0.06	3.35	0.91	0.50	0.09	0.50	5.60
Mid-South		0.06	0.00	1.53	0.82	0.96	0.11	0.24	3.72
Lower		0.07	0.01	1.37	0.58	0.37	0.05	0.15	2.59
OVERALL		0.13	0.03	2.09	0.67	0.51	0.09	0.26	3.76

Growth

In this section we present separate estimates of growth and growth rates in terms of changes in fork length and changes in weight. Sample sizes for changes in weight were limited, relative to length data, as only 10-11% of the fish were weighed during typical tagging sessions (but all fish were weighed in 2012 and 2016).

For fish that were at large for about half a year, median increases in length ranged from 20 to 99 mm, with corresponding changes in weight ranging from -0.1 to +82 g (Table 12, Figure 10). Fish at large for about 1.5 years had median growth ranging from 79 to 183 mm, and 104 to 348 g. For fish that were in the Reservoir for about 2.5 years, the median difference in length and weight between tagging and recapture ranged from 211 to 300 mm, and 458 to 787 g. Fish at large for about 3.5 years grew by a median 320 to 330 mm and 924 g to 1.7 kg. Fish at large for about 4.5 years grew by a median 409 to 441 mm and 1.3 to 2.8 kg. Fish released in 2011 and recaptured in 2016, which were in the Reservoir for 5.5 years, grew 532 mm and 4.0 kg on average (Table 12, Figure 10). Figure 11 shows the distributions of size-at-release and size-at-2016-recapture for each cohort.

Table 12. Median changes in fork length and weight between PIT tagging and recapture events, and median relative weight at recapture, by release year and by time in the Reservoir (in years since tagging).

Release Year	Years Since Tagging						
	0	0.5	1.5	2.5	3.5	4.5	5.5
Median change in Fork Length (mm)							
2011	0	54	79	211.5	320	441	532.5
2012	0	87	147	221	330.5	409	
2013	0	79	128	255	328		
2014	0	99	174.5	300			
2015	0	52	183				
2016	0	20					
Median change in Weight (g)							
2011	0	nm	103.9	618.7	1689.7	2759.1	3958.1
2012	0	66.9	312.3	457.9	943.1	1314.6	
2013	0	62.8	196.7	496	923.8		
2014	0	82.1	320	787			
2015	0	2.7	347.9				
2016	0	-0.1					
Median Relative Weight (%) at tagging and at recapture							
2011	102%	nm	84%	89%	93%	96%	97%
2012	121%	77%	85%	94%	93%	91%	
2013	109%	76%	86%	87%	89%		
2014	108%	75%	89%	91%			
2015	114%	75%	90%				
2016	101%	85%					

nm: Fish were not weighed upon recapture in 2011

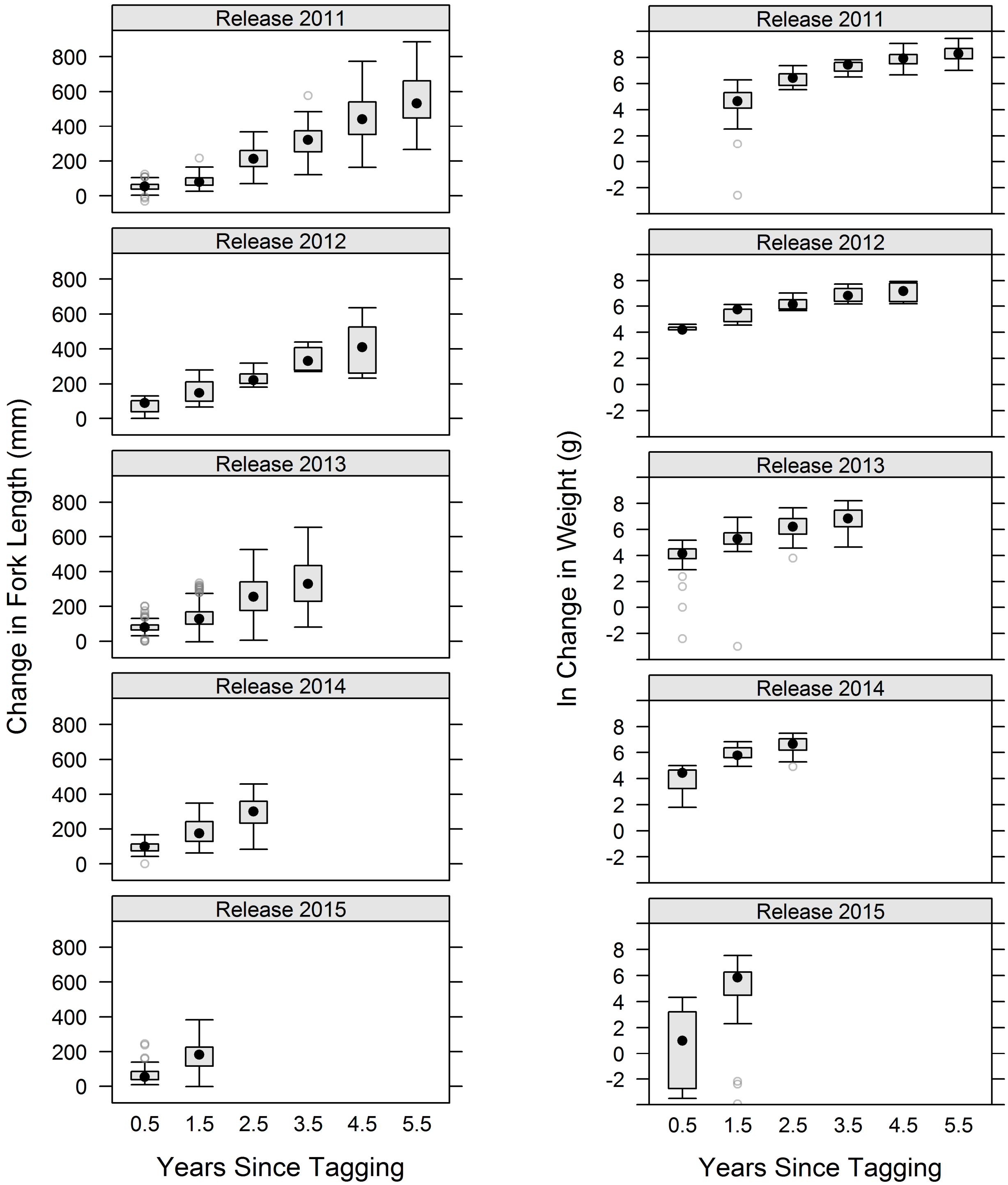

Figure 10. Changes in fork length (left column) and weight (right column), by release year (rows) and years since tagging (x-axis). Increases and decreases in weight are presented on a natural log scale as positive and negative ln values. Boxes enclose the 25th to 75th percentiles, with a dot at the median; error bars extend either to the maximum value, or to 1.5 times the interquartile range (beyond which individual points are plotted).

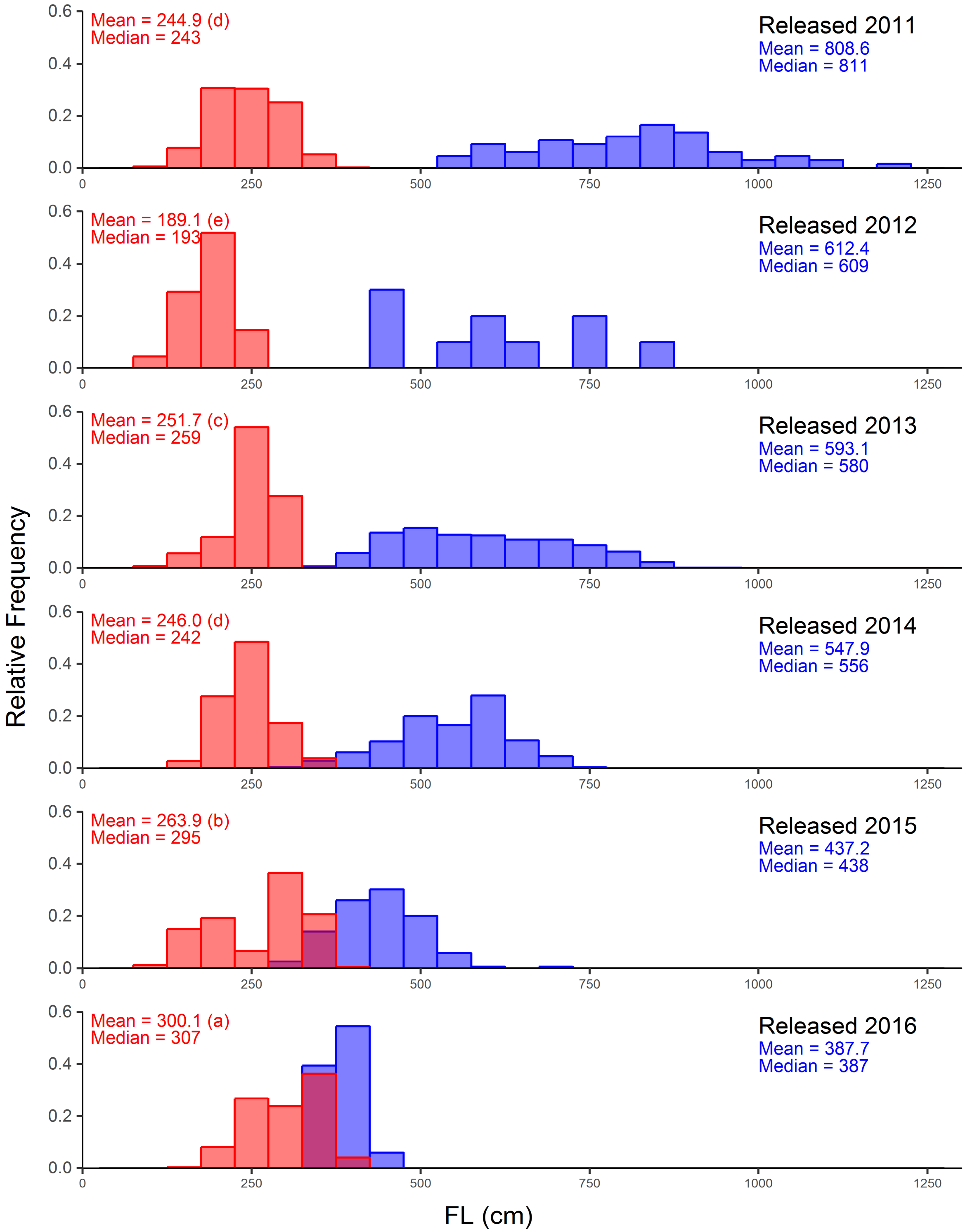

Figure 11. Fork length distributions at the time of tagging (red) and at recapture in 2016 (blue), by release year. Means and medians shown for each release group. Upon release (red text), letters (shown after mean values) indicate statistically significant Tukey tests (release sites with no shared letters are statistically different from each other).

Growth rates, scaled to annual time frames, are shown in Table 13. For fish recaptured about half a year after release, median extrapolated growth rates ranged from 54 to 188 mm/yr (likely biased high due to extrapolation from a period that includes mostly months with greatest growth potential). Median annual growth rates, calculated for fish that were in the Reservoir for 1.5 years, ranged from 53 to 123 mm/year. Median annual growth rates of fish at large for 2.5 years, ranged from 82 to 117 mm/year. Integrating growth over 3.5 to 5.5 years, annual rates ranged from 90 to 98 mm/year (Table 13). Some initial declines in weight were observed in the first half-year after release, but for the most part, weights increased. Median annual weight changes, extrapolated from fish caught after < 1 yr in the Reservoir ranged from -0.3 to +148 g/yr. Annual rates calculated from fish caught after 1.5 years ranged from 71 to 238 g/yr, which were followed by an apparent upward shift in growth rates. Rates calculated for fish caught after 2.5 years ranged from 187 to 311 g/yr. Growth rate continued to increase thereafter for the 2011 release group (477, 609, and 745 g/yr after 3.5, 4.5, and 5.5 years, respectively), but levelled off (range: 262-293 g/yr) for the other cohorts.

Table 13. Growth rates (change in fork length and weight) as measured after various amounts of time since tagging (scaled to 365 days), by release year.

Release Year	Years Since Tagging					
	0.5 *	1.5	2.5	3.5	4.5	5.5
Median annual growth rates, Fork Length (mm/year)						
2011	123.4	53.3	82.2	90.3	96.9	97.6
2012	187.4	97.5	96.2	95.1	91.4	
2013	147.0	84.9	101.3	93.2		
2014	169.5	111.7	117.4			
2015	107.3	122.8				
2016	53.8					
Median annual growth rates, Weight (g/year)						
2011	nm	71.1	239.3	476.6	608.9	744.9
2012	148.4	206.1	186.9	276.2	293.7	
2013	113.0	134.5	198.0	262.4		
2014	147.0	205.8	310.7			
2015	4.7	238.0				
2016	-0.3					

nm: Fish were not weighed upon recapture in 2011.

* Growth rates extrapolated from the half year period following release that includes mostly spring and summer months will be biased high compared to those interpolated from longer periods that include the slower growth potential fall and winter months.

Size and Relative Weight at Recapture

At the time of tagging, most measured fish were at or above their standard weight (cohort medians were 101% to 121%; Table 12, Figure 12). After release, condition appeared to undergo a rapid initial decline: median relative weight of fish recaptured about a half a year after tagging ranged from 75 to 85% (Figure 12). A gradual recovery appears to be underway, as the median relative-weights-at-recapture have tended to increase with time spent in the Reservoir (Table 12, Figure 12).

In all four indexing surveys, fish released in 2013 that were caught in the lower parts of the Reservoir were significantly larger in terms of both length (2013: $F_{3,421} = 5.2$, $P = 0.002$; 2014: $F_{3,540} = 61.9$, $P < 0.0001$; 2015: $F_{3,521} = 92.9$, $P < 0.0001$; 2016: $F_{3,744} = 183.4$, $P < 0.0001$) and weight (2013: $F_{3,421} = 10.7$, $P < 0.0001$; 2014: $F_{3,535} = 87.8$, $P < 0.0001$; 2015: $F_{3,521} = 92.4$, $P < 0.0001$; 2016: $F_{3,735} = 145.0$, $P < 0.0001$) than those in the upper parts (Figure 13). During the 2014 indexing work, fish caught in the lower parts of the Reservoir had significantly higher relative weight ($F_{3,535} = 14.1$, $P < 0.0001$) than those recaptured in the upper parts of the Reservoir. A different pattern was observed in 2016: relative weights in the Mid-South zone were significantly lower than in the Mid-North or Lower zones ($F_{3,735} = 5.2$, $P = 0.001$; Figure 13), and there was no pattern in 2013 or 2015 (2013: $F_{3,421} = 3.4$, $P = 0.017$ [no post-hoc Tukey comparisons were significant]; 2015: $F_{3,521} = 2.2$, $P = 0.09$; Figure 13). From 2014 to 2016, the fish recaptured in the lower parts of the Reservoir had put on significantly more weight since tagging (2014: $F_{3,82} = 10.2$, $P < 0.0001$; 2015: $F_{3,56} = 6.5$, $P = 0.0007$; 2016: $F_{3,101} = 19.3$, $P < 0.0001$) than those caught in the upper reaches (Figure 14), whereas growth data were too sparse in the lowest reaches to draw any conclusions from the 2013 data ($F_{1,47} = 2.4$, $P = 0.13$; Figure 14). To contrast with these recapture data, we examined the sizes of fish at release. Although there were statistically significant differences among release sites in terms of length ($F_{2,7972} = 159.8$, $P < 0.0001$), weight ($F_{2,836} = 17.4$, $P < 0.0001$), and relative weight ($F_{2,836} = 7.8$, $P = 0.0004$), the fish released at the lower sites were never the longest, heaviest, or in best condition (Figure 15).

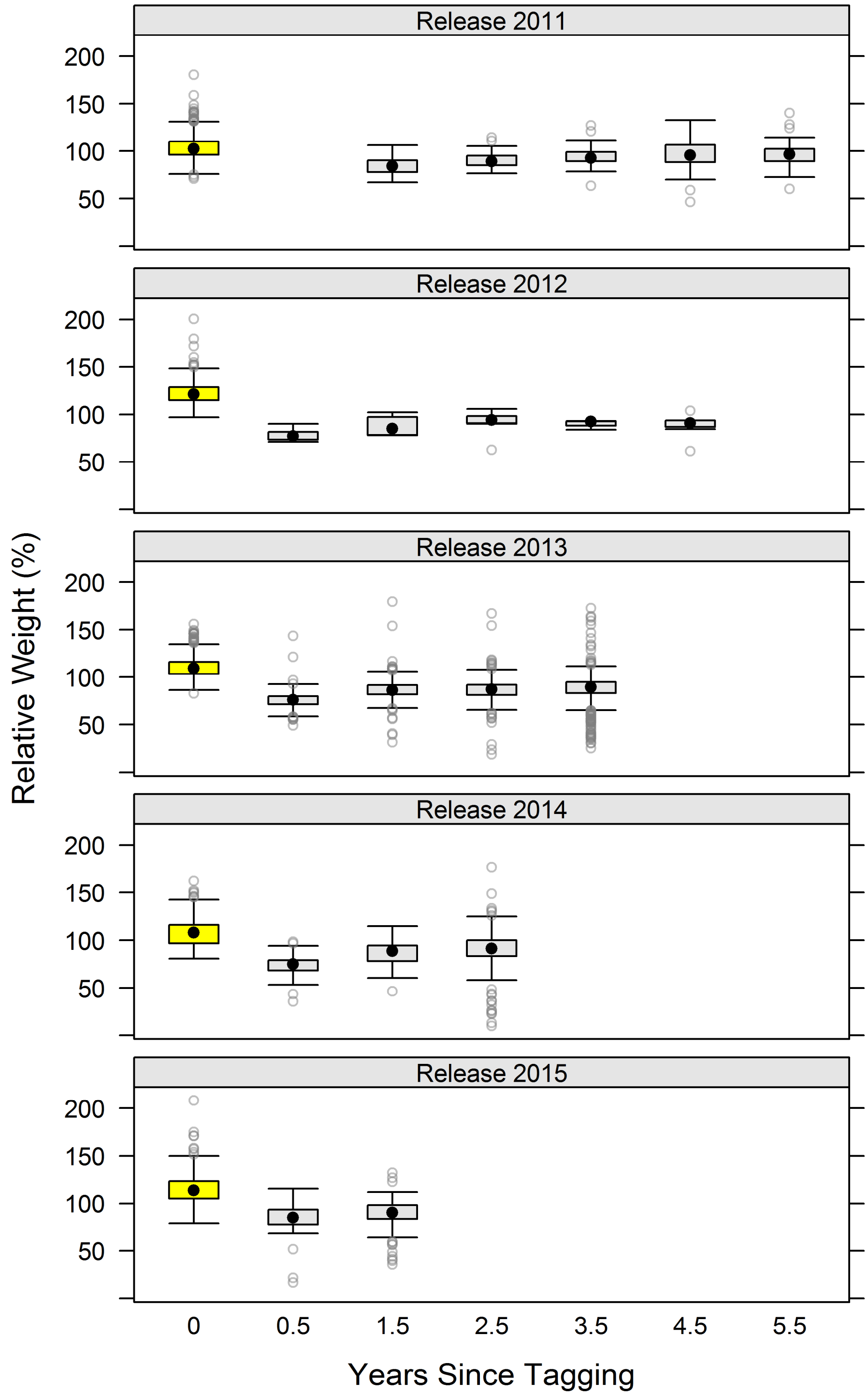

Figure 12. Relative weight of sturgeon at tagging (yellow) and at recapture (grey), by release (panels) and recapture year (x-axis).

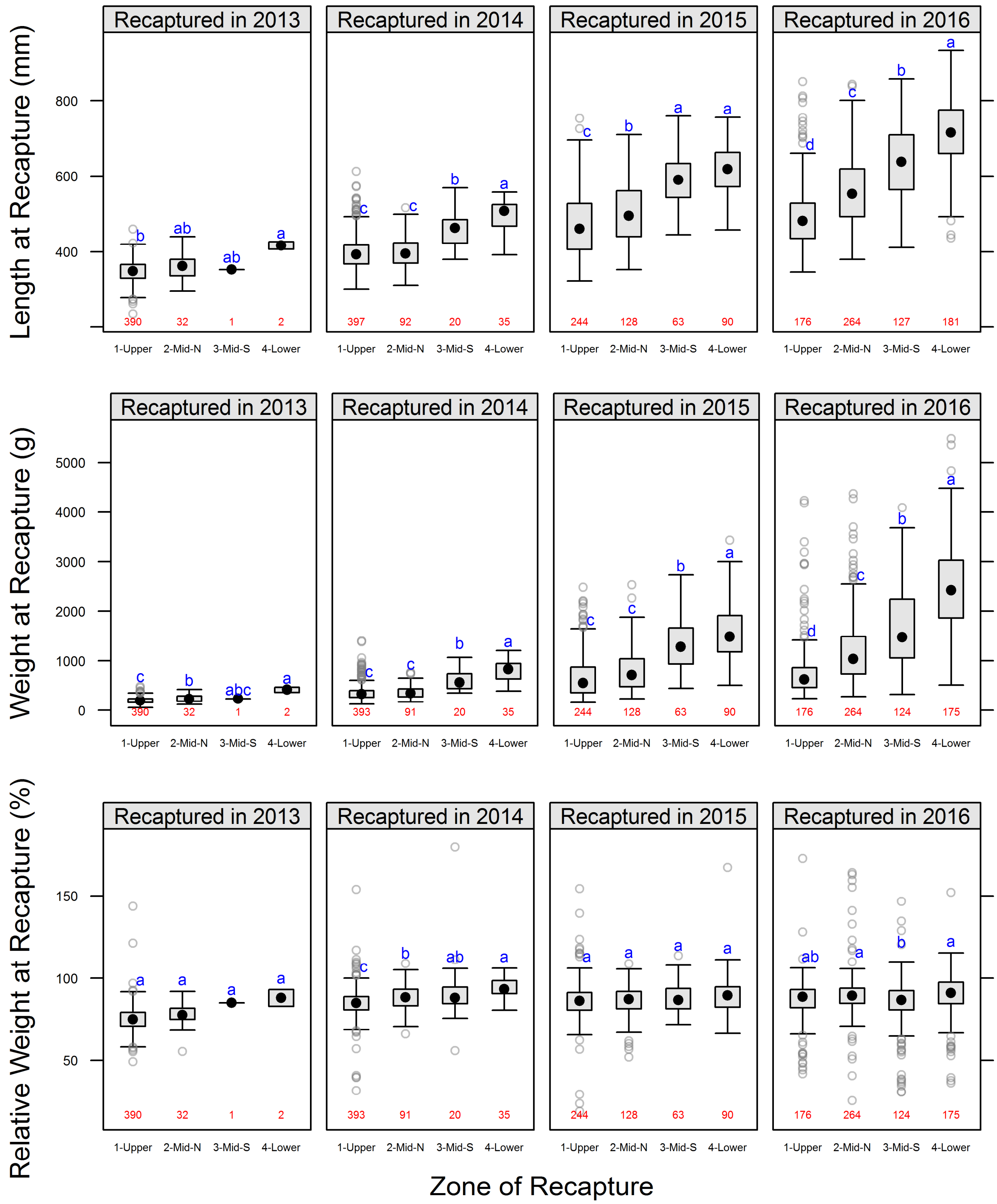

Figure 13. Distributions of length, weight and condition (relative weight) of the fish released in 2013, by recapture year and recapture zone. Sample sizes are shown along the horizontal axes. Within a panel, letters indicate statistically significant Tukey tests (recapture zones with no shared letters are statistically different from each other).

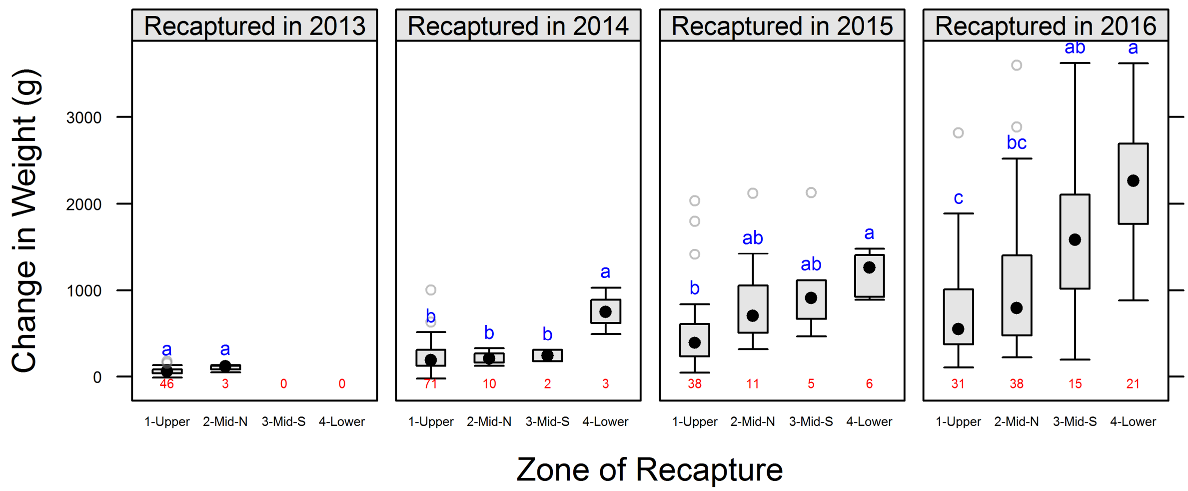

Figure 14. Growth (change in weight between tagging and recapture) distributions for fish released in 2013, by recapture year and recapture zone. Sample sizes are shown along the horizontal axis. Within a panel, letters indicate statistically significant Tukey tests (recapture zones with no shared letters are statistically different from each other).

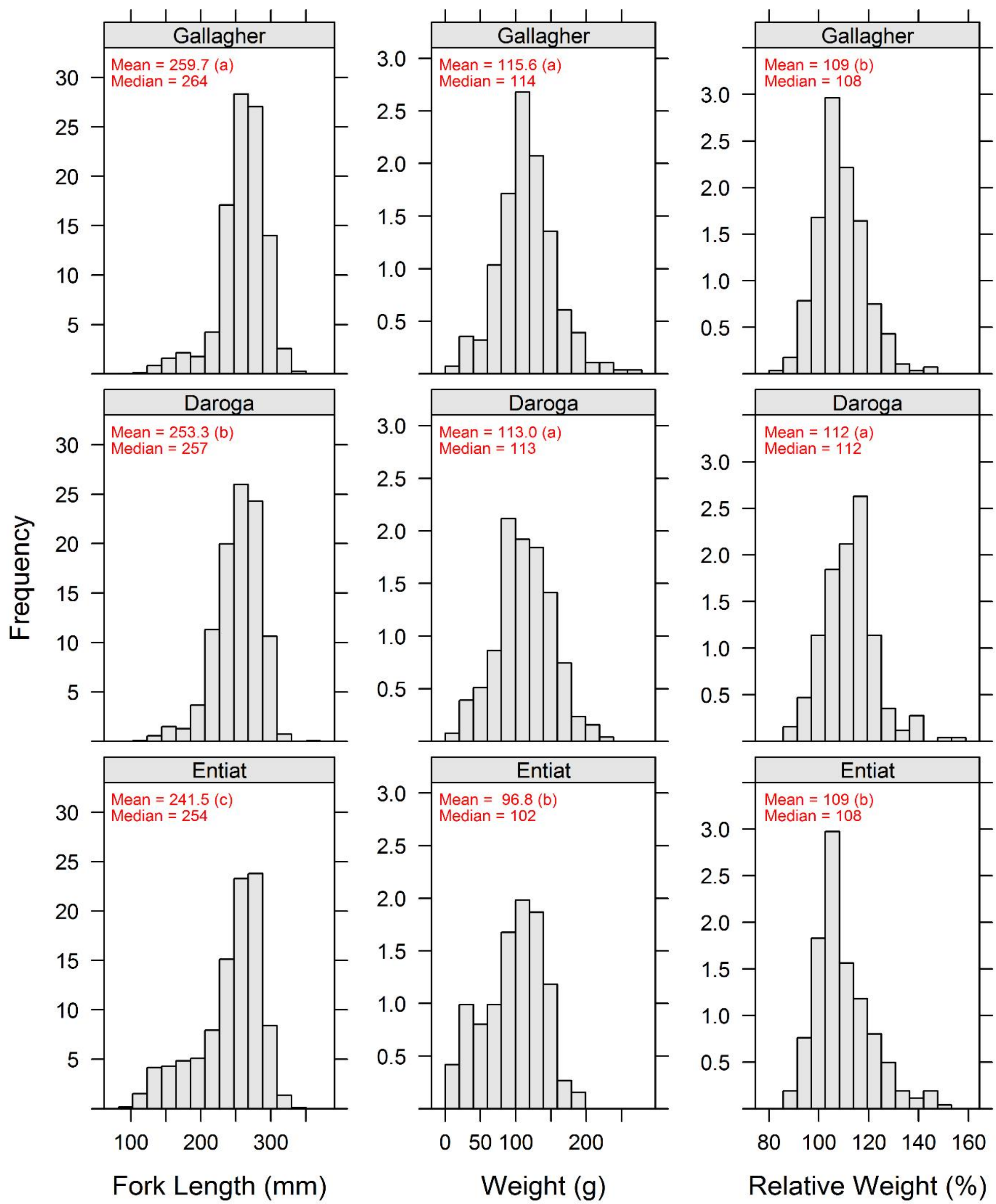

Figure 15. Fork length, weight and condition (relative weight) distributions for fish released in 2013 at the time of tagging, by release site. Within a column, letters (shown after mean values) indicate statistically significant Tukey tests (release sites with no shared letters are statistically different from each other).

Survival Estimation

Nuisance and Confounding Issues

Prior to performing the main survival analyses of interest, ancillary analyses were conducted to determine the best method for dealing with detection issues, specifically those related to the changes in methodology that occurred throughout the study period. Robichaud et al. (2016) found evidence that post-release survival differed by time scales (i.e., short- and long-term, with the potential for intermediate-term survival differences as well), thus time-scales were also considered in the current analysis.

Releases from 2016 were not included in the present analyses because there were too few recaptures to provide reliable survival estimates for this cohort. The time intervals between sampling bouts (Table 5) were adjusted appropriately. Note also that the 2015 release group has not been in the Reservoir for long enough to permit estimation of their long-term survival rate.

Detection Model

The structure of the detection model was first determined before any of the main survival analyses were carried out. A total of 20 different detection models were considered, looking at the impact of sampling technique (i.e., incidental, targeted and random), the setline configuration (i.e., short setlines with 80 treble hooks; short setlines with 80 circle hooks; and long setlines with 40 circle hooks), sampling effort (along with log transformed effort), sturgeon age (along with log transformed age), and year-to-year changes (both random year-to-year differences and temporal trends). Apart from an additional setline configuration (i.e., short setlines with 40 circle hooks) the detection model set was identical to Robichaud et al. (2016). Fitting was performed using a fixed survival model: one that used a common long-term survival rate for all release groups, with allowances for differences in short-term survival.

Detection model ranking results were generally consistent with Robichaud et al. (2016). Full details and ranking results for all 20 detection models are available in Appendix B. Generally, more complicated detection models tended to rank higher. The highest-ranked detection models tended to accommodate for: sampling technique; setline configuration; effort; age; and the interaction between method, setline configuration, effort, and year-specific effects. The highest-ranking detection model allowed for differences among sampling techniques and between setline configurations, *and* accounted for varying fish age and effort among sampling techniques and between setline configurations, as well as year-to-year differences in these effort and age relationships. Log transforming the effort metric and age further improved support. Detection models that included age of the individual sturgeon (known for all individuals given their hatchery origin) were well supported, suggesting gear efficiency was affected by age (or more likely by size, for which age was a proxy measure).

The top-supported detection model required 35 parameters and estimated year-to-year changes in the effect of method-specific effort and of age on capture rates (see Appendix B). Employing such a complicated detection model did not always allow all model parameters to be consistently estimated in subsequent survival analyses. As such, the second ranked model (33 parameters) was chosen. The selected model was not a ‘simplification’ of the top-supported model, *per se*; rather it used a slightly different approach. As described in Appendix B, the 33 parameters accommodated for sampling techniques, setline configuration, effort (with efficiencies varying by year), and age-related effects:

$$\text{logit}(p_{i,t}) = M_t + H_t + year_t\!:M_t\!:H_t\!:\log(E_t) + M_t\!:H_t\!:\log(A_{i,t}) + M_t\!:H_t\!:\log(E_t)\!:\log(A_{i,t})$$

The selected detection model provided unique capture probabilities for each individual (subscript i) and sampling bout (subscript t). The term M_t represented the sampling technique (a categorical variable), H_t was the setline configuration (categorical variable), the term E_t was the effort metric used for a specific bout (see Table 5), and $A_{i,t}$ was the age of individual i in bout t. The interaction term $year_t\!:H_t\!:M_t\!:\log(E_t)$ allowed for a different effort relationship (i.e., logistic regression slope representing the per-unit capture efficiency) for each unique combination of sampling technique and setline configuration, which was then independently estimated each year. The interaction term $M_t\!:H_t\!:\log(A_{i,t})$ allowed for detection rates to vary by age for each unique combination of sampling technique and setline configuration. The term describing the interaction between age and effort ($M_t\!:H_t\!:\log(E_t)\!:\log(A_{i,t})$) allowed the per-unit effort effectiveness of a method-type to differ with age (i.e., gear selectivity changes with age). This detection model provided the most consistent results of any detection models considered, and was employed in all of the subsequent survival analyses.

<u>Survival on Differing Time Scales</u>

Robichaud et al. (2016) conducted an in-depth analysis exploring the viability of different models that parameterized survival at different time scales (e.g., immediately after release versus long-term). Results from this analysis were then used to construct a viable set of survival models which were used in the remainder of their analyses (Robichaud et al. 2016). The current analysis maintains this set of survival models, though here they are tested against an expanded data set, including an additional year of recapture data (i.e., from 2016).

Apparent Survival Rates

In this section, we modeled how short-, intermediate-, and long-term apparent survival rates varied among release cohort (i.e., by the year in which they were released into the Reservoir, see Table 1). Seven different models describing release cohort survival were fitted and ranked (Table 14). Model 1 used constant survival across all release cohorts and represented a null hypothesis (i.e., no difference between release cohorts). Model 2 introduced group-specific survival differences for each release cohort (G_i), but made no distinction in survival over differing time periods. Model 3 added a constant offset to represent differences in short-term survival immediately after release ($R_{i,t}$). Model 4 was similar to Model 3, but allowed this offset to be specific to each release cohort ($R_{i,t}\!:G_i$). Model 5 extended Model 3, allowing individual short-term survival to be a function of an individual's length ($R_{i,t}\!:\log(L_i)$). Model 6 was similar to Model 5, but allowed the 'length vs. short-term survival' regression slope to differ among release cohorts (i.e., $R_{i,t}\!:G_i\!:\log(L_i)$). Model 7 extended Model 6 by adding a survival offset to represent survival differences in the first year after the short-term survival period (intermediate-term survival, $Y_{i,t}^1$). This period

Table 14. Model ranking results from the analysis of apparent survival by release cohort. Models are shown in order of support from most to least.

	Apparent Survival Model	npar	AICc	**Δ**AICc	Weight	Deviance
7	$\text{logit}(\phi_{i,t}) = G_i + R_{i,t} + R_{i,t}{:}G_i{:}\log(L_i) + Y^1_{i,t}$	43	37807.65	0.00	1.00	37721.52
6	$\text{logit}(\phi_{i,t}) = G_i + R_{i,t} + R_{i,t}{:}G_i{:}\log(L_i)$	42	37824.42	16.77	0.00	37740.29
5	$\text{logit}(\phi_{i,t}) = G_i + R_{i,t} + R_{i,t}{:}\log(L_i)$	38	37845.66	38.01	0.00	37769.56
4	$\text{logit}(\phi_{i,t}) = G_i + R_{i,t}{:}G_i$	41	38016.31	208.66	0.00	2523.99
3	$\text{logit}(\phi_{i,t}) = G_i + R_{i,t}$	37	38024.05	216.40	0.00	2539.76
2	$\text{logit}(\phi_{i,t}) = G_i$	36	38156.51	348.86	0.00	2674.22
1	$\text{logit}(\phi_{i,t}) = \beta$	32	38741.61	933.96	0.00	3267.34

ranged from about the third month post-release to up to the next sampling event which could be as long as the 16th month post-release; the long-term survival period started after the intermediate period. More complicated survival models were also considered (e.g., intermediate-term survival specific to a release group), but parameter estimates were not reliable and so these models were not considered further.

The top-ranked model (Model 7; Table 14) included release cohort specific long-term survival differences, and length-specific short-term survival effects that were specific to the release cohorts, and an allowance for survival differences at different time scales after release (i.e., intermediate- and long-term survival). The top ranked survival model was the most complex model and had virtually all the support.

Given that ΔAICc values were large (i.e., greater than 10), the top-ranked model was used to generate average independent estimates of short-, intermediate-, and long-term apparent survival (Model 7; Table 14):

$$\text{logit}(\phi_{i,t}) = G_i + R_{i,t} + R_{i,t}{:}G_i{:}\log(L_i) + Y^1_{i,t}.$$

Estimates of the short-term apparent survival exhibited large differences among release cohorts, with a substantial decline starting after 2012 (Figure 16). Because individual covariates (i.e., L_i) were used in the survival models, our short-term survival estimates represent the average survival over the observed lengths-at-release. Estimates in Figure 16 have been presented as the probability of surviving the initial period after release (which varied in duration, see bouts C1, C2, C6, C16, and C31; Table 5), and also as 'per-year' rates (Table 15) for direct comparison with cohort-specific intermediate- and long-term apparent survival rates (see below).

Individual sturgeon short-term survival rates also varied by length-at-release, with longer individuals having relatively higher survival rates, which can be observed by comparing the logistic regression slopes (Figure 17). A slope of zero indicates no benefit of length-at-release, while slopes greater than zero indicate a short-term survival benefit. Overall, longer fish had better survival, with a similar effect across all release

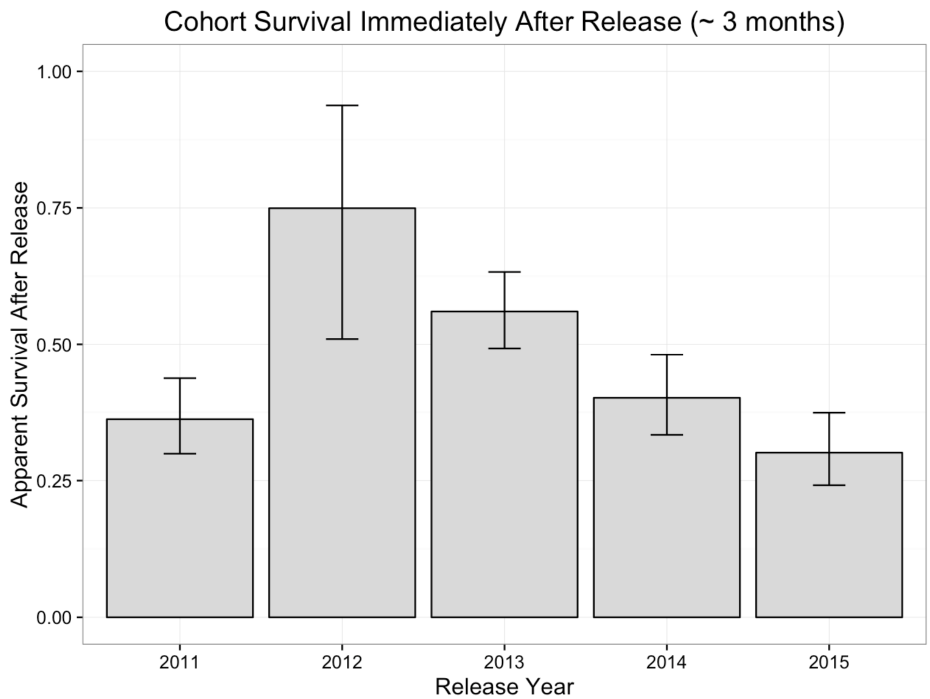

Figure 16. Estimates of average short-term apparent survival (apparent survival over the period immediately after release) by release year. Not scaled to a 'per year' basis. Error bars indicate 95% confidence intervals.

Table 15. Estimated average short-term apparent survival, by release year, scaled to a 'per-year' rate.

Release Year	Apparent Survival	Standard Error	Lower 95% CI	Upper 95% CI
2011	0.021	0.008	0.010	0.043
2012	0.245	0.200	0.037	0.730
2013	0.107	0.026	0.065	0.171
2014	0.034	0.012	0.017	0.067
2015	0.017	0.007	0.008	0.036

cohorts except the 2015 cohort which showed a much smaller benefit of length-at-release. The 2012 release group point estimate was higher, but the confidence intervals were quite wide due to low sample size, so it is unclear if it differed significantly from the other cohorts.

Estimates of intermediate-term survival (Figure 18) followed a similar pattern to short-term, but with overall higher survival rates. The similarity in the among-cohort pattern was primarily due to model structuring, as it was not possible with the available data to independently estimate survival rates by cohort for each time

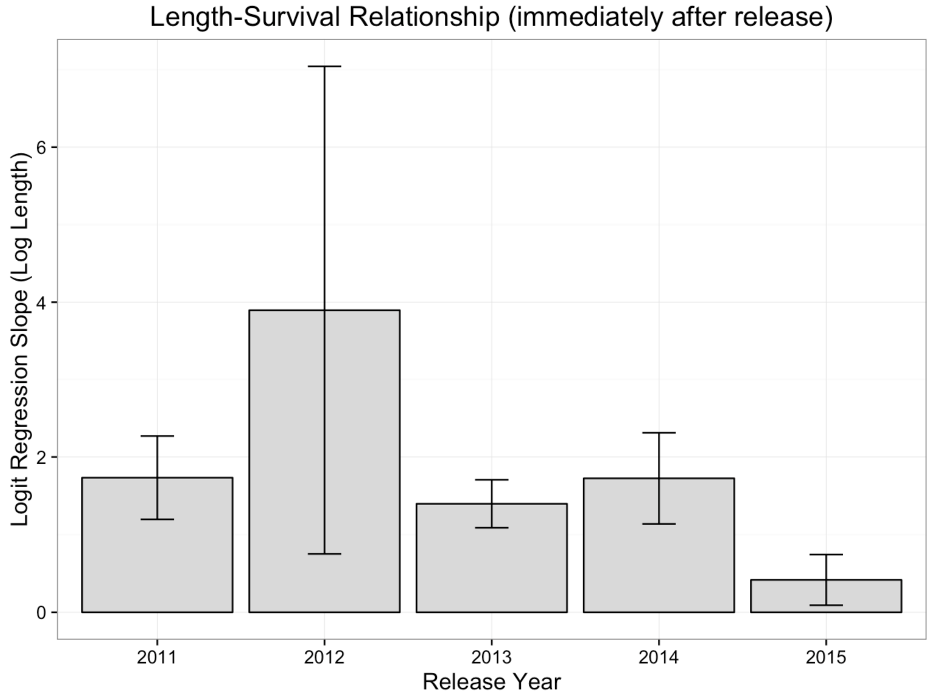

Figure 17. Estimated length-survival relationships for the period immediately after release, by release cohort. Values indicate the logit regression slope for centered and scaled log-transformed and standardized lengths-at-release. Bars indicate 95% confidence intervals.

scale (i.e., short-, intermediate-, and long-term). While the per-year intermediate-term apparent survival rates were higher than short-term apparent survival, these rates also apply over differing periods of time (Table 16). As such, the percentage of available sturgeon surviving each period was roughly similar (i.e., Figure 16 vs. Figure 18). It is worth noting that Figure 18 is scaled on a per-year basis, but would change only slightly if it were adjusted to the actual observed time periods since the latter were close to a year in duration (Table 16).

Cohort-specific long-term apparent per-year survival rates (Table 17, Figure 19) were generally higher than either short- or intermediate-term survival, indicating the highest survival rates were for sturgeon surviving past the first year post release. Patterns in estimated long-term survival showed generally high survival for most release groups. Similar to short- and intermediate-term survival, the shared among-cohort pattern was primarily due to model structuring constraints. Because this constraining happens on the logit scale, some differences in the among-cohort patterns resulted from the need to back-transform estimates to the anti-logit scale (i.e., to derive the survival probability). As estimates approach a boundary (e.g., perfect survival) the differences become less pronounced. As noted before, estimates of long-term survival for the 2015 cohort were not yet possible as an insufficient amount of time has transpired (i.e., less than a year) since the intermediate-term survival period ended for this release cohort.

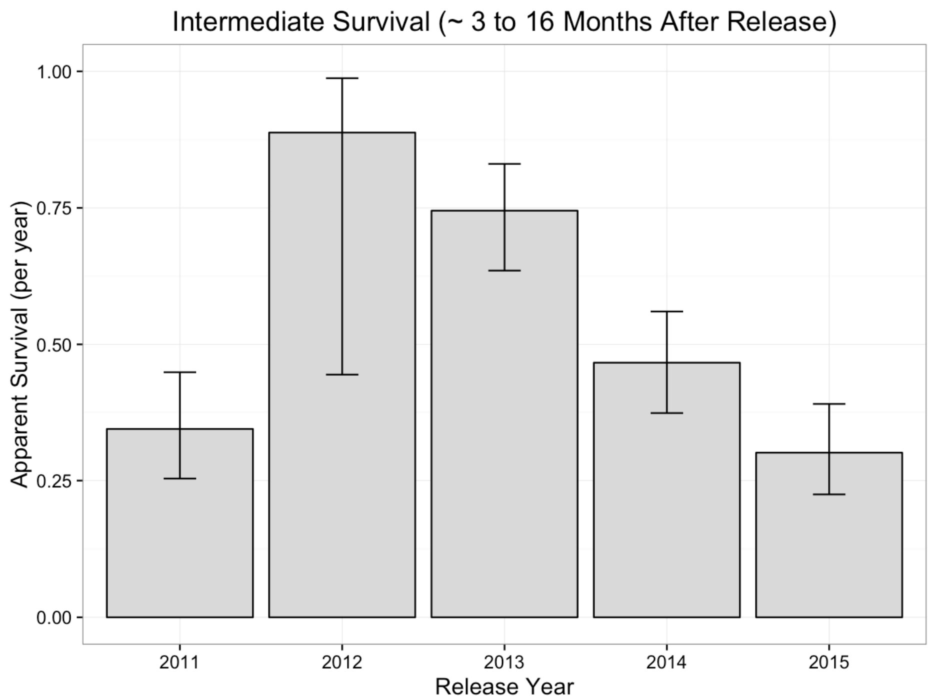

Figure 18. Estimates of average intermediate-term apparent survival (apparent survival over the period three months after release to the next recapture event approximately 16 months after the initial release). Error bars indicate 95% confidence intervals.

Table 16. Time periods, relative to release, that correspond to intermediate-term apparent survival.

Release Year	Number of Months Post-Release: Start	Number of Months Post-Release: End	Duration (Months)
2011	3.2	12.9	9.7
2012	2.5	12.1	9.6
2013	3.1	14.8	11.7
2014	3.3	15.2	11.9
2015	3.6	16.2	12.7

Table 17. Estimated average annual long-term apparent survival for release cohorts that have been observed for more than one year after the short- and intermediate-term survival periods (rates scaled to a 'per year' basis).

Release Year	Apparent Survival	Standard Error	Lower 95% CI	Upper 95% CI
2011	0.718	0.034	0.648	0.779
2012	0.975	0.029	0.793	0.997
2013	0.934	0.019	0.887	0.962
2014	0.808	0.040	0.717	0.875

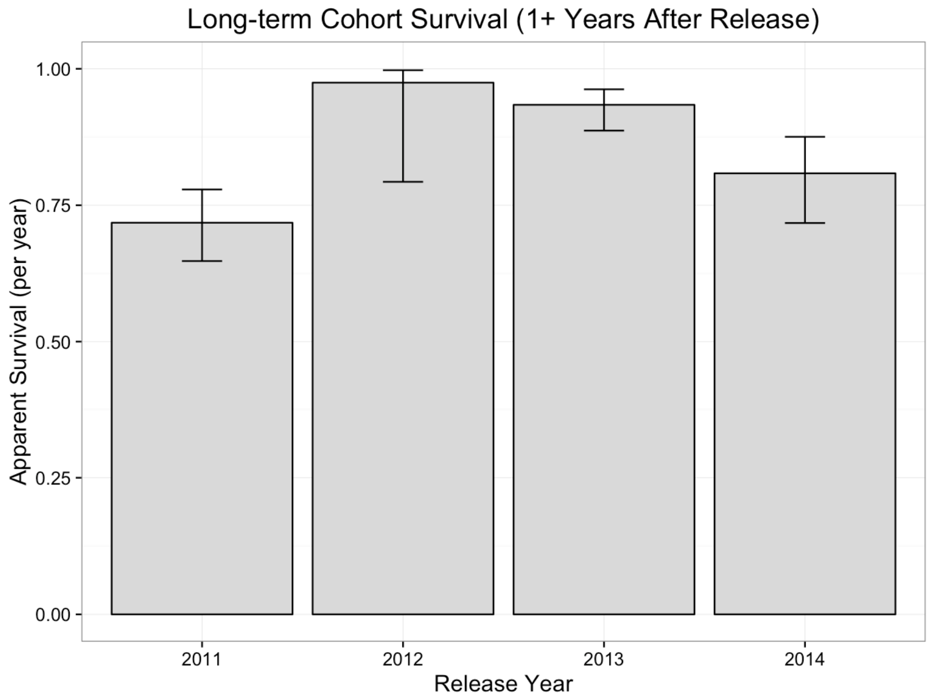

Figure 19. Estimates of average long-term yearly apparent survival for release cohorts that have been observed for more than one year after the short- and intermediate-term survival periods. Error bars indicate 95% confidence intervals.

True Survival Rates

Between the time of release and the subsequent recapture session, tag loss was assumed to affect 4.3% of the tags, and 1.45% of the fish were assumed to emigrate, for a total loss of 5.69% (assuming both were independent processes). Afterwards, losses were assumed to occur through emigration after each fall recapture session at a rate of 2.54%, 2.35%, and 2.10% in each year thereafter. Based on these numbers, ‘loss on captures’ were set, the top release cohort model was re-run, and ‘true’ survival rates were estimated (Table 18).

Changes between the true and apparent survival estimates were computed as a percent relative to the original apparent survival estimates (Table 19). As expected, estimates of true survival were higher than those of apparent survival. In general, the differences between true and apparent survival were highest and most variable for short-, and intermediate-term survival estimates, and lowest for long-term survival. For long-term survival, the differences between true and apparent values were largest for cohorts observed for the longest (2011 release group) and shortest (2015 release group) periods of time (Table 19).

Table 18. Estimated average true survival, by release year. Short-term rates are for the probability of surviving the interval from release to the first sampling occasion (approximately 3 months afterwards). Intermediate-term rates are the probability of surviving one year *after* the initial 3-month (short-term) period. Long-term rates are the probability of surviving *each* year after the short- and intermediate-term periods.

Release Year	Estimate	Lower 95% CI	Upper 95% CI
True Short-term Survival			
2011	0.376	0.308	0.456
2012	0.769	0.517	0.950
2013	0.586	0.517	0.660
2014	0.413	0.341	0.498
2015	0.307	0.244	0.386
True Intermediate-term Survival			
2011	0.452	0.351	0.560
2012	0.921	0.526	0.992
2013	0.785	0.669	0.868
2014	0.494	0.393	0.596
2015	0.296	0.214	0.392
True Long-term Survival			
2011	0.734	0.663	0.795
2012	0.977	0.791	0.998
2013	0.942	0.897	0.968
2014	0.816	0.725	0.882

Table 19. Percent change in survival estimates of the release cohort analysis after accounting for emigration and tag loss.

Release Year	Cohort Survival		
	Short-term	Intermediate-term	Long-term
2011	3.69%	7.29%	2.24%
2012	2.57%	1.37%	0.26%
2013	4.68%	4.62%	0.87%
2014	2.95%	5.65%	0.97%
2015	2.08%	4.90%	-

Known Mortalities

Since 2011 there have been 13 recorded mortality events of supplementation-released White Sturgeon, including three fish that were released in 2011, three in 2013, four in 2014, and three in 2015 (Table 20). These varied from 131 to 1,538 days post-release, with 8 of the 13 mortalities (62%) occurring more than a year following release. The index fishing mortalities in 2014 occurred from swallowed treble hooks and the 2016 mortality was due to line entanglement. Five of the tag recovery mortalities were found at bird colonies, and the remaining three were in the Rocky Reach Dam trash rack, likely having drifting along surface of the Reservoir before encountering it.

Age-Structured Abundance of Supplementation Fish

Annual abundance estimates were calculated for each cohort, and lined-up among calendar years to generate an age-structured abundance time series (Figure 20). In terms of hatchery-origin fish, the only fish in the Reservoir in 2011 were those that were released in 2011. Of the 6,376 fish released in the spring, 37.6% survived (true rate) and 1.45% emigrated during the first few months in the Reservoir, resulting in a total estimated abundance of 2,363 fish during the fall 2011 survey. Very few fish were released in 2012, hence the 2011 cohort continued to dominate the population during the 2012 sampling year, while overall abundance declined as a result of the intermediate-term true survival of the 2011 cohort (45.2%). The short-term true survival rate of the fish released in 2013 was 58.6%, and since a great number was released (7,957 fish), this cohort dominated the population during the 2013 indexing survey. The total abundance of hatchery-produced fish in 2013 was estimated at 5,445. Poor short- and intermediate-term true survival rates of the 2014 and 2015 releases meant that the 2013 cohort continued to be the dominant year-class from 2014 onwards. Since short-term survival of the 2016 cohort could not yet be estimated, the overall abundance in the Reservoir in 2016 is not known, but it is calculated that the 2011-2015 cohorts summed to 4,702 fish.

Table 20. Details on confirmed mortality events of PIT tags, including tag recoveries and index fishing mortalities.

PIT ID	Recovery Date	Recovery Site	Release Date	Days Post Release	Rearing Location
Index Fishing Mortalities					
3D9.1C2DF76D41	25 Aug 14	Wells Tailrace East Bank	22 May 13	460	Chelan Hatchery
3DD.0077427B3B	23 Sep 14	Big Cove	14 May 14	132	Columbia Basin
3DD.007742F0BC	23 Sep 14	Big Cove	15 May 14	131	Columbia Basin
3D9.1C2E0ABF27	27 Sep 14	Pebble Beach	23 May 13	492	Chelan Hatchery
3DD.00776B4291	5 Sep 16	Ferry Landing	29 May 15	465	Columbia Basin
Tag Recoveries					
3D9.1C2D89AF3E	28 Sep 11	Badger Island Colony	20 Apr 11	161	Marion Drain
3D9.1C2D8E9506	24 Sep 12	Badger Island Colony	20 Apr 11	523	Marion Drain
3D9.1C2E0A6FEC	13 Nov 13	RI Forebay Waterbird Colony	21 May 13	176	Columbia Basin
3D9.1C2D899408	6 Jul 15	Rocky Reach Trash Rack	20 Apr 11	1,538	Chelan Hatchery
3DD.0077539237	13 Jul 15	Rocky Reach Trash Rack	22 Jun 14	386	Unknown
3DD.00777BBD2C	15 Oct 15	RI Forebay Waterbird Colony	14 May 14	519	Unknown
3DD.007741C0E4	15 Oct 15	RI Forebay Waterbird Colony	29 Apr 15	169	Columbia Basin
3DD.00776A40B0	18 Oct 16	Rocky Reach Trash Rack	27 Apr 15	540	Columbia Basin

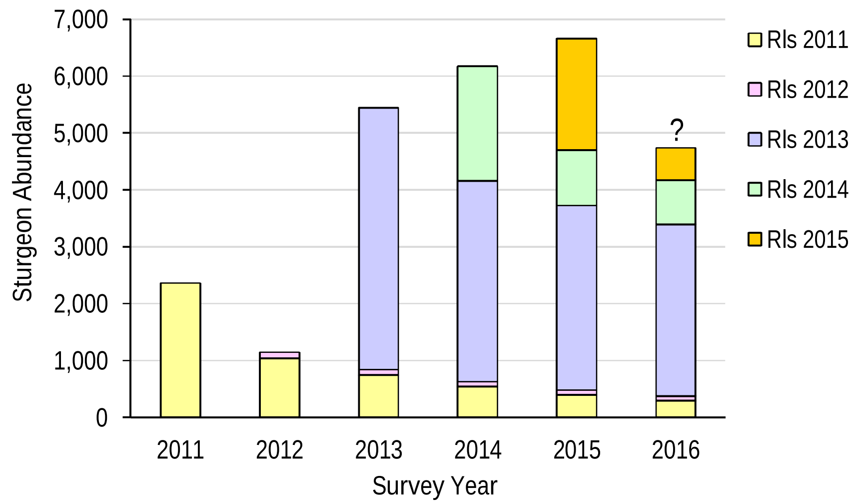

Figure 20. Estimated sturgeon abundance during each indexing survey year, by release cohort. The “?” refers to the unknown number of fish from the 2016 cohort that survived the first few months in the Reservoir.

Diet Study

Diet Fishing

Diet fishing took place over three sessions (18-20 April, 17-19 July and 19-21 October) in 2016 (Table 21). Fishing effort was originally intended to be equally spread throughout the Reservoir, but low catch rates in the lower reaches meant that more fishing had to be apportioned to the upper parts in order to obtain adequate sample sizes. CPUE in the upper zone was 17 fish per day, while the mid-north zone had 1.5 fish per day, and the two lowest zones had no captures despite at least one full day of dedicated effort per session. The locations of captured sturgeon are shown in Figure 21. The depths at which sturgeon were captured ranged from 9.1 m to 41.1 m (mean = 21.3 m).

Gastric lavage was performed on each of the 70 captured sturgeon: 31 fish (44%) expelled nothing during the lavage; and stomach content samples were collected from the other 39 fish (56%; Table 22). Though the collected sturgeon covered a wide range of sizes (358-1038 mm FL, mean = 608 mm FL), they were predominantly age-4 (released in 2013, 56%) and age-6 (released in 2011, 30%), and all but two 'non-empty' stomach samples collected were from these two ages (the other two were from a release years 2012 and 2016; Table 22).

Table 21. Diet sampling, including effort, catch, samples collected, and non-empty samples per day, by Reservoir Zone and session during 2016.

Category	Days fished	Catch	Samples Collected	'Non-empty' samples/day
Reservoir Zone				
Upper Reservoir	4	68	37	9.3
Mid-Reservoir North	1.3	2	2	1.5
Mid-Reservoir South	1.3	0	0	0.0
Lower Reservoir	2.3	0	0	0.0
Session				
18-20 April 2016	3	14	8	2.7
17-19 July 2016	3	27	13	4.3
19-21 October 2016	3	29	18	6.0
Totals	9	70	39	4.3

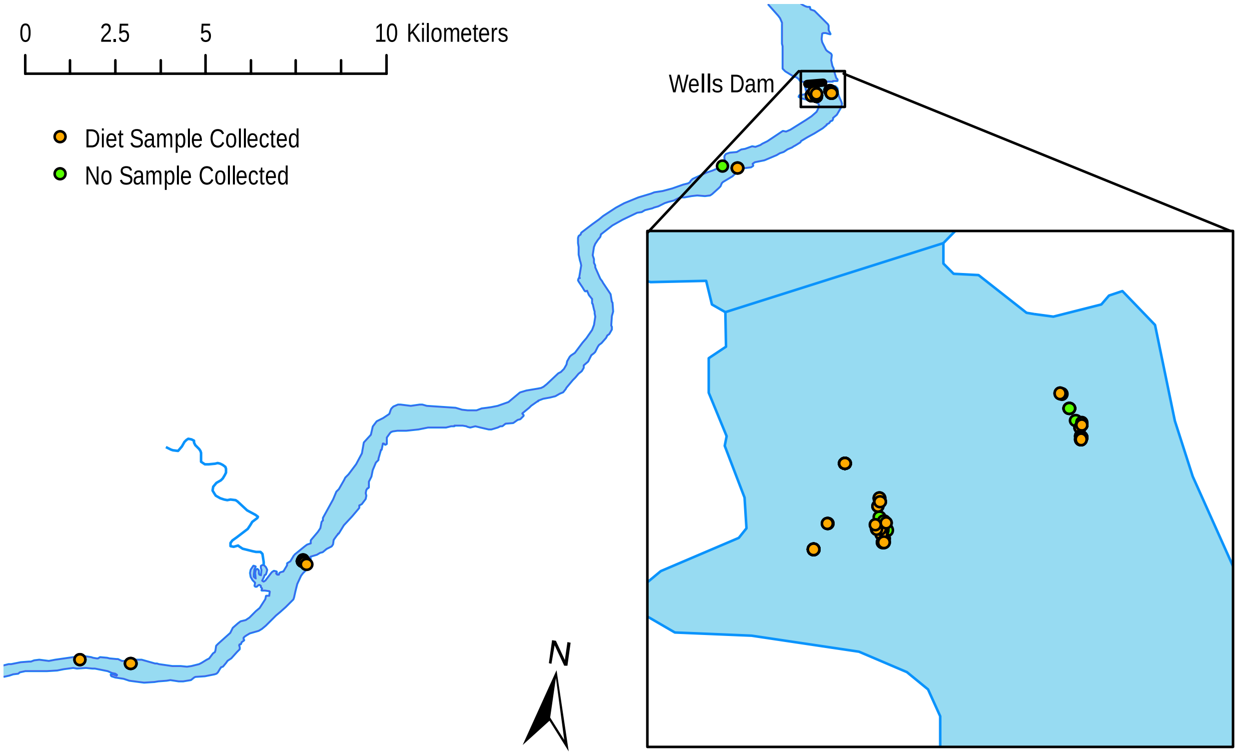

Figure 21. The locations of sturgeon captured during diet study in 2016. Diet samples were collected from 39 sturgeon (orange dots), and all others had empty stomachs (green dots).

Table 22. Release year and age of all sturgeon captured and sturgeon with samples collected during the diet study in 2016.

Release Year	Age	Catch	Empty Stomachs	'Non-empty' Samples Collected
2011	6	21	9	12
2012	5	1	0	1
2013	4	39	18	21
2014	3	2	2	0
2015	2	0	0	0
2016	1	3	2	1
Unknown		4	0	4
Total		70	31	39

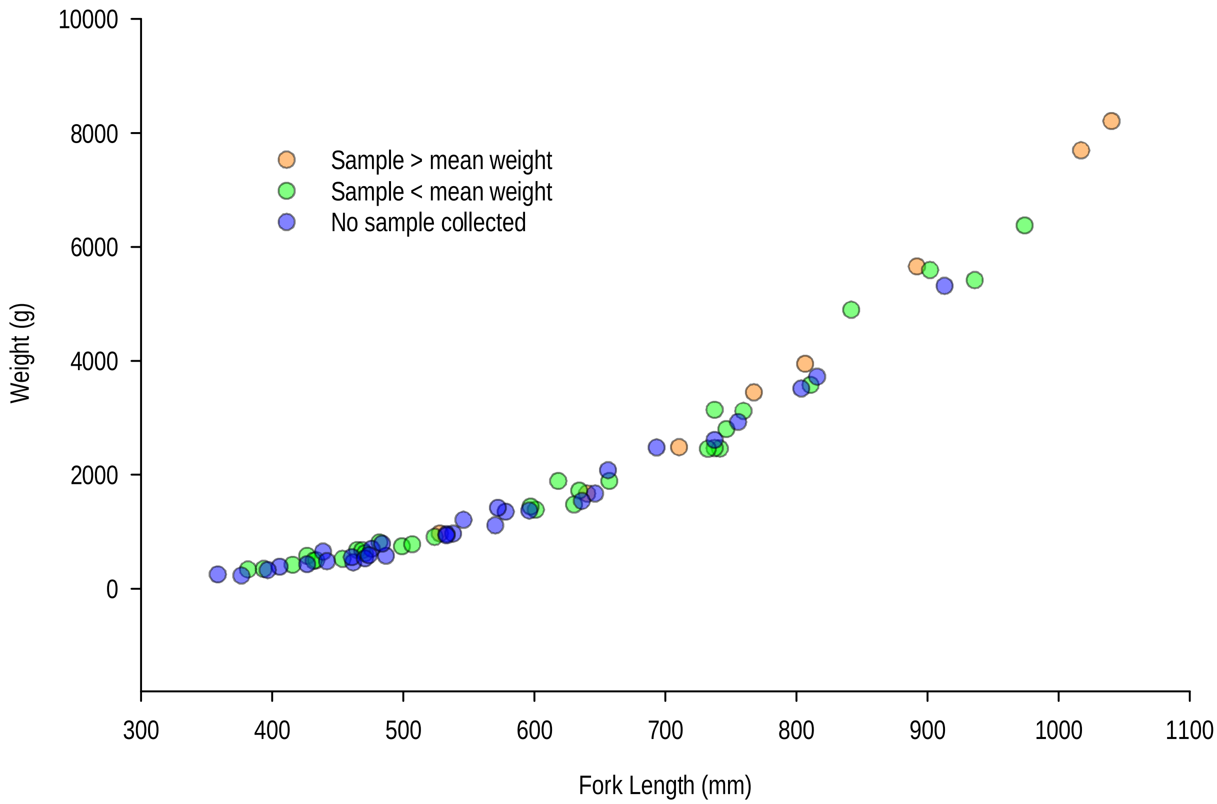

Figure 22. Lengths and weights of fish captured during the 2016 diet study. Colors indicate whether the fish expelled nothing during the lavage (blue), had a sample weight less than the mean of the ‘non-empty’ samples (green), or had a sample weight greater than the mean (orange).

Diet Composition

For non-empty stomachs, the mean sample weight was 3.0 g (range 0.01 to 47.1 g), though the distribution was skewed toward smaller weights: only eight of the 39 fish had stomach sample weights greater than the mean (all with FL greater than 527 mm; Figure 22), including two samples that were more than one standard deviation above it (with content weights of 22.9 and 47.1 g). Stomach-content analysts at WDFW divided the collected matter into 25 unique ‘taxa’ (Table 23). The most prevalent group of taxa by frequency of occurrence were amphipods (82.1%), followed by fishes (71.8%), gastropods (59.0%) and isopods (51.3%; Table 23). By weight, the dominant prey items included fish (overall, comprising 76% of the collected dietary materials), mammals, crayfish, and birds (Table 23).

Table 23. Frequency of occurrence, weight, and proportion (by weight) of sturgeon stomach contents, by taxon. The dominant taxa for each category are highlighted.

Prey Taxa	Number of samples (N= 39)	Frequency of occurrence (% out of 39 samples)	Weight (g) all samples	Proportion of total weight	Mean proportion of individual's sample weight
Fish					
Unknown Fish	18	46.2%	53.17	45.2%	22.6%
Unknown Salmonid	1	2.6%	0.52	0.4%	0.4%
Unknown Non-salmonid	3	7.7%	0.28	0.2%	3.7%
Chiselmouth (*Acrocheilus alutaceus*)	1	2.6%	28.02	23.8%	1.5%
Sculpin (Cottidae)	1	2.6%	0.61	0.5%	0.5%
Three-spined Stickleback (*Gasterosteus aculeatus*)	9	23.1%	1.49	1.3%	10.0%
Northern Pikeminnow	2	5.1%	5.15	4.4%	2.2%
All Fish	28	71.8%	89.24	75.8%	40.9%
Other					
Unknown Mammals	6	15.4%	8.39	7.1%	6.3%
Birds	5	12.8%	5.28	4.5%	4.4%
Rodents	1	2.6%	1.24	1.1%	0.1%
Coleoptera (Beetles)	1	2.6%	0.09	0.1%	0.1%
Diptera (Flies)	14	35.9%	0.11	0.1%	0.5%
Ephemeroptera (Mayflies)	3	7.7%	0.05	< 0.1%	< 0.1%
Hemiptera (True bugs)	1	2.6%	< 0.01	< 0.1%	< 0.1%
Plecoptera (Stoneflies)	1	2.6%	0.01	< 0.1%	< 0.1%
Tricoptera (Caddisflies)	9	23.1%	0.05	< 0.1%	0.6%
Unknown Insect Parts	5	12.8%	0.01	< 0.1%	< 0.1%
Amphipoda (freshwater shrimp)	32	82.1%	0.65	0.6%	8.6%
Annelid (ringed or segmented worms)	9	23.1%	0.14	0.1%	3.3%
Bivalvia (mussels, clams)	4	10.3%	0.36	0.3%	0.3%
Decapoda (crayfish)	7	17.9%	6.93	5.9%	7.8%
Gastropoda: Physidae (bladder snails)	23	59.0%	1.61	1.4%	10.4%
Isopoda (woodlice)	20	51.3%	0.38	0.3%	2.7%
Zooplankton: *Daphnia*	4	10.3%	< 0.01	< 0.1%	0.0%
Organic Material	27	69.2%	1.96	1.7%	11.5%
Unknown Material	4	10.3%	1.25	1.1%	2.5%

Frequency of occurrence and percent contribution to sample weights were compared among sessions to determine how diet changed among seasons. The frequency of occurrence of fish, shrimp, crayfish, snails, woodlice, and organic material all declined from spring to summer then rebounded somewhat by fall (Figure 23). Insects showed the largest seasonal decline, dropping from 100% of stomachs in spring to <50% in summer and fall. Birds increased each session while other taxa showed no seasonal pattern. In terms of weight, fish contributed 72% and 93% of the weight of prey items collected during the spring and summer sessions, and dropped to 10% in the fall (Figure 24). The prey items constituting the largest weight contribution in the fall were bivalves (mussels/clams) and birds. Mammals contributed 21% of the weight in the spring. All other taxa were minor (<5%) contributors to weight, and were variable over time.

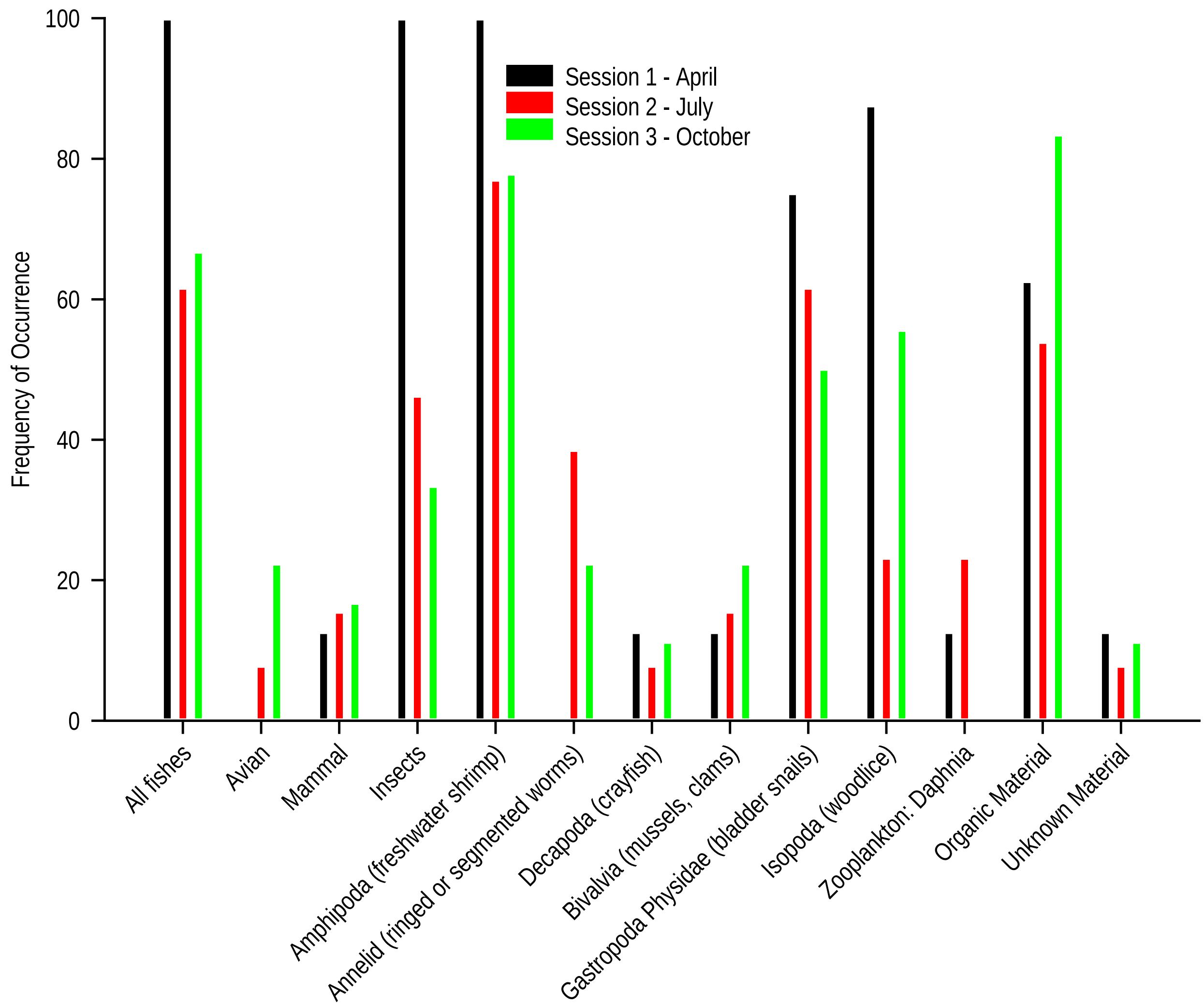

Figure 23. The frequency of occurrence (% of stomach samples in which item was observed) of prey types for each session of diet fishing in 2016.

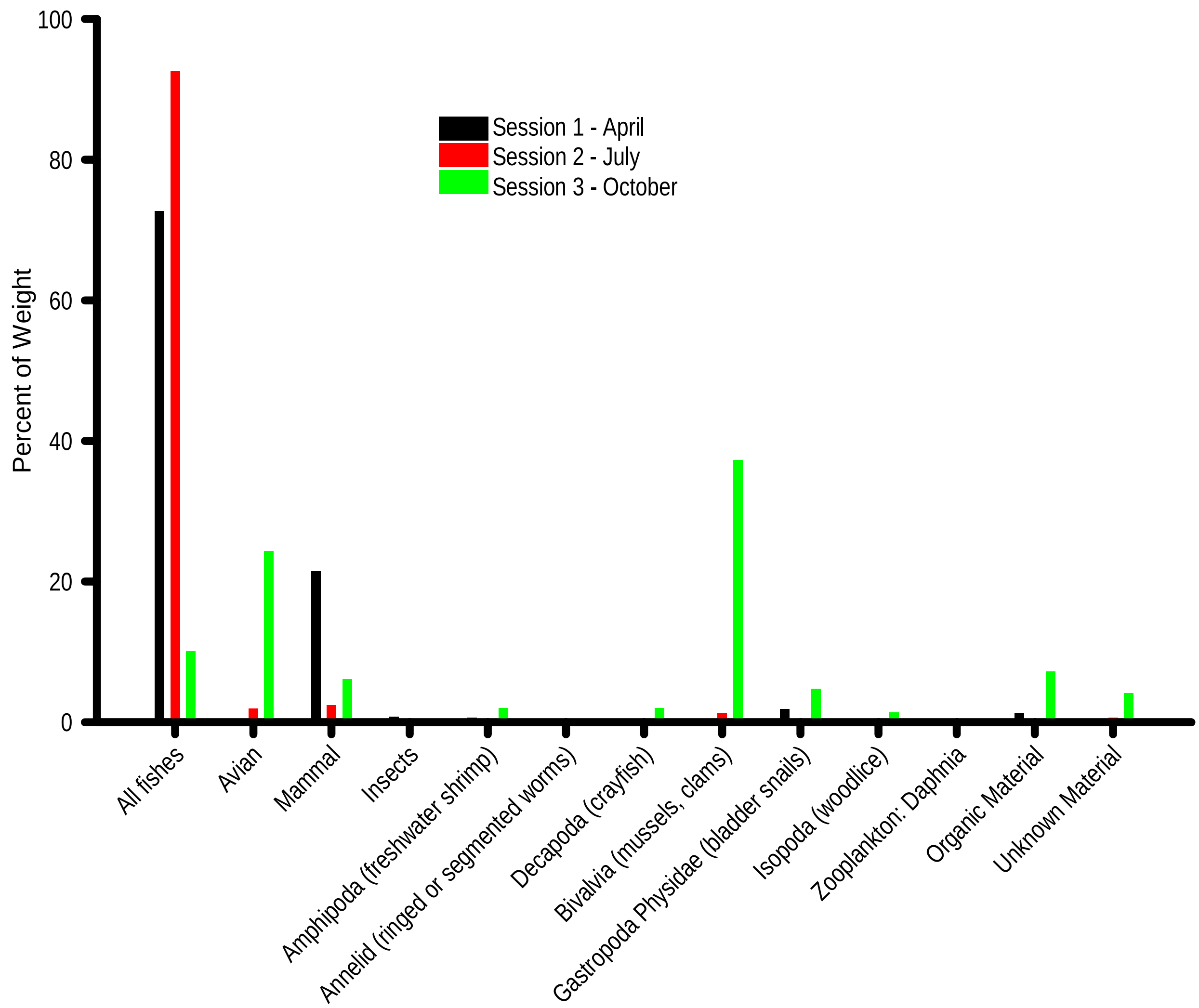

Figure 24. The percent composition by weight of prey types for each session of diet fishing in 2016.

Comparing diet among zones was precluded by sample size, as only two samples (5.1% of the 39 'non-empty' stomachs) came from the middle zone. Nevertheless, it is interesting to note that 76.5% of the upper zone samples contained fish, yet none were found in the middle zone samples. The two samples from the middle zone were comprised of amphipods, snails, isopods and birds.

Discussion

Movements and Distribution

The dominant behavior patterns that have been seen in past study years persisted in 2016 with some exceptions. Robichaud et al. (2016) identified three dominant patterns: 1) initial post-release movements tended to be in the upstream direction; 2) sturgeon appeared to mostly use the upper parts of the

Reservoir; and 3) movements occurred mainly in the warmer months. In 2016, there was no release of acoustic tags, and the 2015 tags were predominately (78%) released within 5 km of Wells Dam, thus our ability to observe upstream post-release movements was limited. However, the other two dominant movement patterns persisted in 2016: high use of the upper Reservoir and reduced movement in winter months.

In previous years, there were many acoustic-tagged age-1 fish, released directly from the hatchery, which moved readily for the first 6 months, and settled down thereafter. In 2016 there were no age-1 fish tagged, thus it was not surprising that 78% of all movements detected in 2016 were made by older fish that were tagged in the fall 2015. These fish were recaptured and tagged at either 2.5 or 4.5 years after their initial release from the hatchery, and any behavior related to their initial release likely subsided. Interestingly, these 2015-released sturgeon seemed to fall into two categories: 1) the half that didn't moved out of the Wells tailrace; and 2) the other half that made substantial movements both upstream and downstream, regardless of whether they were released below Wells or in the lower Reservoir. In fact, the number of upstream and downstream movements was nearly equal for 2016, while upstream movements predominated in previous years. Many of the fish tagged in 2015 traveled large distances through the Reservoir, and some even made multiple reservoir transits (e.g. pg.16 of Appendix A), which is behavior that has been observed in adult sturgeon in the Reservoir (Wright et al. 2015). Thus, the 2016 tracking results differed somewhat from previous years, mainly as a result of differences in the tagged population. It will be interesting to gather further tracking data on these older juveniles to determine when other adult behavioral patterns will emerge, such as using one of two known adult overwintering areas.

Mobile Tracking

The three mobile tracking surveys performed in 2016 concurred with the fixed-station receiver data in that there is generally good Reservoir-wide distribution of fish, regardless of original release location. On a finer scale, there were areas of concentration and sparsity that were fairly consistent over the sessions. As more data become available in future study years, our ability to identify preferred habitats at fine scales should increase. On the other hand, our sample sizes are declining: many of the deployed tags have or will expire, and without additional tagging, the number of fish available to track will reduce to 50 individuals from 2018 through 2020.

Emigration and Tag Loss

Because PIT tags have a relatively low probability of being detected when downstream-migrants pass hydropower projects, especially for bottom-oriented juvenile sturgeon, one of our primary objectives was to measure emigration from the Reservoir using acoustic telemetry. To date, 10 of 219 acoustic tags have been detected downstream of the Reservoir. Two of these emigration events occurred within a week of release at Entiat, and were likely representative of a pulse of emigration that probably occurs soon after a group of hatchery fish is released into the Reservoir. Seven of the eight remaining emigration events occurred in the fall. Three of the events occurred in the fish's first fall at large, within 4-5 months of release. Two other events occurred in the fish's second fall at large, between 19 and 20 months after release, and two were in the third fall, 28-32 months after release. In addition, a single emigration event took place in the spring, 1.8 years after release from the hatchery. All eight of the last emigrants were either released in the upper Reservoir or traveled to the upper Reservoir prior to emigration, which suggests that release location was not a predominant factor in emigration fate.

The increase in downstream movements of tagged sturgeon during the fall months may result from seasonal volitional movements. These fall movements could be in response to the low autumn flows that could encourage exploration, the fish could be searching for overwintering habitat, or simply moving in response to food availability. The tracking data showed that when sturgeon began downstream movements, they moved steadily and travelled varying distances downstream. Regardless of the trigger, fish that emigrate may simply be redistributing farther than others in the population, resulting in passage through Rocky Reach Dam and out of the Reservoir. Passage routes through the dam are unknown, though spillway gates and powerhouse turbines were the most likely routes since fish passing through the juvenile bypass surface collector would have had their PIT tags detected (other than some suspected mortalities immediately following release in 2011, no sturgeon PIT tags have been detected in the bypass).

The fate of emigrating individuals is not known, although survival is assumed to be high (e.g., Parsley et al. 2007). Initially, they will contribute to the population in Rock Island Reservoir, if not farther downstream over time. If they move far enough, they may contribute to downstream fisheries. Theoretically, they could eventually become part of the breeding population in whatever area they ultimately settle.

PIT tag loss proportions were estimated at 4.3%, representing 153 'untagged' individuals out of the 3,532 examined. Although this was not a controlled experiment designed to measure tag loss, the relative durability of the secondary (scute) marks, the duration of the study, and the large sample size support the accuracy of the estimate. Tag loss in this study was on the order of that observed by Ombredane et al. (1998) for juvenile brown trout (*Salmo trutta*), and was considerably better than that published for other salmonids (7-20%; Buzby and Deegan 1999, Hill et al. 2006, Acolas et al. 2007) of varying size and species, or for sturgeon (7-45%; Holmes 2002, Hamel et al. 2012). Based on the literature cited here, it appears that species, fish size, position of the injection, and skill of the technician can affect tag loss rates.

These emigration and tag loss results, in combination with rates of apparent survival, were used to reconstruct the age-structured population within the Reservoir (Figure 20). With these data, managers may choose to adjust supplementation levels to achieve or maintain desired population levels. In the longer-term, supplementation fish released by DCPUD are likely to continue to immigrate into the Rocky Reach Reservoir. To date, eight of DCPUD's acoustic-tagged sturgeon are known to have emigrated (5.4% overall, along with eight of their PIT-tagged sturgeon (Robichaud and Gingerich 2017). If this input persists, it may mitigate for emigration of Chelan PUD's fish and potentially even permit reductions in the levels of sturgeon supplementation in the Rocky Reach Reservoir.

Survival Estimation

As the study evolved, changes in methodology were inevitable. The present study handled these changes by introducing sampling bouts, which allowed differing sampling methodologies to be associated with unique capture probabilities. The capture probability for each particular bout was allowed to vary by setline configuration (i.e., setline length; hook number and type), sampling method (i.e., incidental, random, or targeted), effort, and the age of an individual fish. This complex detection model reduced unexplained heterogeneity in capture probabilities and allowed for more precise estimates of survival than would have been otherwise possible.

The cohort survival analysis showed evidence for differences in survival among three different time scales (i.e., short-, intermediate-, and long-term). Mortality rates appeared to be the highest immediately after release, and declined over time. Compared to Robichaud et al. (2016), our cohort-specific estimates for short- and long-term survival were higher. This is consistent with our estimates of intermediate-term survival falling somewhere in between short- and long-term estimates, and the fact that Robichaud et al. (2016) only estimated survival differences on the short- and long-term time scale (i.e., not the intermediate time scale). Models that do not accommodate for survival differences on the intermediate time scale will be forced to partition any intermediate-term mortality between the short- and long-term survival parameters, which would have resulted in lower survival estimates for both the short- and long-term time periods. Using data to the end of 2015, Robichaud et al. (2016) found mixed evidence for differences in intermediate-term survival, whereas the inclusion of the 2016 data produced strong evidence for this difference. The additional year of recaptures provided enough information to make comparisons among these estimates.

We could not estimate short-term survival for the 2016 release cohort (due to its few recaptures), or the long-term survival for the 2015 cohort (because of the way our time-scales were defined). Nevertheless our analysis did provide additional insights over those presented by Robichaud et al. (2016). For example, the 2015 release cohort appears to be continuing the trend of declining survival for each successive release cohort. Short- and intermediate-term survival for the 2015 cohort were the lowest of all the release cohorts, and the survival benefit of longer fork lengths was also diminished. The importance of an individual sturgeon’s length-at-release is well known, typically resulting in increased survival rates for larger individuals (e.g., Justice et al. 2009). It is therefore concerning that the relationship between fork length and survival remained relatively constant for all release cohorts except 2015, which was the first cohort to show signs of a reduced benefit of size. This observation is also consistent with the earlier suggestion that changes in Reservoir conditions may be affecting early juvenile survival (Robichaud et al. 2016). That said, long-term survival for all cohorts appeared to be generally quite good. As the indexing study progresses, long-term survival for the 2015 and 2016 cohorts, along with future releases, should become estimatable. As they do, they will reveal whether long-term survival will continue to follow a downward trend.

Survival models that accommodated for cohort-specific differences did so by estimating a common cohort-specific survival pattern (on the logit scale) across short-, intermediate-, and long-term time scales. This modelling constraint enforced a consistency in the among-cohort survival patterns across the differing time scales. Models that attempted to further relax this constraint (i.e., by independently estimating cohort-specific differences at each time-scale) failed to converge and could not be considered as part of this analysis. As such, it is not clear whether the pattern was an artifact of the modelling constraint used, or whether it represents a true cohort-specific survival pattern that occurs in a consistent manner across differing time scales. As the indexing study continues, it may be possible to accumulate enough information to relax this modelling constraint, allowing for separate cohort-specific survival patterns to be independently estimated at differing time scales.

As with all studies, there were some limitations to the current survival analyses. The survival of the 2016 release cohort could not be estimated. This can likely be attributed to a combination of the dearth of recaptures for this release cohort, and a change in methodology that occurred in 2016 (i.e., change in setline length and hook number). As such, it is likely that there was not enough information to adequately estimate age-specific differences in capture rates for younger ages when deploying this new sampling method. There were also large differences in ΔAICc values among many of the detection and survival models, suggesting that unmodelled heterogeneity or lurking factors may still exist. As suggested by Robichaud et al. (2016), spatial heterogeneity continues to be the most likely candidate. As this study is slated to continue into 2020 and the number of recaptures increases, future analyses will be able to estimate survival for the 2016 release cohort. In addition, future analyses may also be able to successfully fit more nuanced survival models that may be able to independently estimate cohort-specific survival differences at different time scales, as well as accommodate for some of the suspected spatial heterogeneity.

Reservoir Abundance

The age-structured abundance of hatchery-produced fish in the Reservoir was reconstructed by applying the estimated true survival rates (cohort-specific short-, intermediate-, and long term), and emigration proportions (during four time periods post-release) to the number of fish released, calculated for each cohort on an annual time-step. Although the numbers of fish in the Reservoir appeared to increase from 2012 to 2015, the 'effectiveness' of each successive release event has been declining. For example, the increase in abundance between the 2013 and 2014 surveys was 723 fish (Figure 20), which is 15% of the 4,962 fish that were added to the Reservoir during that period. From 2014 to 2015, abundance increased by 487, or 8% of the 6,487 fish that were released in that time. While the cause of the decline in effectiveness is not known, it is suggestive of possible density-dependent effects, especially when coupled with the consistent gradual declines in short-, intermediate- and long-term survival rates with each successive cohort since 2012 (Table 18). While these values are consistent with the possibility of density-dependent survival, more information would be required to rule out other potential causes of the observed survival patterns but some obvious factors are not likely important. For example, size at release was included in the survival model; and there were no great differences among years in release timing.

Growth

Growth rates of juvenile White Sturgeon in the Reservoir varied among cohorts. For releases from 2011 to 2015, sturgeon grew in their first half year in the Reservoir an average of 107-188 mm/year (fork length; extrapolated to 365 days; note that these initial rates may be overestimated due to extrapolation of growth in the spring-summer 'growing' season over a whole year). These rates are within the range reported for age 1 sturgeon in the Keenleyside and Roosevelt reaches (280 mm/year; n = 326; Golder Associates 2009), in the middle Columbia River (143 mm/year; n = 3; Golder Associates 2010), and in the Kootenai River (120 mm/year; n = 52; Neufeld and Spence 2002). By contrast, growth rates for the 2016 cohort were slower, averaging only 54 mm/year when extrapolated to 365 days. The 2016 cohort was significantly larger at release than previous cohorts, which may have contributed to the lower growth rates; yet the result is consistent with density dependent Reservoir saturation effects. Future data will reveal whether the pattern of slower growth carries forward throughout their lives.

Although average growth was relatively consistent among cohorts and among years, the individually-observed values ranged widely. For example, the fork lengths of 749 fish from the 2013 release year that were recaptured in 2016 ranged from 346 to 932 mm, and there was no relationship to initial size. The fork lengths of 45 fish from the 2011 release year ranged from 537 to 1190 mm when they were recaptured in 2016. Wide ranges in growth make it difficult to hindcast a fish's age based on its length. For example, a fish measuring 700 mm in 2016 could equally likely be from the 2011, 2012, 2013, or 2014 cohorts. That said, large variability in growth rate is not unusual (e.g., Golder Associates 2016).

Diet Study

Sturgeon consumed a variety of items, ranging from zooplankton to mammals. Overall, the most prevalent prey items were amphipods (freshwater shrimp), found in 82% of the samples. Fish remains were found in 72% of the sturgeon's stomach samples and were the dominant prey type by weight. The majority of fish remains were not able to be identified to species. The general diversity and types of prey items consumed in the Reservoir were similar to those from other parts of the Columbia River. That said, specific compositions varied and the prevalence fish taxa was higher than reported elsewhere for comparable-sized sturgeon (Muir et al. 1986, Parsley et al. 2010, Crossman et al. 2016). From a bioenergetic standpoint, fish seemed to be the most important prey item. Interestingly, 82% of samples from the immediate tailrace contained fish, compared to 18% from farther downstream. If Wells Dam functions as a fish food source due to passage-related predation of either downstream migrant juvenile salmonids or upstream migrants using ladders, this could be one factor explaining the very high use of this area. Ideally, more samples will be obtained from other Reservoir areas to bolster the comparison, since the result contrasts with our data showing faster growth of individuals in the lower parts of the Reservoir. Crossman et al. (2016) found that sample sizes of at least 100 are needed to accurately describe diet (as compared with stomach removal); our fishing efficiency would need to be greatly increased, or else we need to choose between spatial sampling vs. robust classification of diet for the population below Wells Dam.

In Summary

Chelan PUD has worked toward the goal of promoting White Sturgeon population growth to a level commensurate with available habitat in the Reservoir by 2039. During Phase I of the monitoring and assessment program, supplementation has increased White Sturgeon abundance in the Reservoir, and the effectiveness of the supplementation program has been evaluated (Robichaud et al. 2016). In 2016, the first year of Phase II, we added diet assessments and mobile tracking, continued to monitor the success of the supplementation program (including estimation of emigration, survival, and growth rates), and added to our knowledge of sturgeon distributions and seasonal movements. These successes provide the foundation for decisions regarding future stocking levels, and create an entry-point for determinations of carrying capacity and natural reproduction potential in the Reservoir.

Acknowledgements

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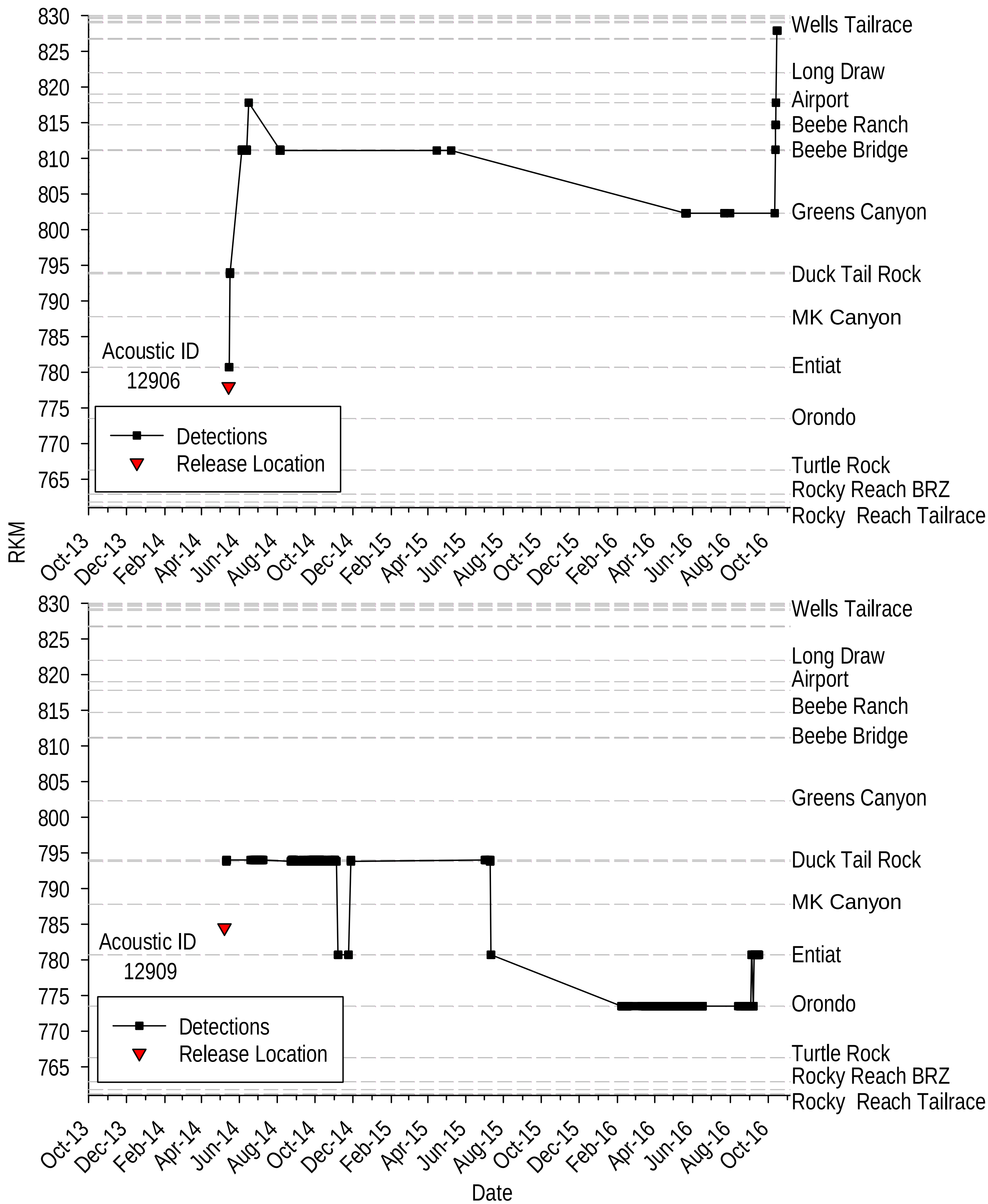
APPENDIX A
Detection Histories of Individual Acoustically-Tagged White Sturgeon

Complete individual detection histories (10 October 2013 to 5 November 2016) for acoustic-tagged sturgeon detected in 2016. Detections are shown as black squares, and black lines connect sequential upstream and downstream movements between detections. Release locations are shown as red triangles. Vertical axis illustrates river kilometer with horizontal dashed grey lines at each VR2W receiver detection array.



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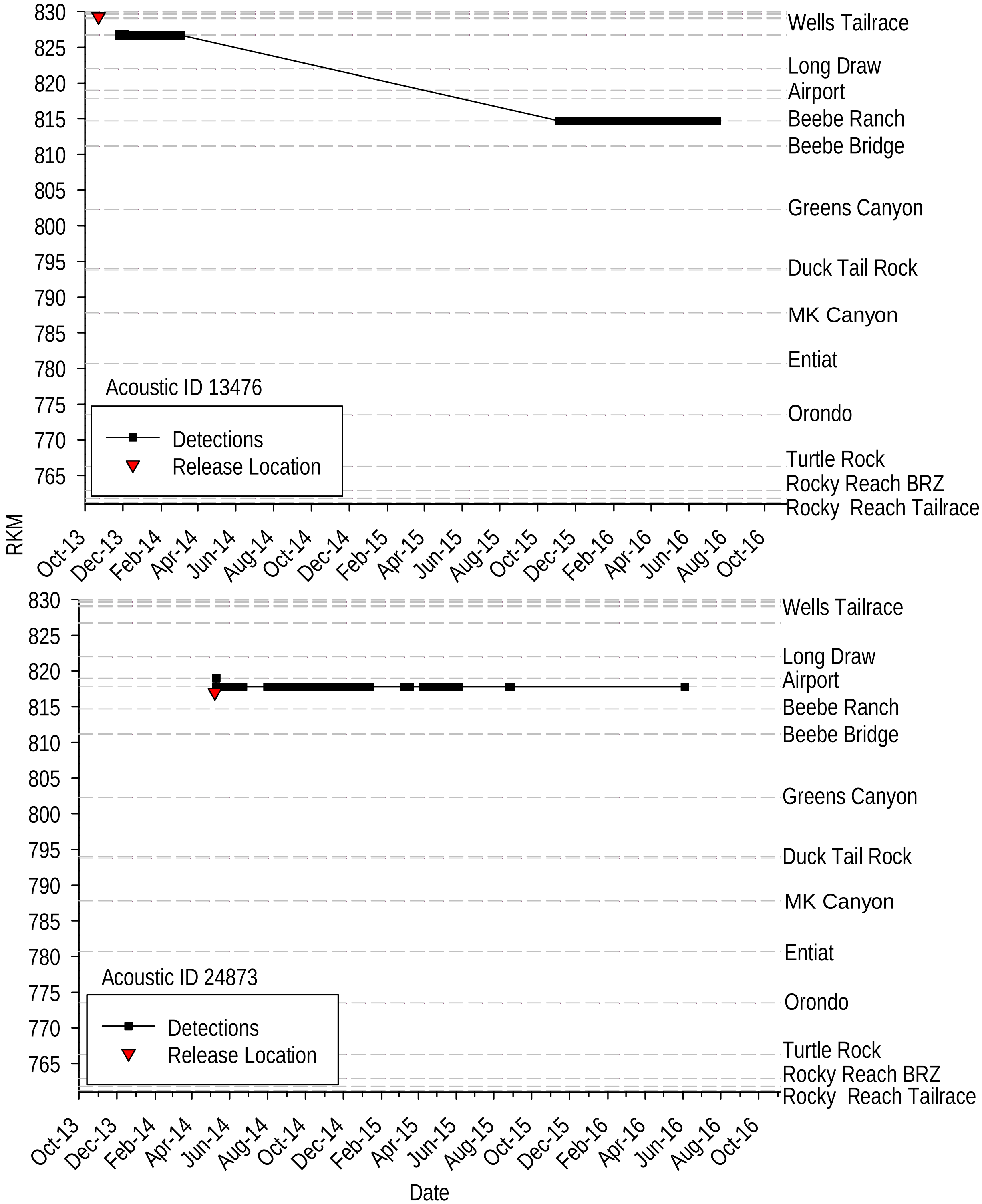
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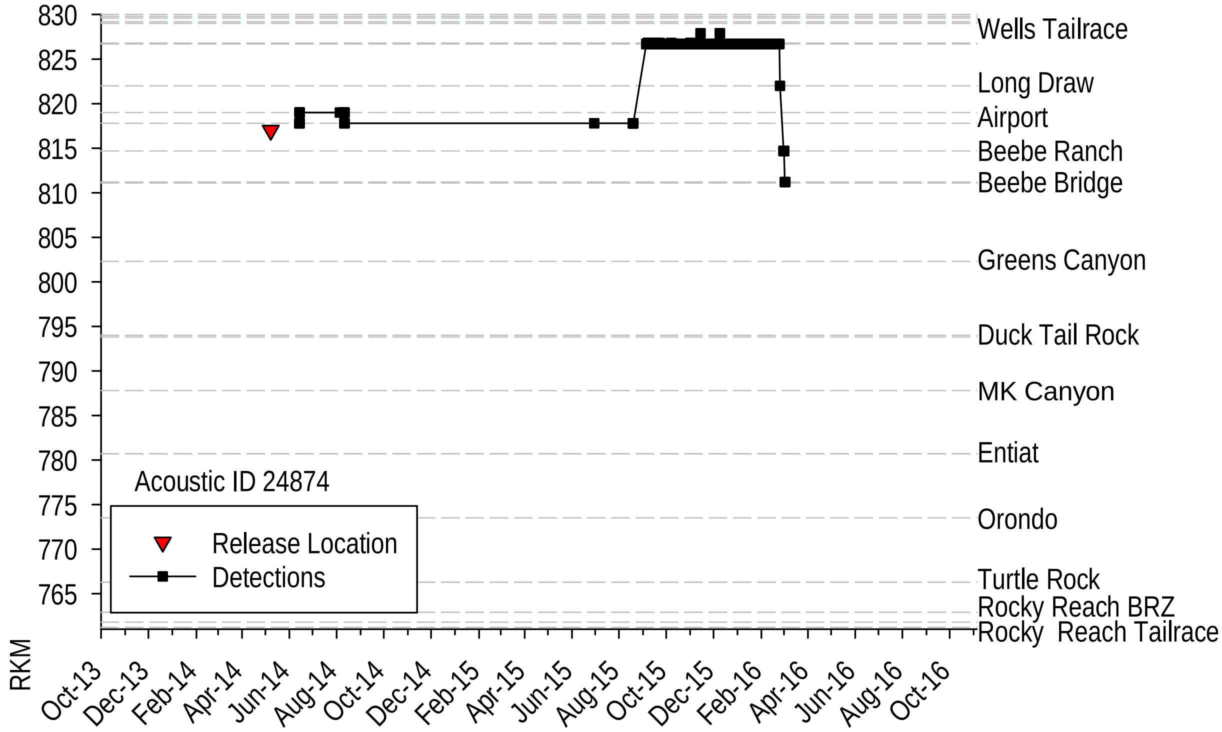

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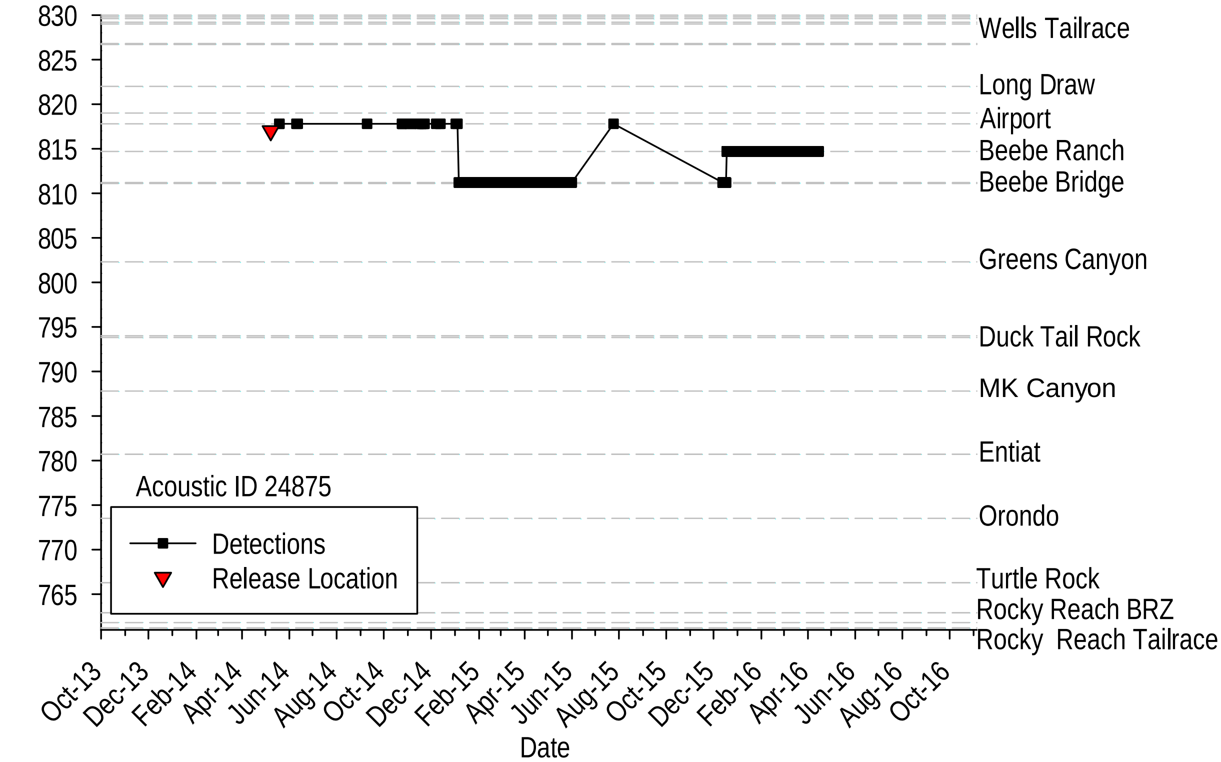

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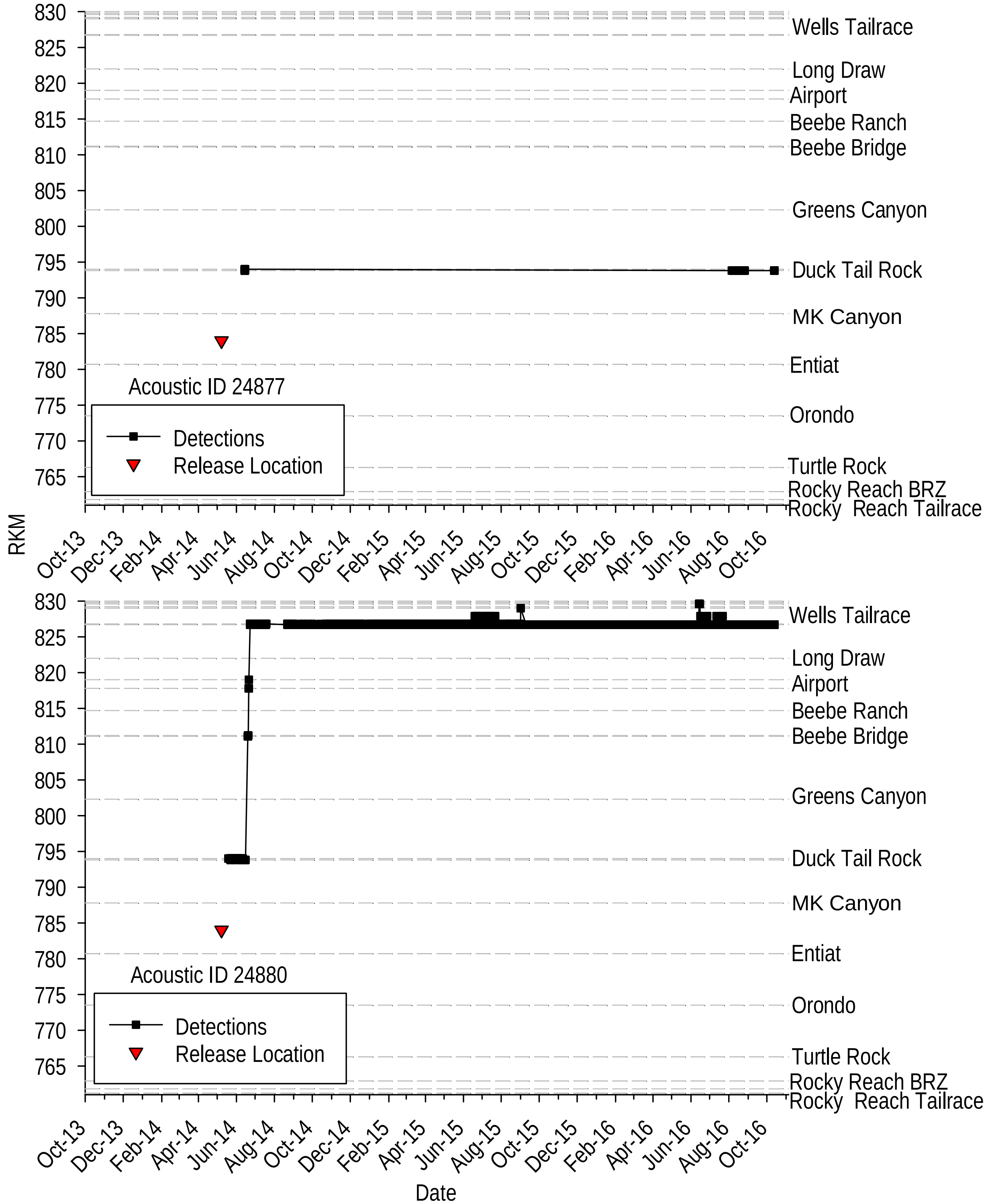
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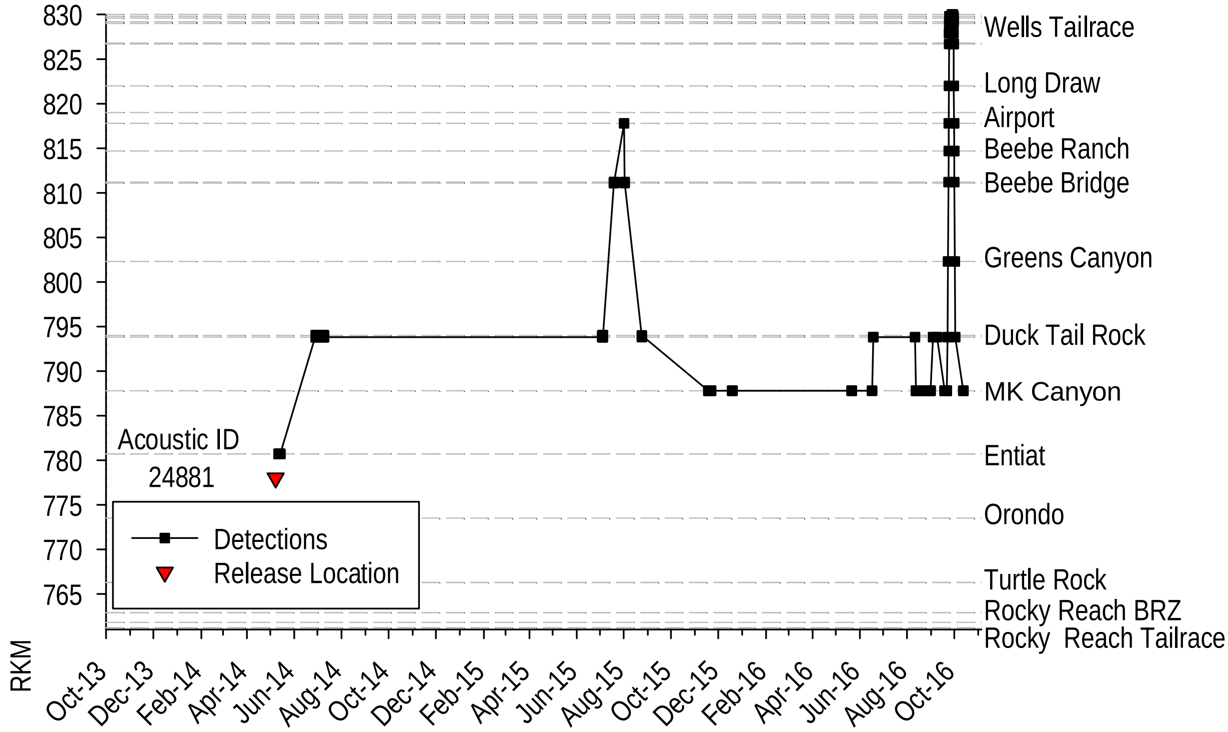
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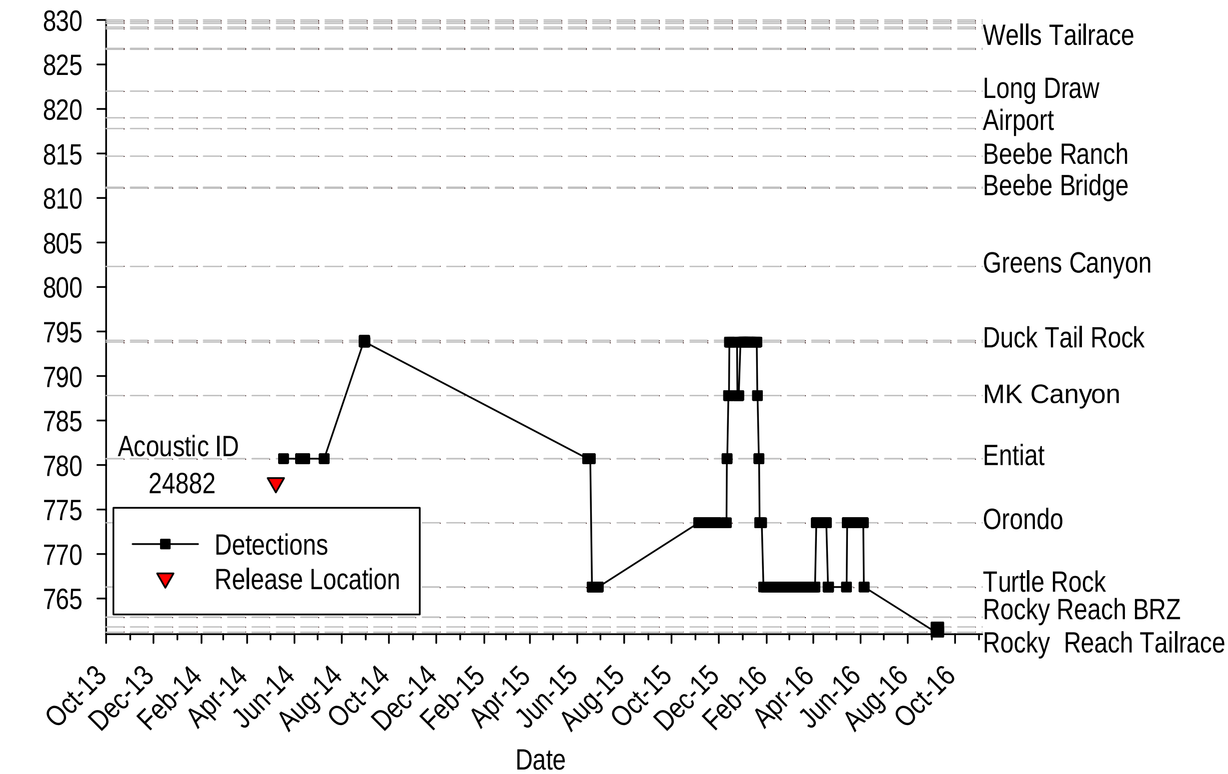
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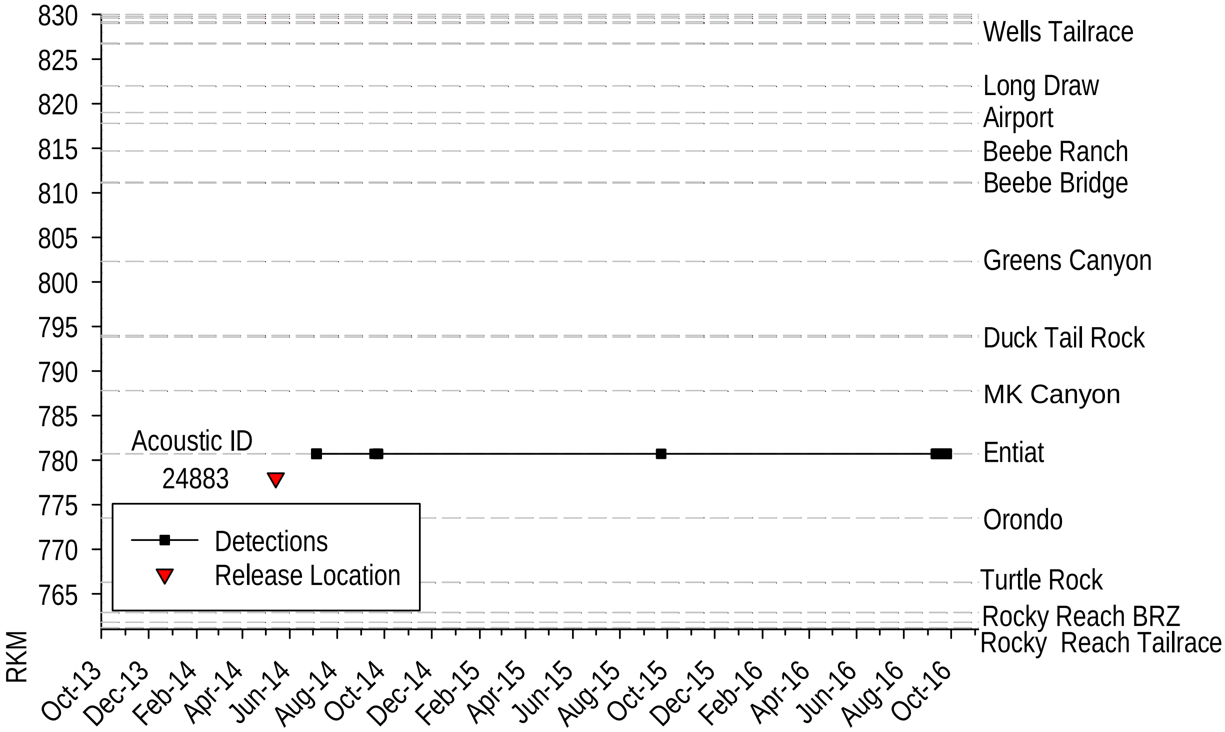
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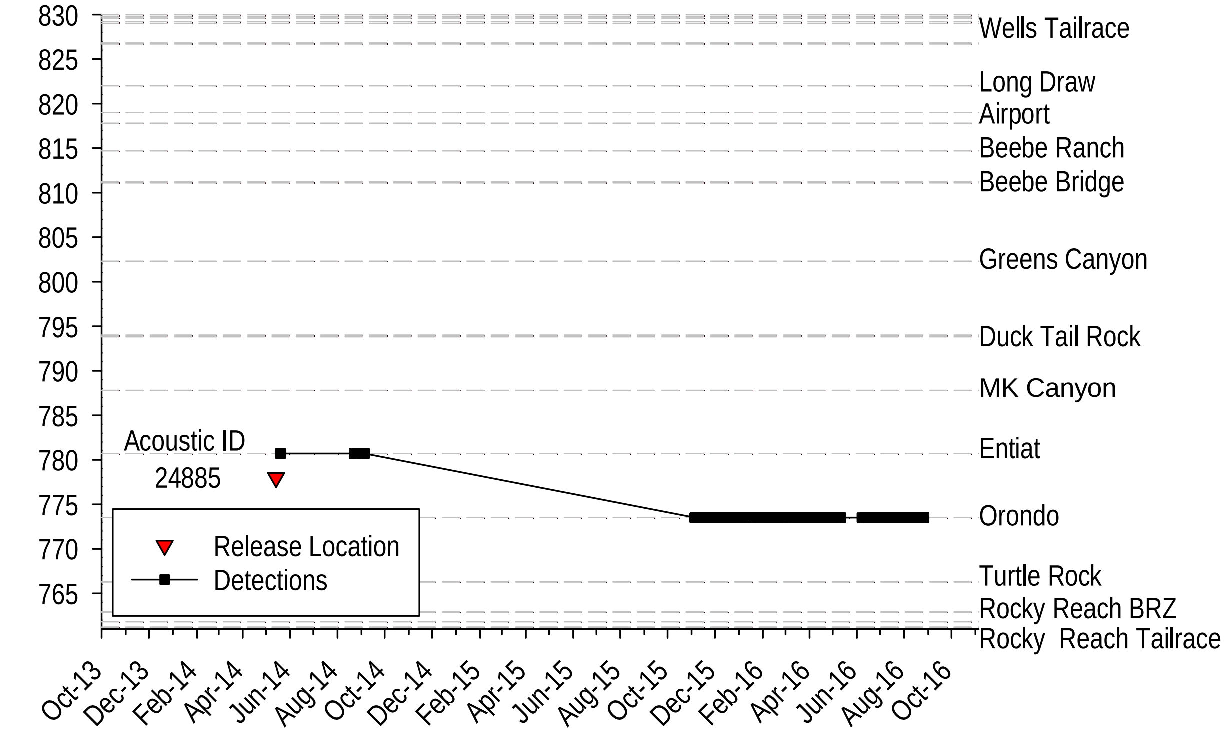
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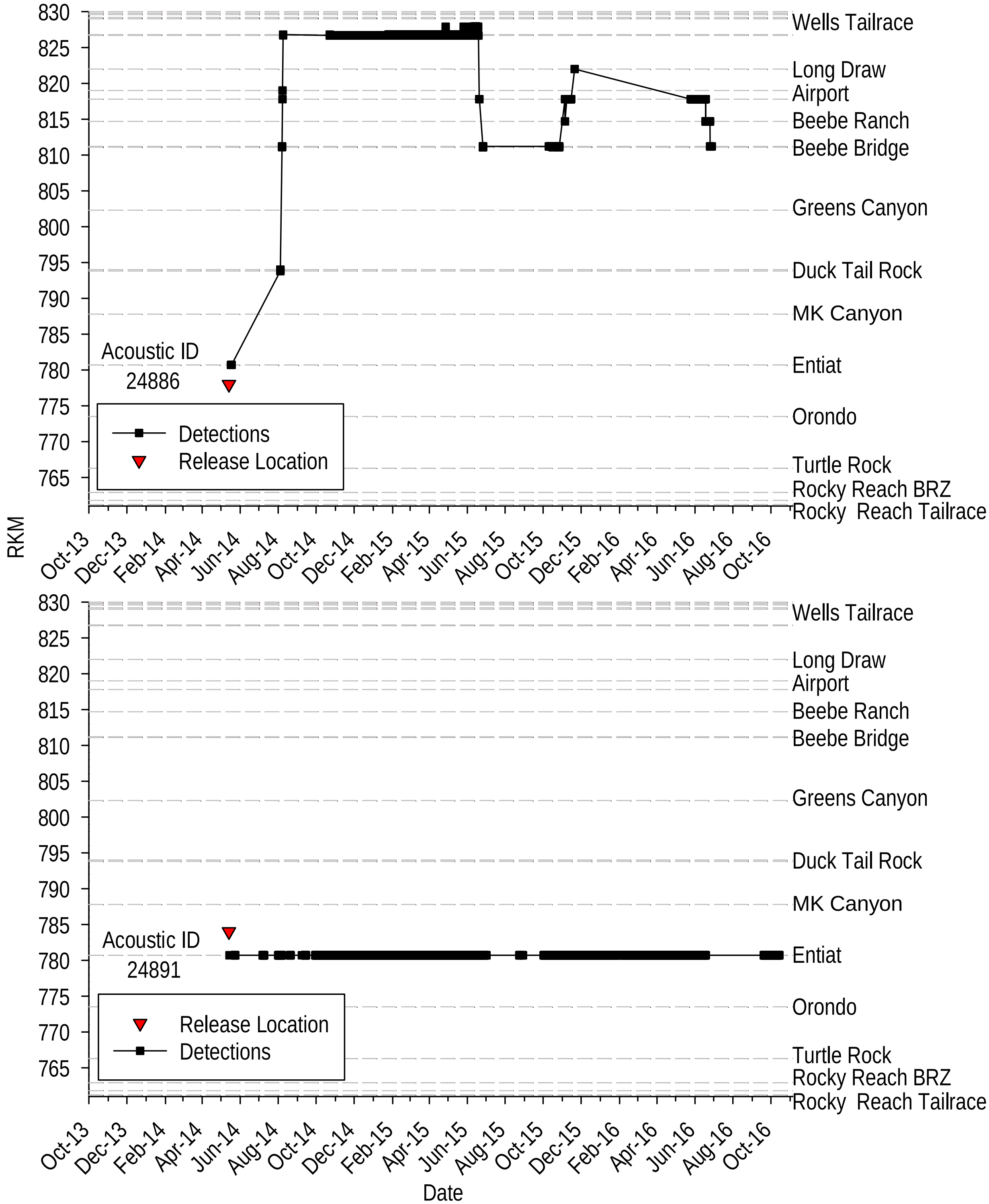

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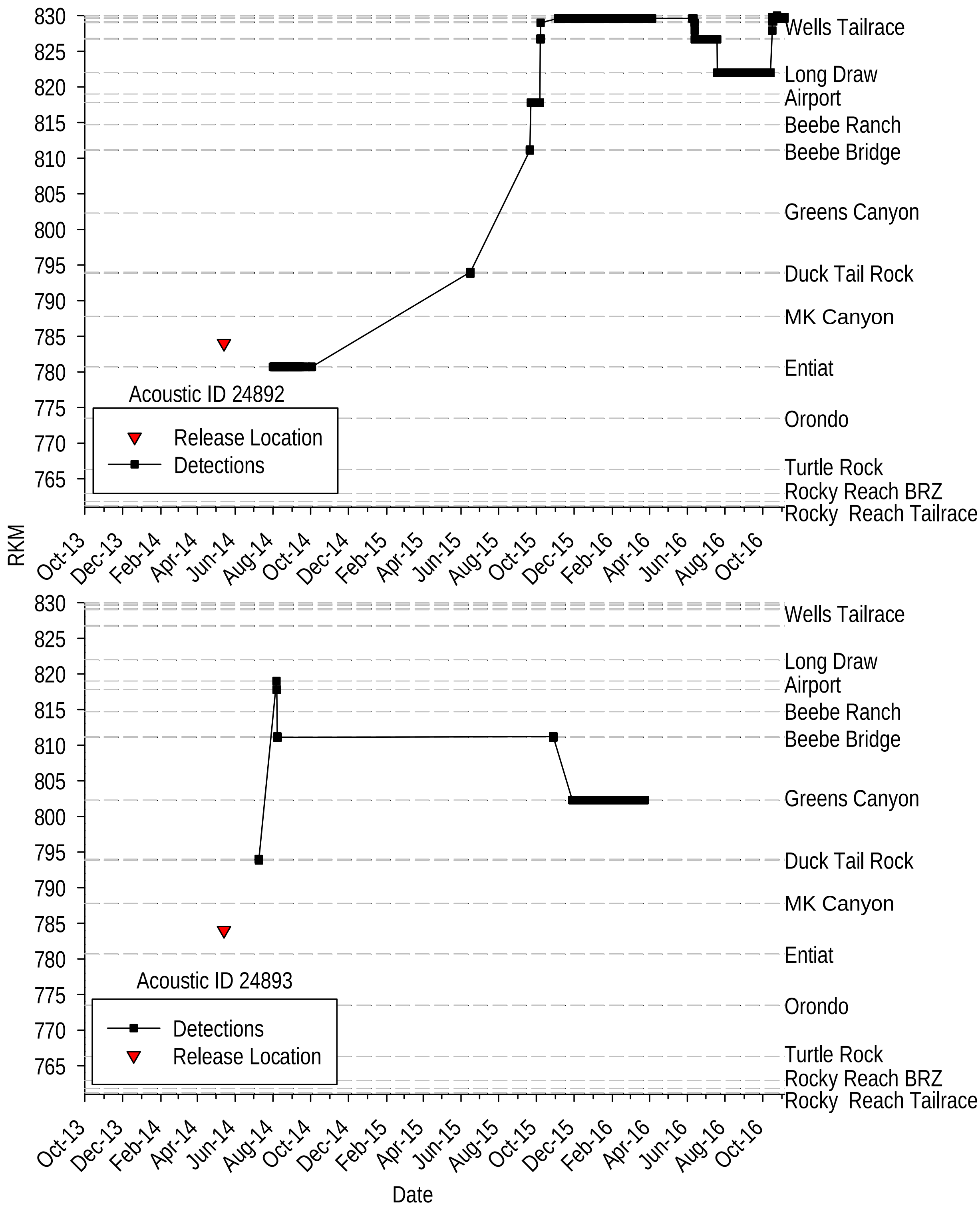

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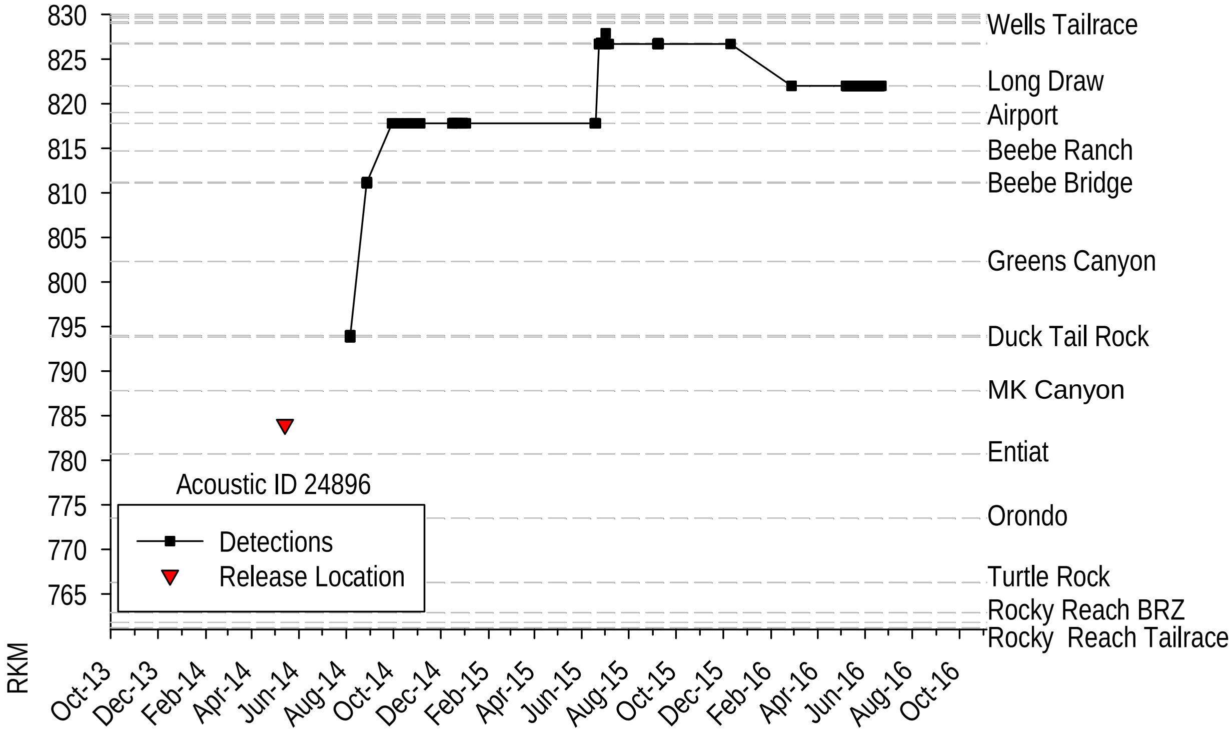
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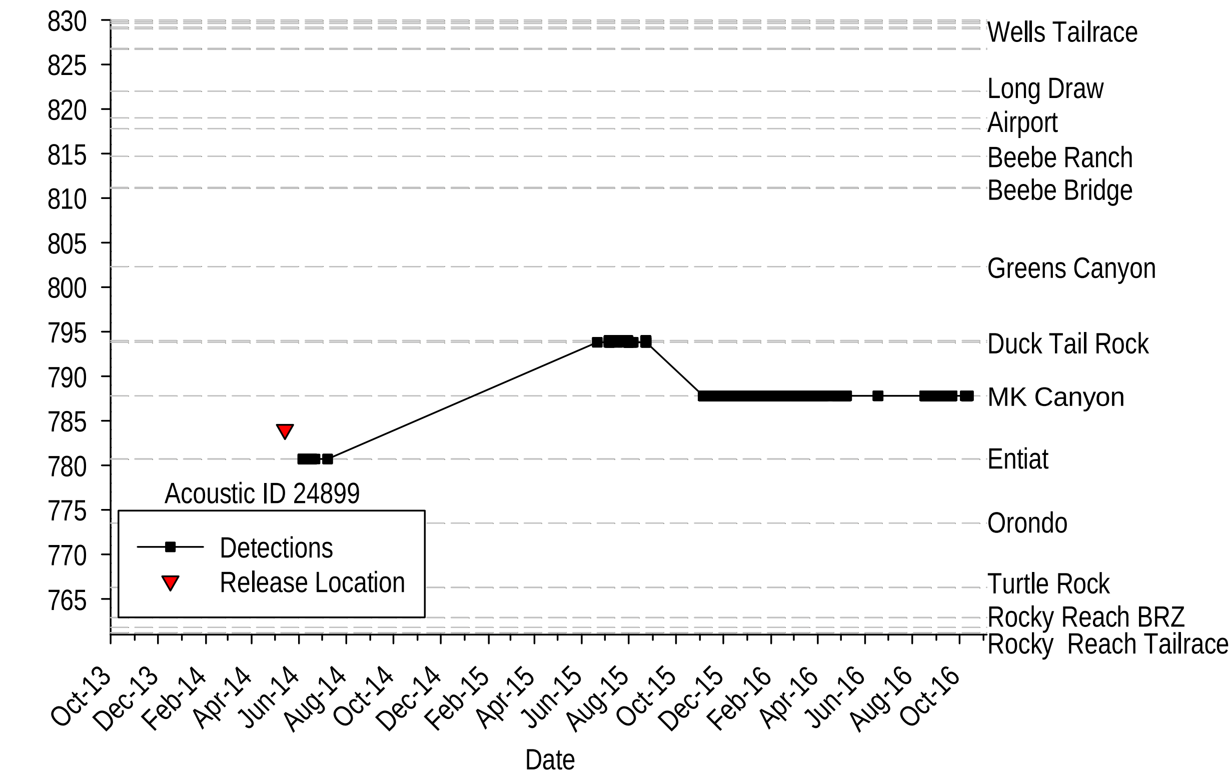
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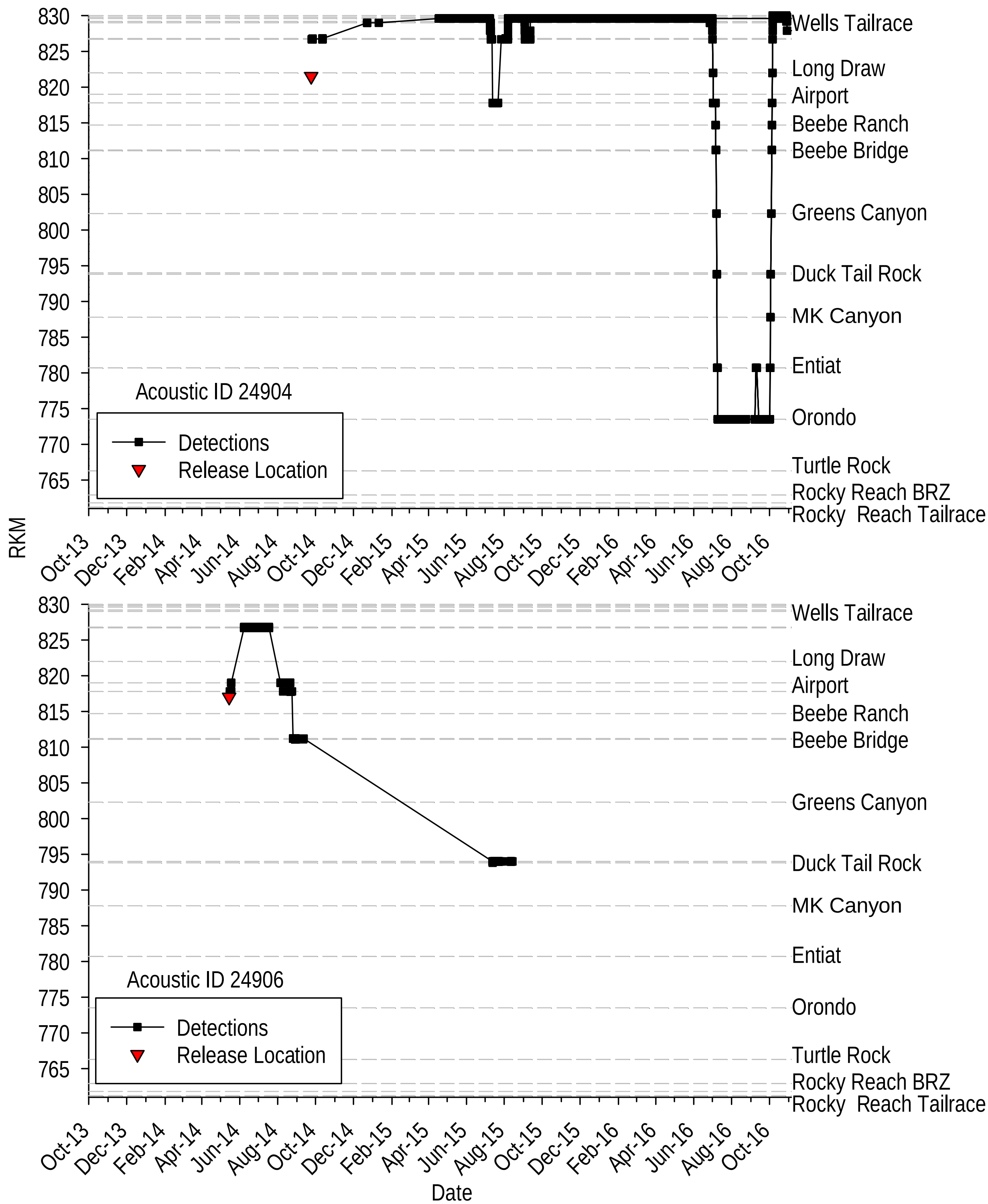

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Long Draw
Airport
Beebe Ranch
Beebe Bridge
Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
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Feb-14
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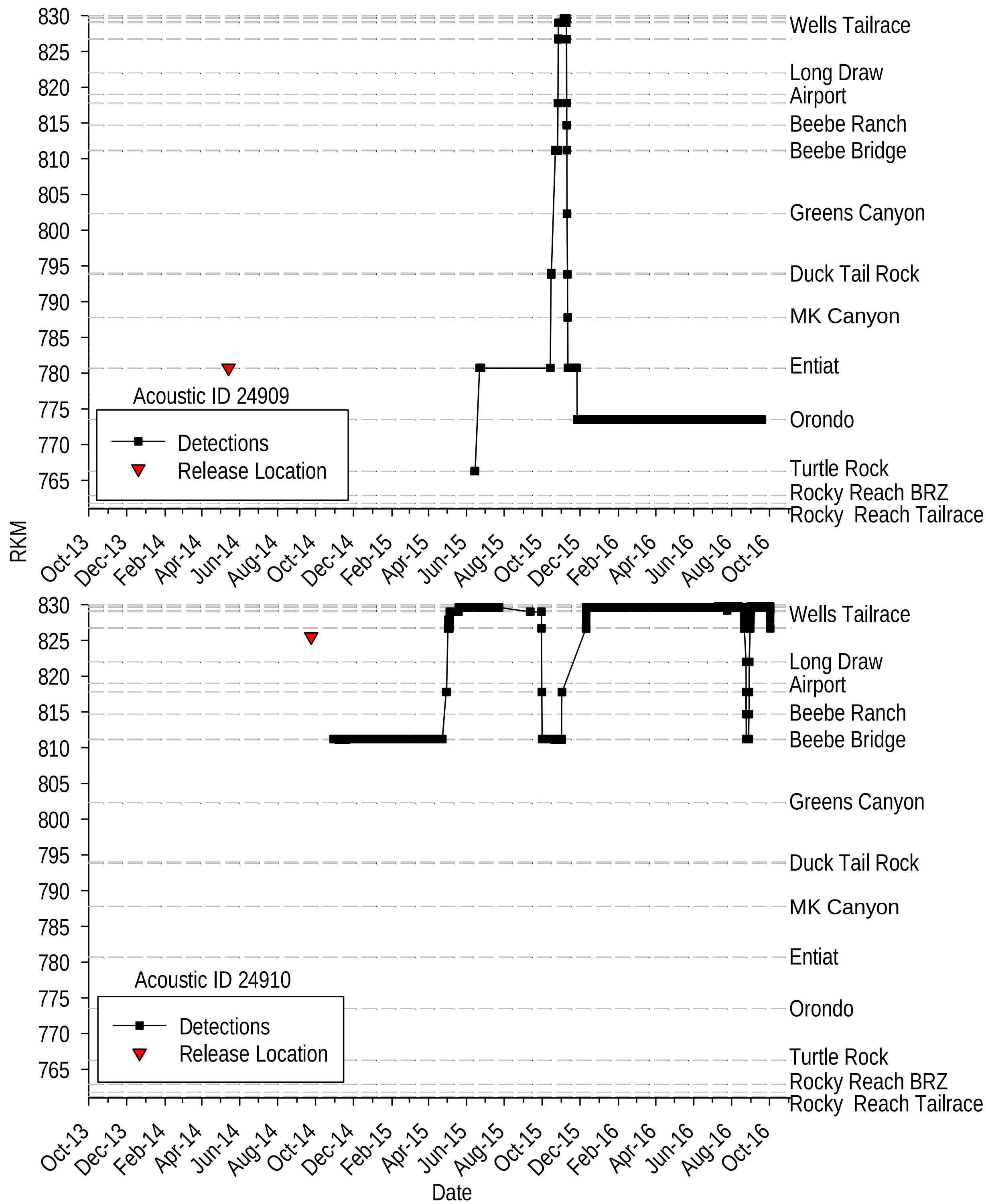
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Airport
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Beebe Bridge
Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
Acoustic ID 24909
Detections
Release Location
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Acoustic ID 24910
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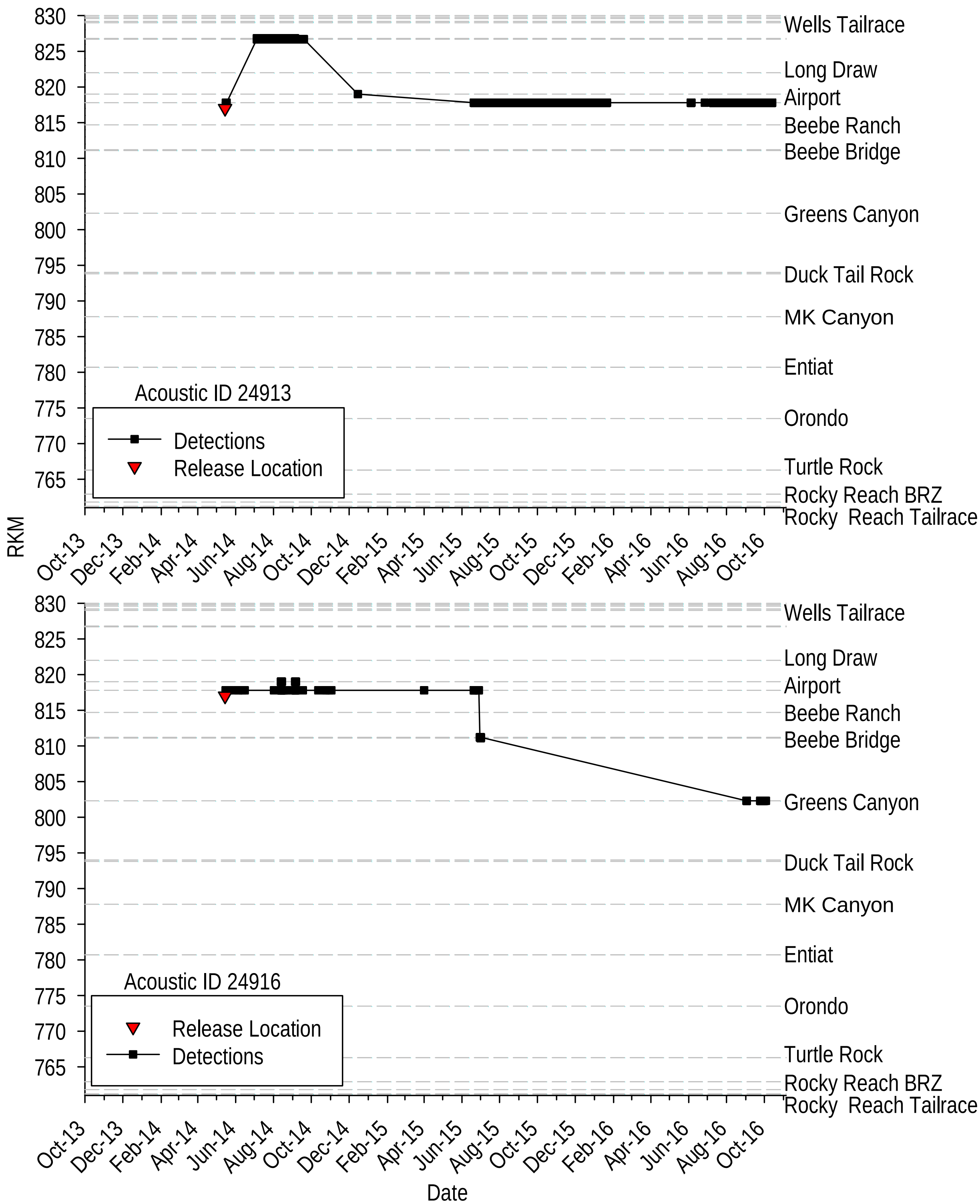
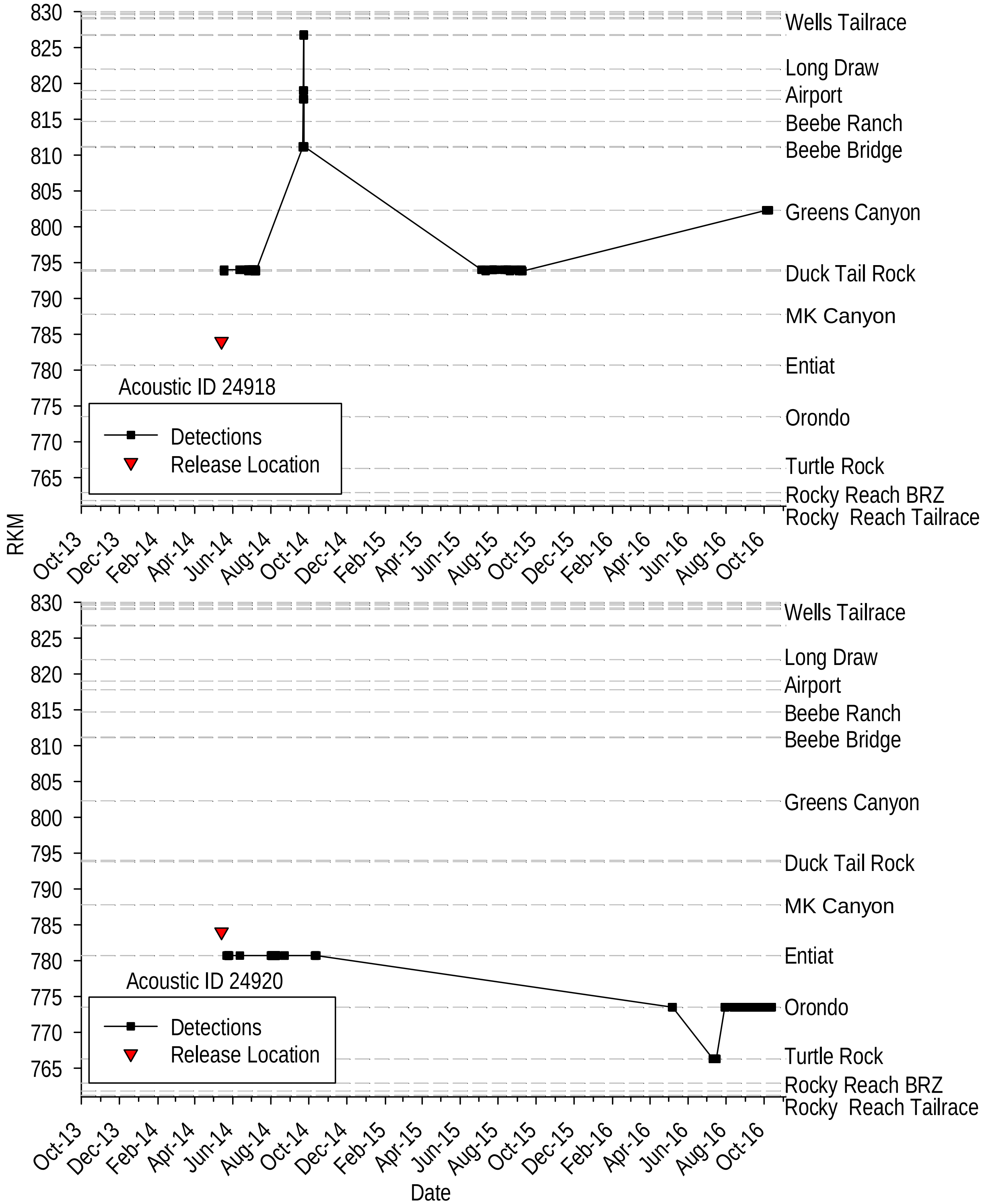


Appendix A- 13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MK Canyon
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Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
RKM
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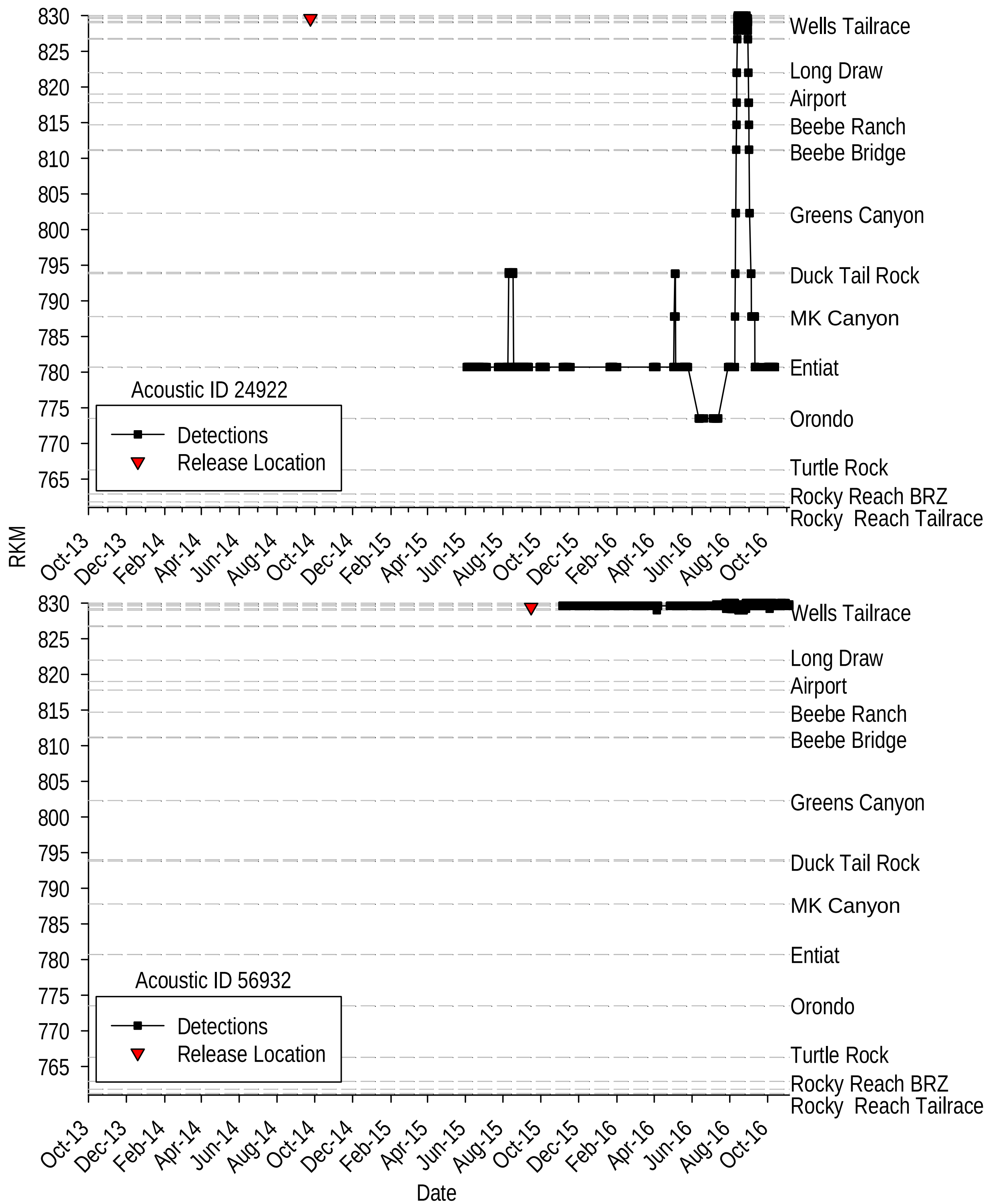

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Airport
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Beebe Bridge
Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
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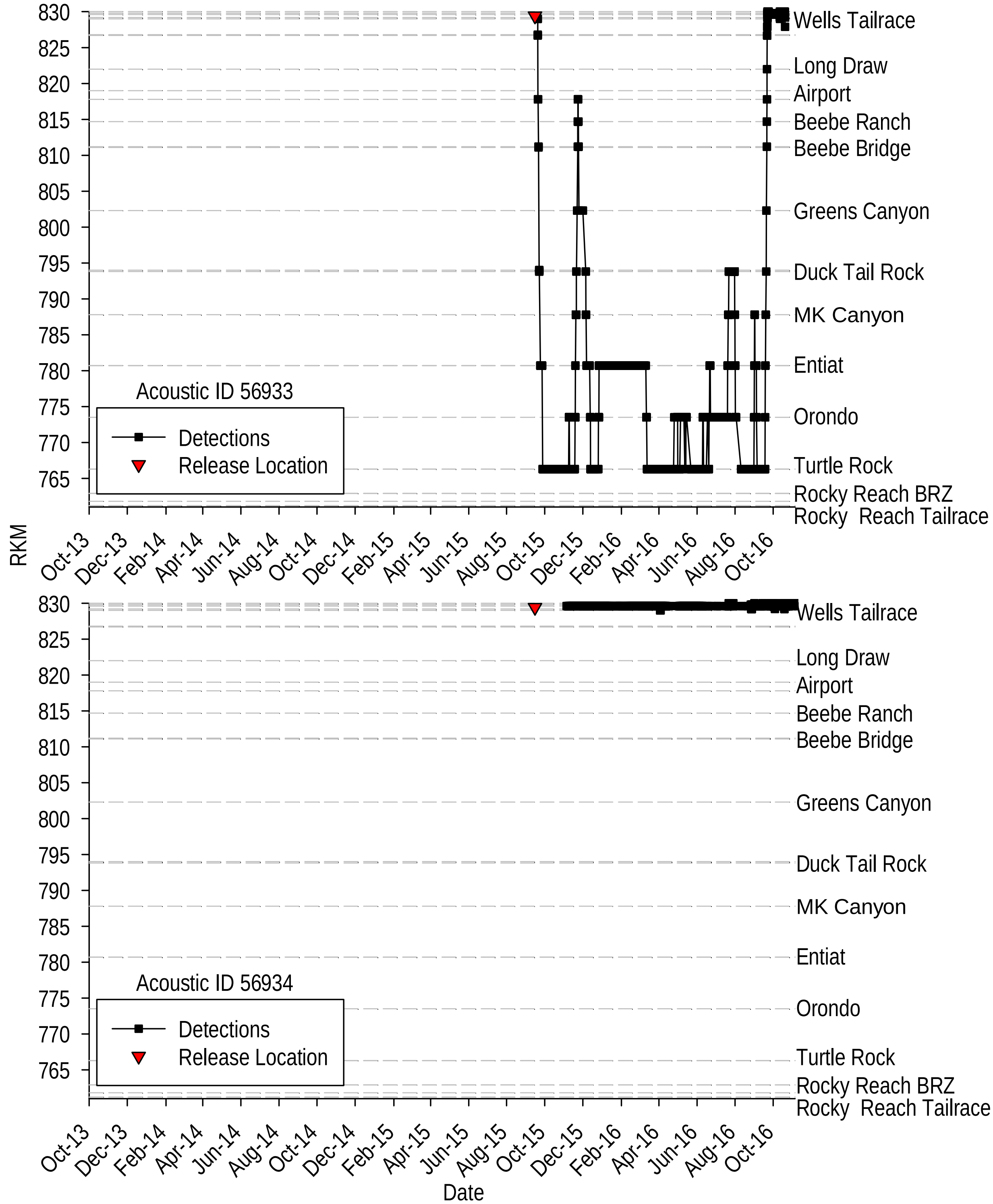
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Airport
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Beebe Bridge
Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
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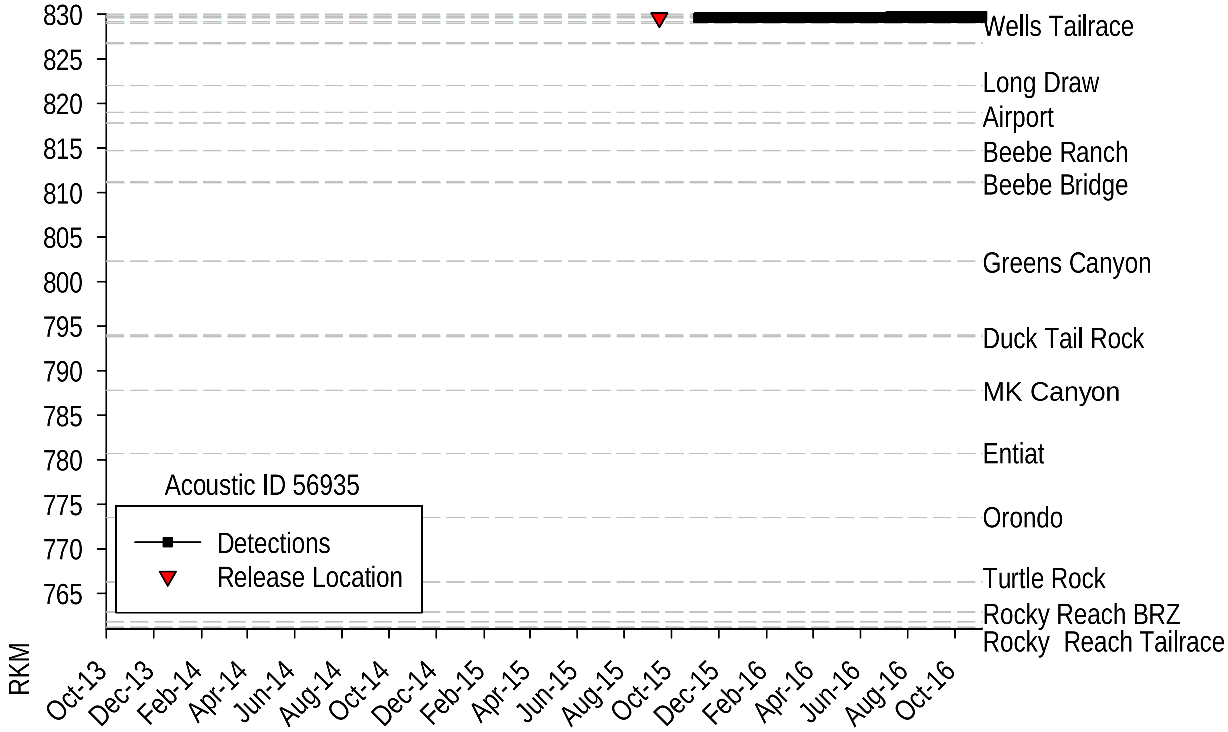

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Airport
Beebe Ranch
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Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
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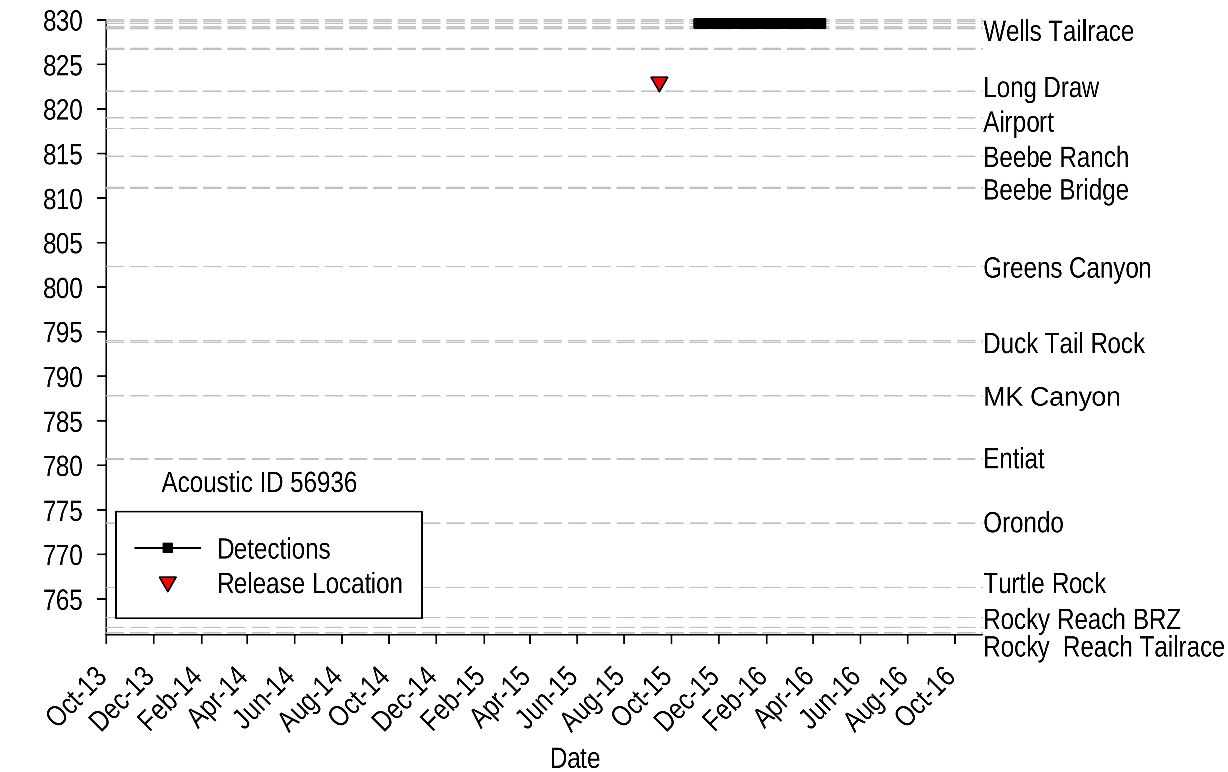

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Airport
Beebe Ranch
Beebe Bridge
Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
Oct-13
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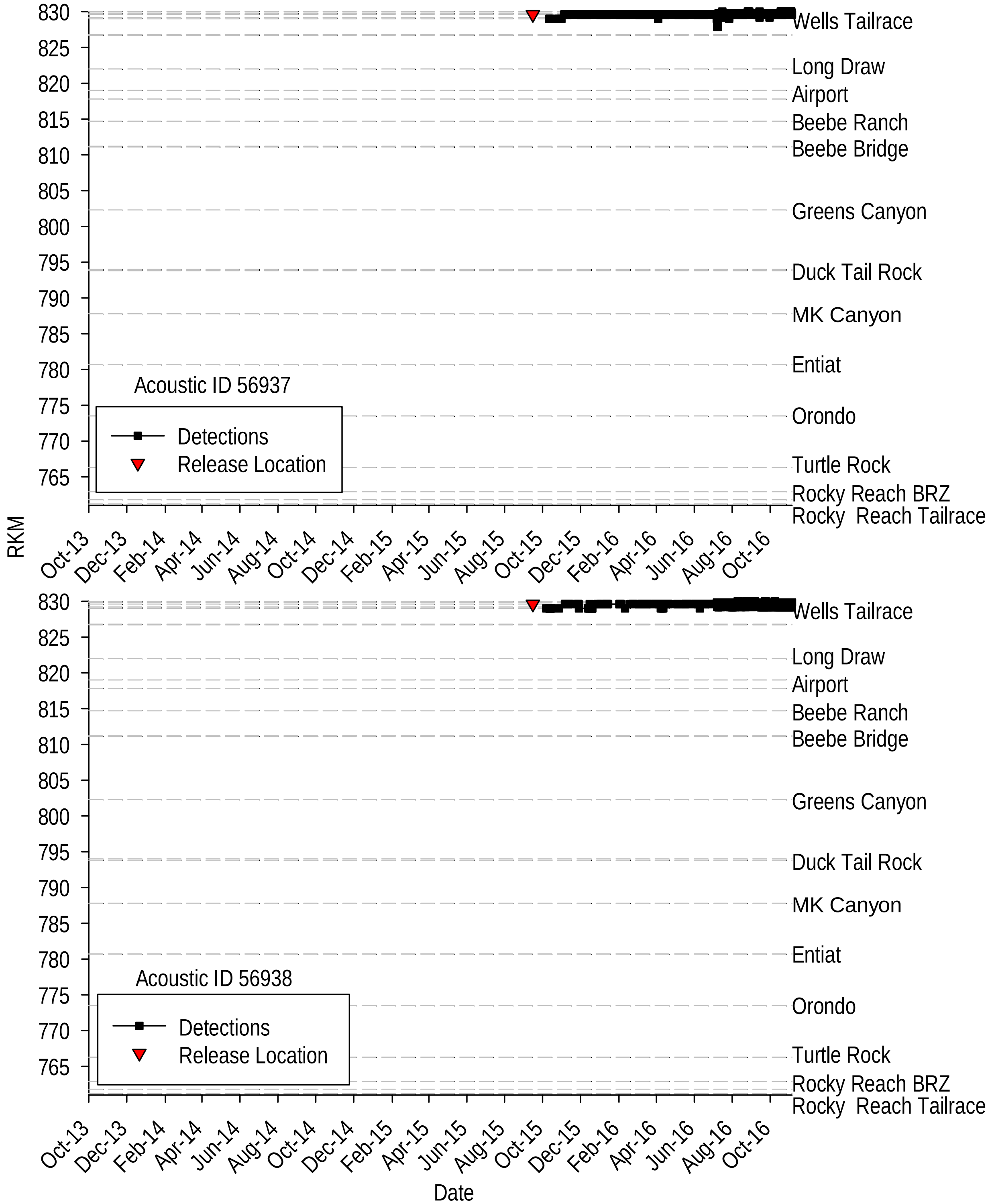
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Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
RKM
Date
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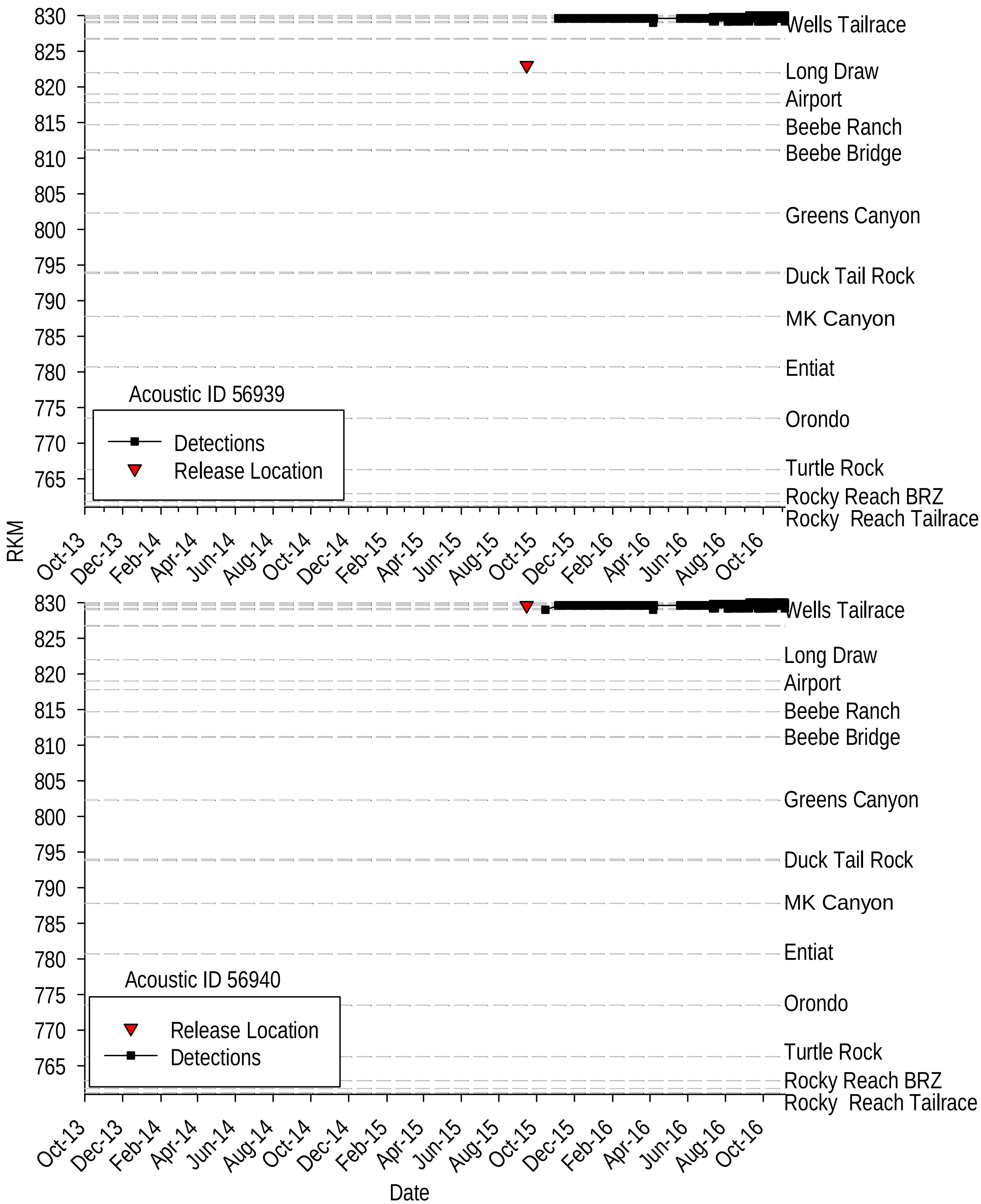
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MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
Acoustic ID 56939
Detections
Release Location
RKM
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Feb-14
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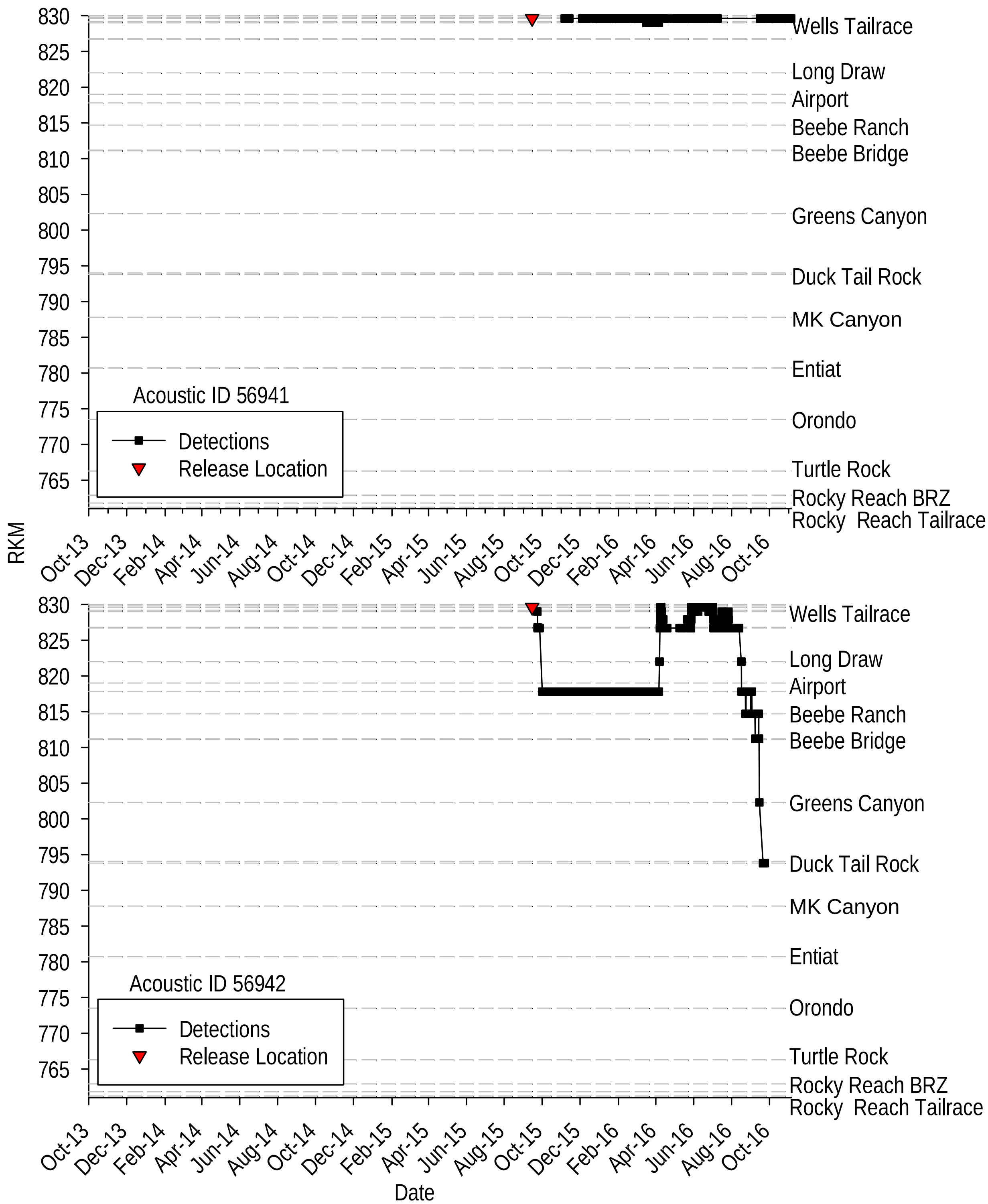
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Airport
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Greens Canyon
Duck Tail Rock
MK Canyon
Entiat
Orondo
Turtle Rock
Rocky Reach BRZ
Rocky Reach Tailrace
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Dec-13
Feb-14
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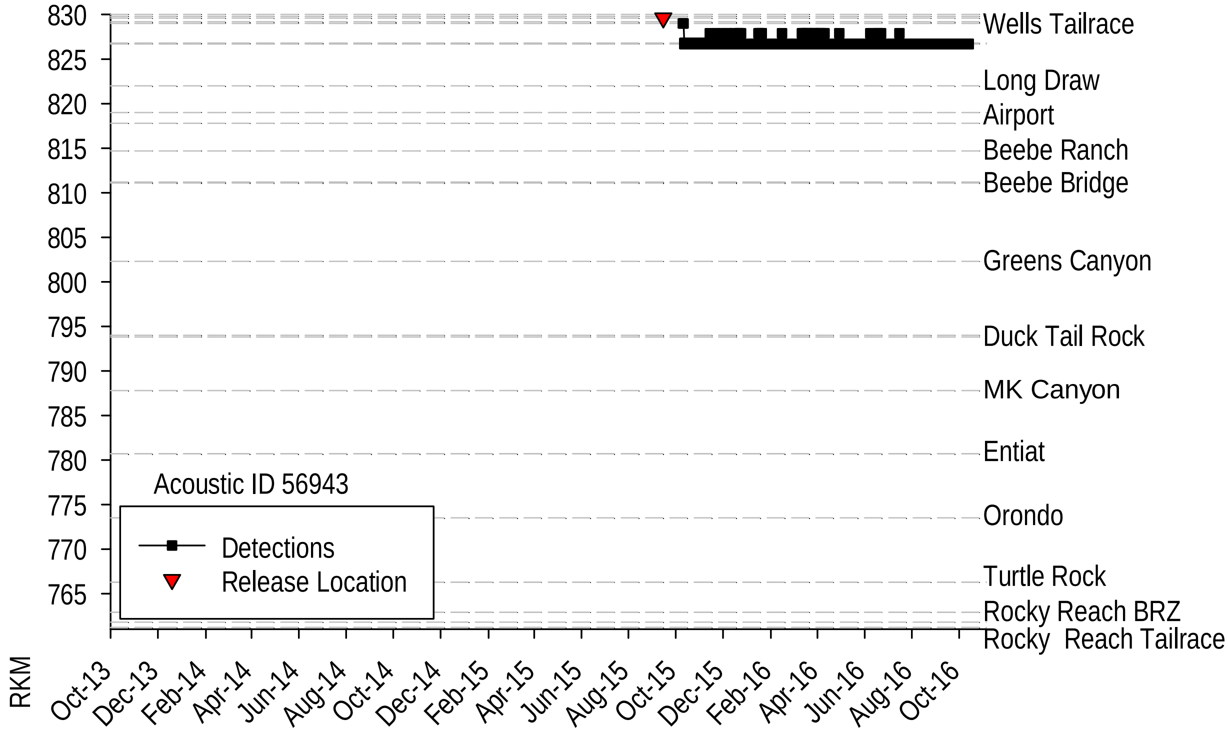
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MK Canyon
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Orondo
Turtle Rock
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Rocky Reach Tailrace
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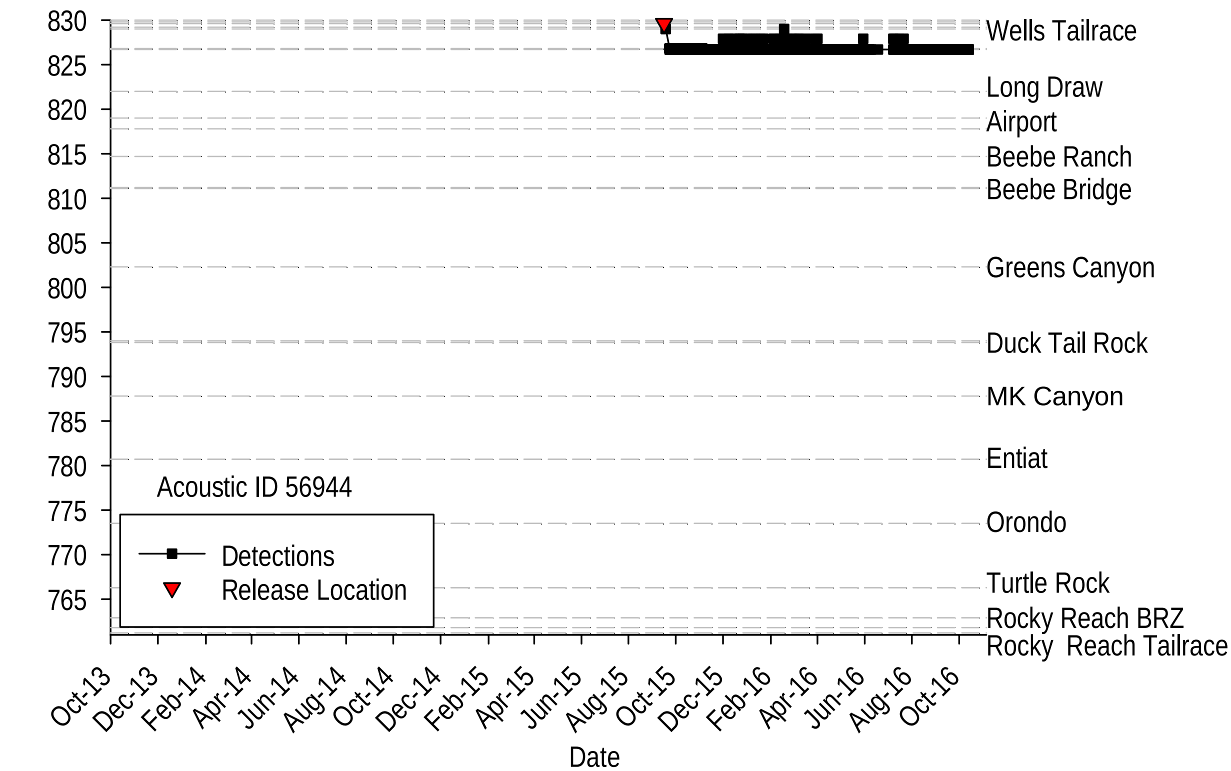
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MK Canyon
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Orondo
Turtle Rock
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Rocky Reach Tailrace
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Release Location
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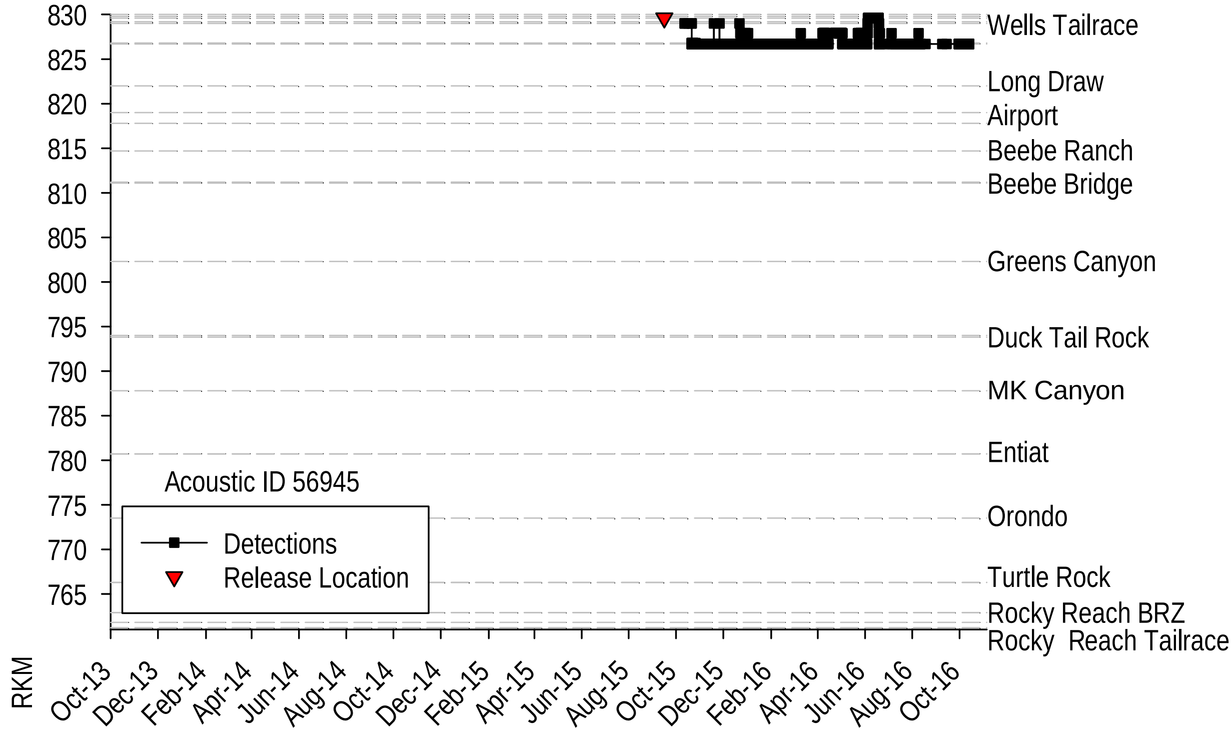
Date



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Orondo
Turtle Rock
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Rocky Reach Tailrace
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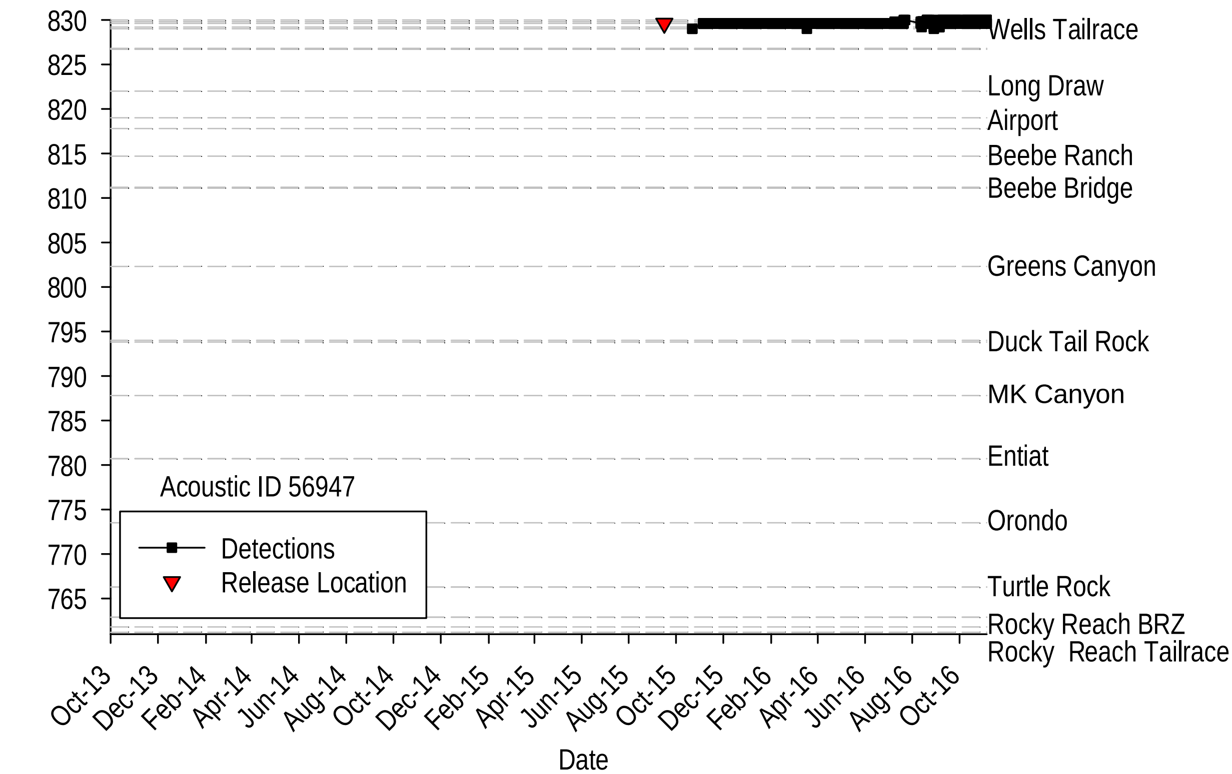

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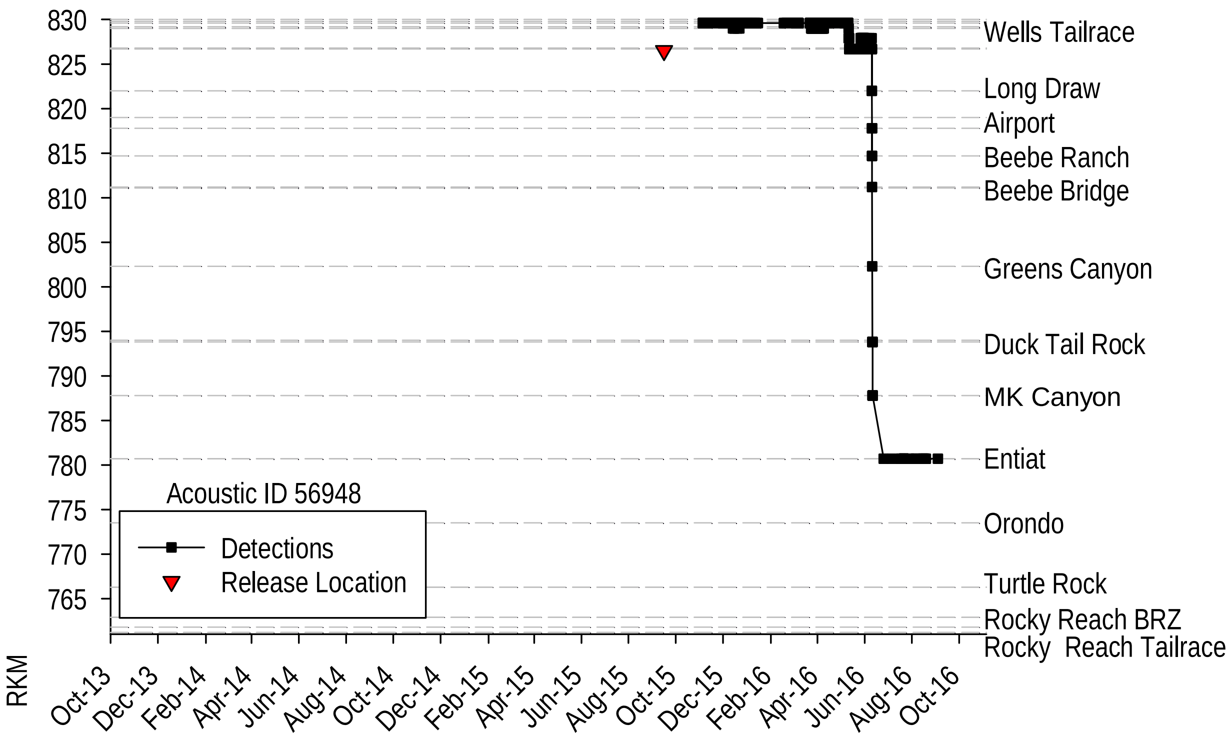
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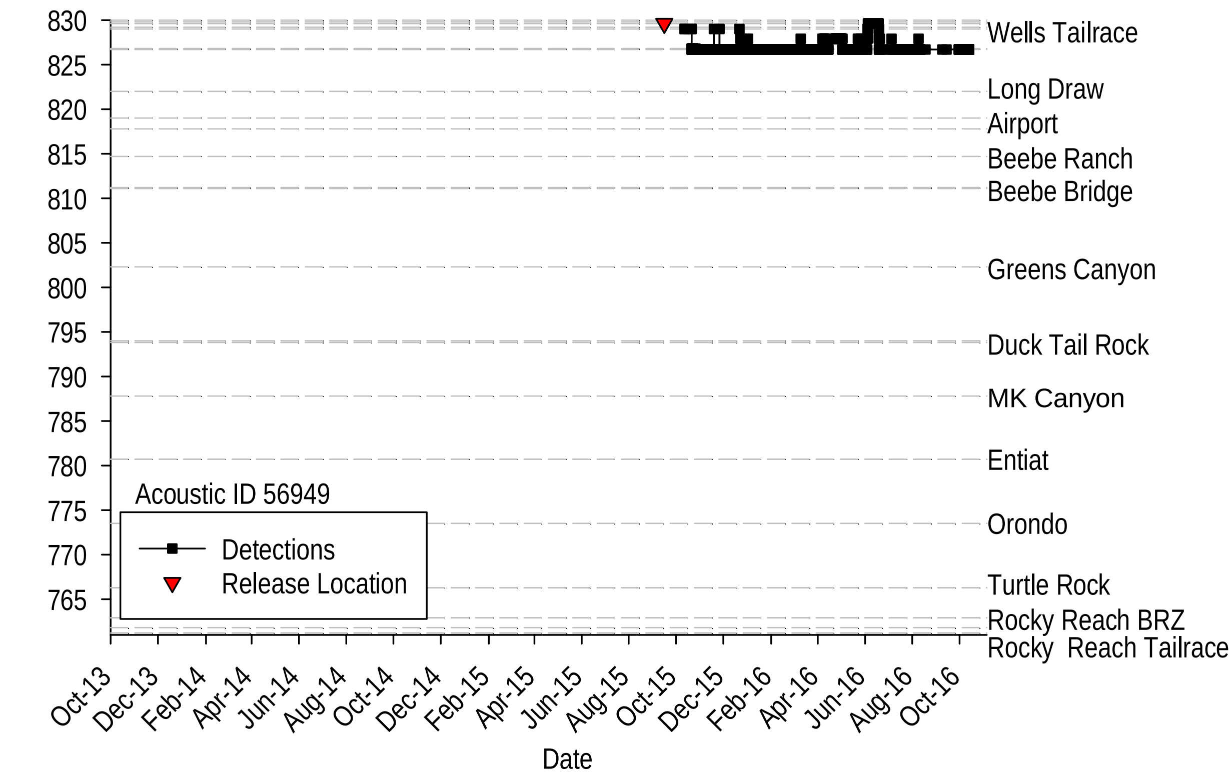
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Rocky Reach Tailrace
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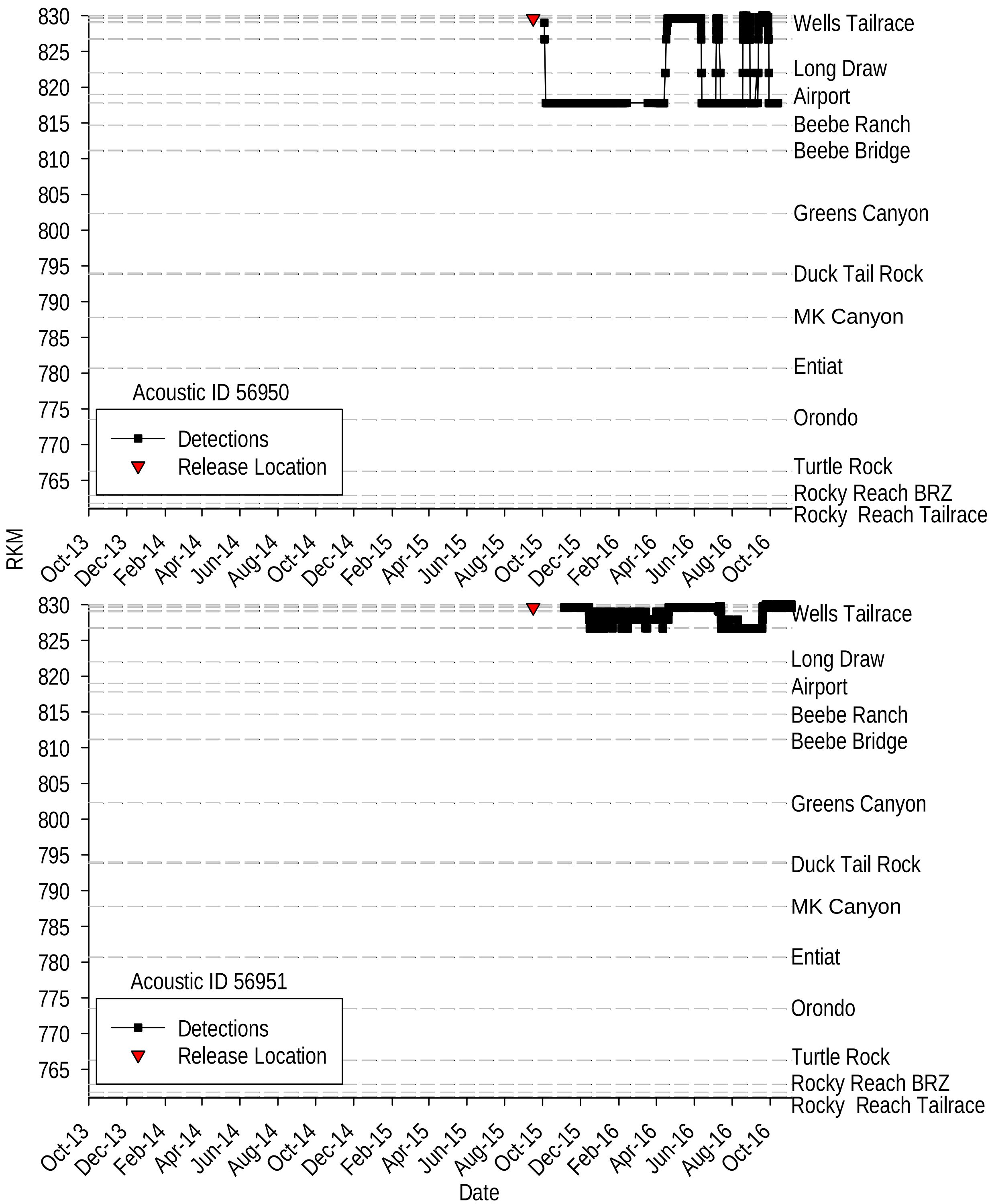
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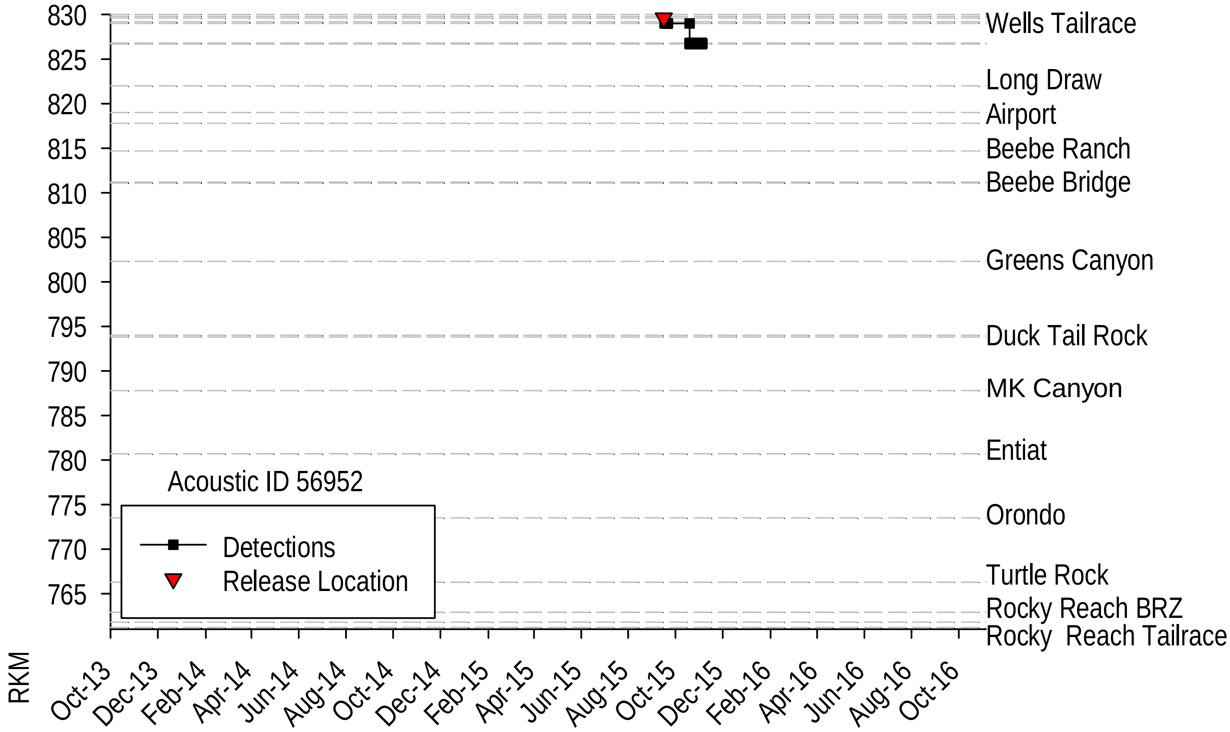
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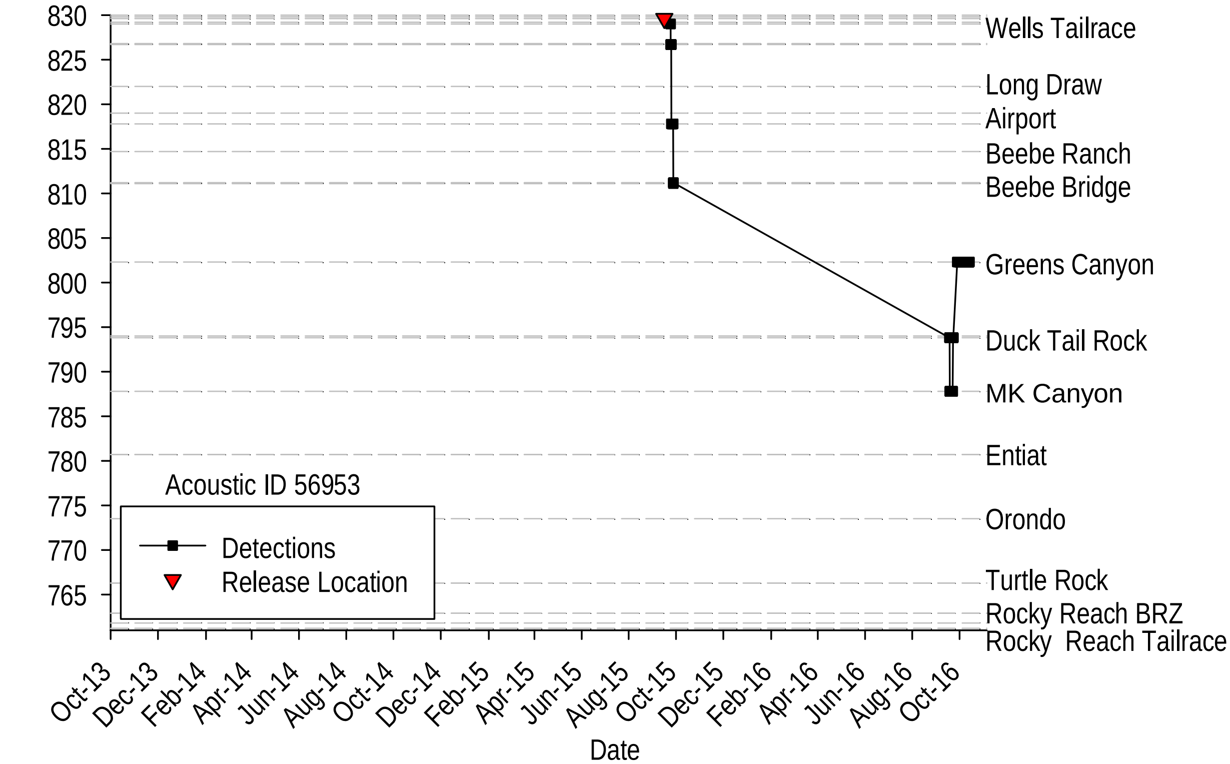
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Rocky Reach Tailrace
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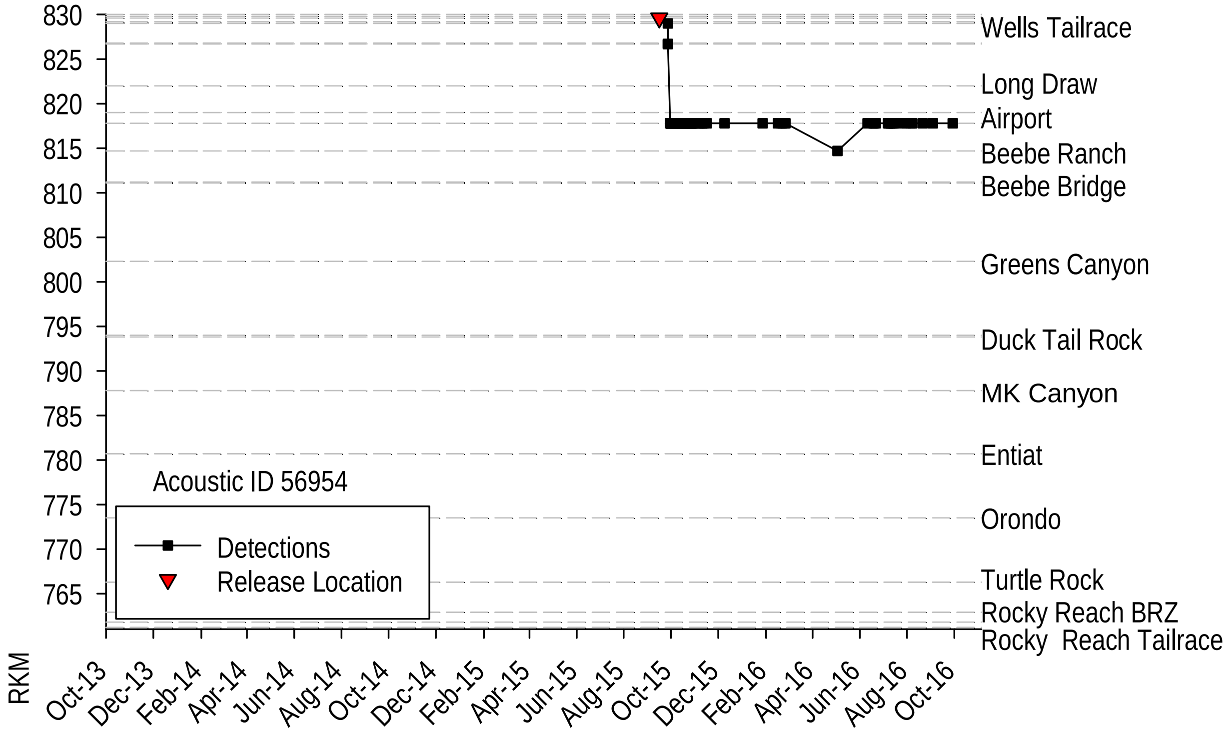
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Orondo
Turtle Rock
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Rocky Reach Tailrace
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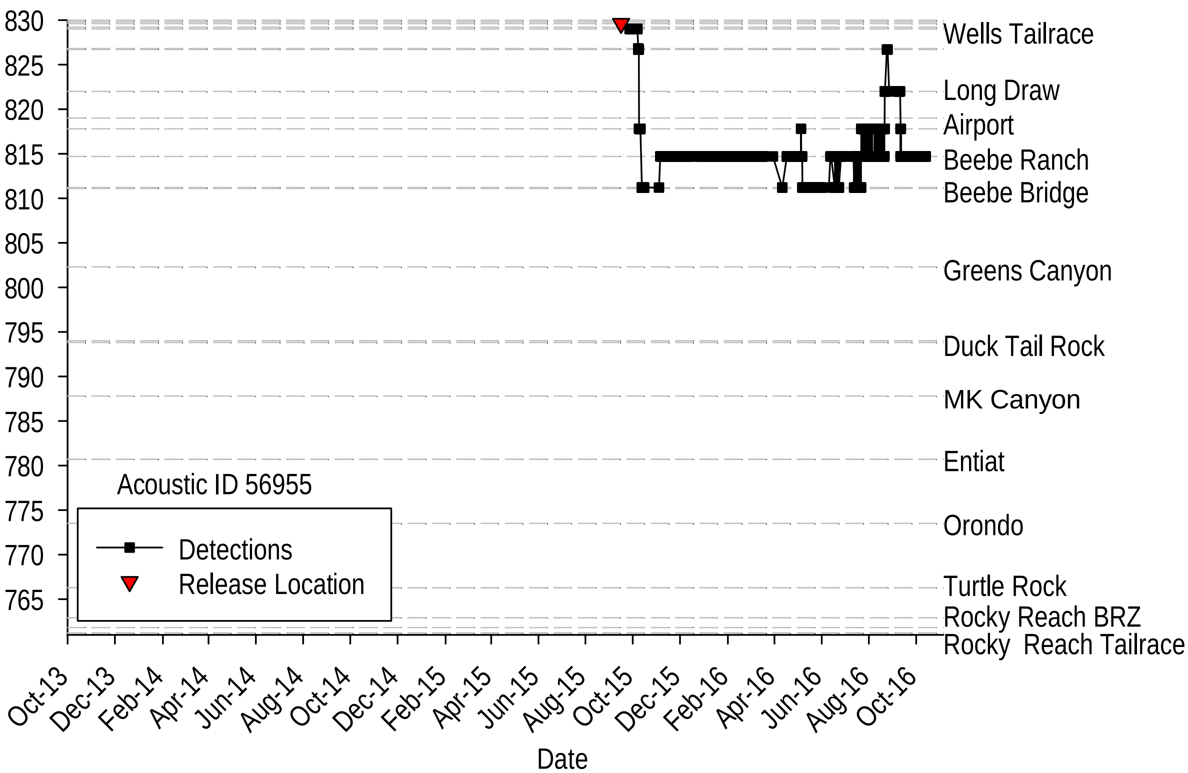
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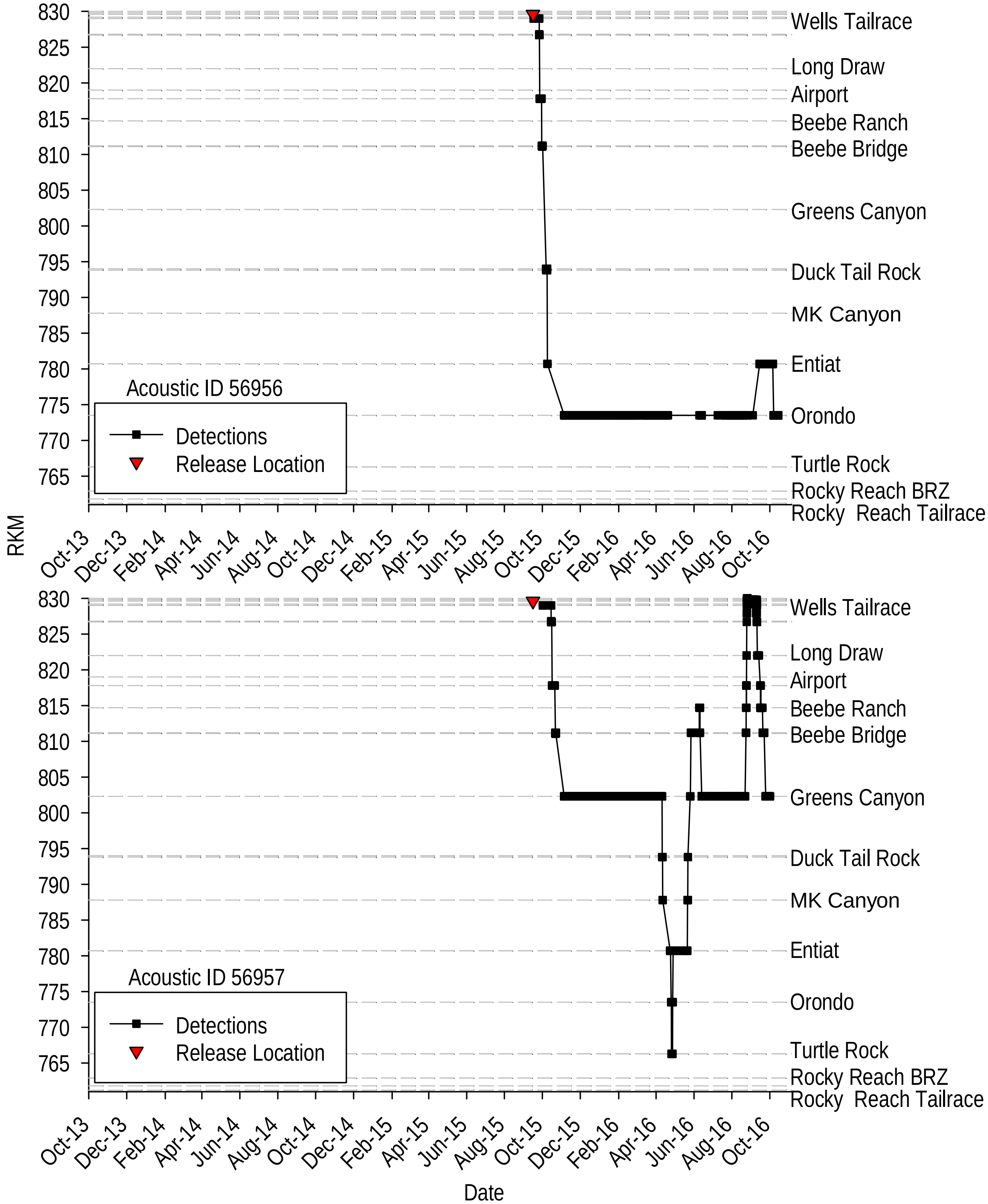
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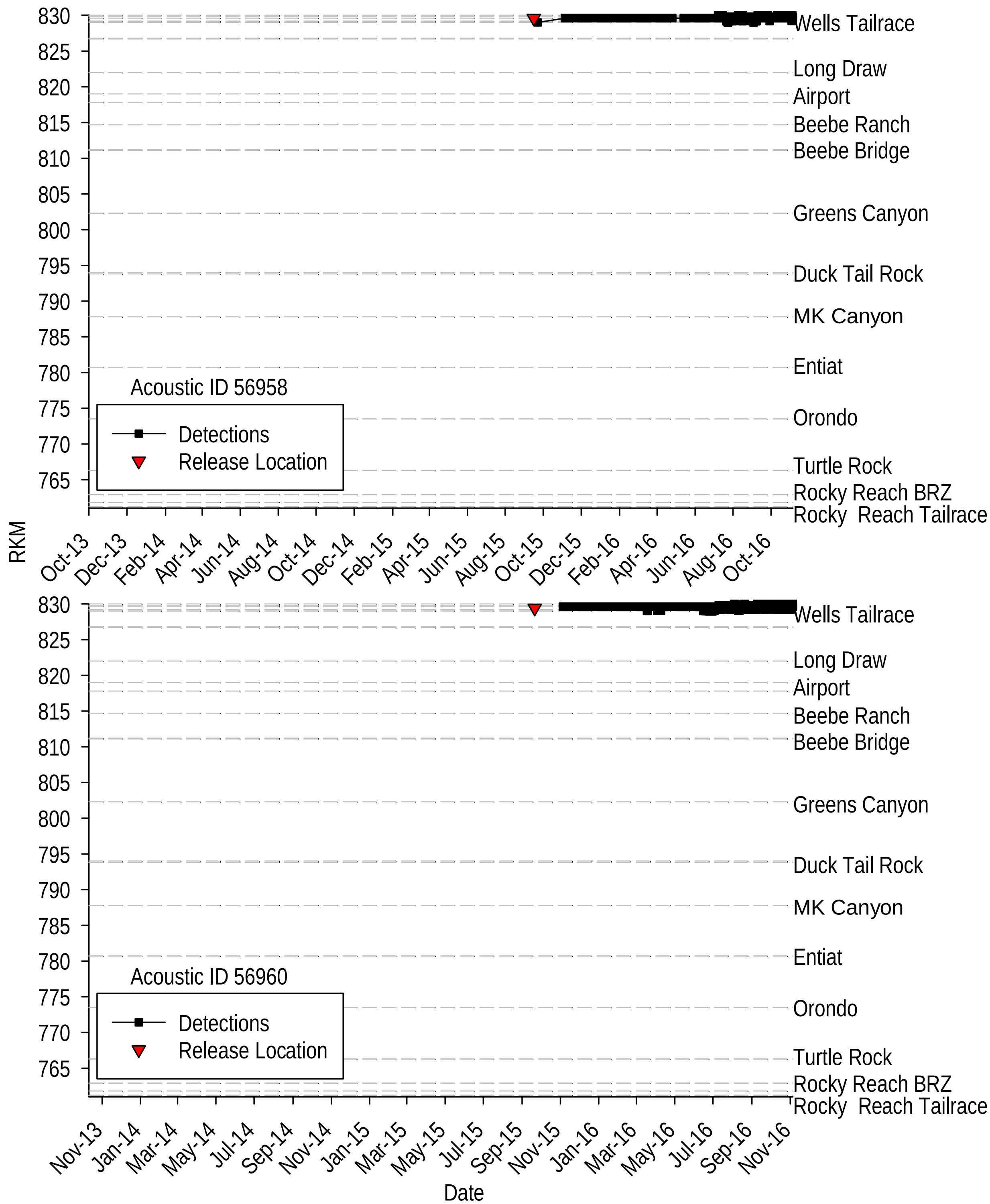
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Orondo
Turtle Rock
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Rocky Reach Tailrace
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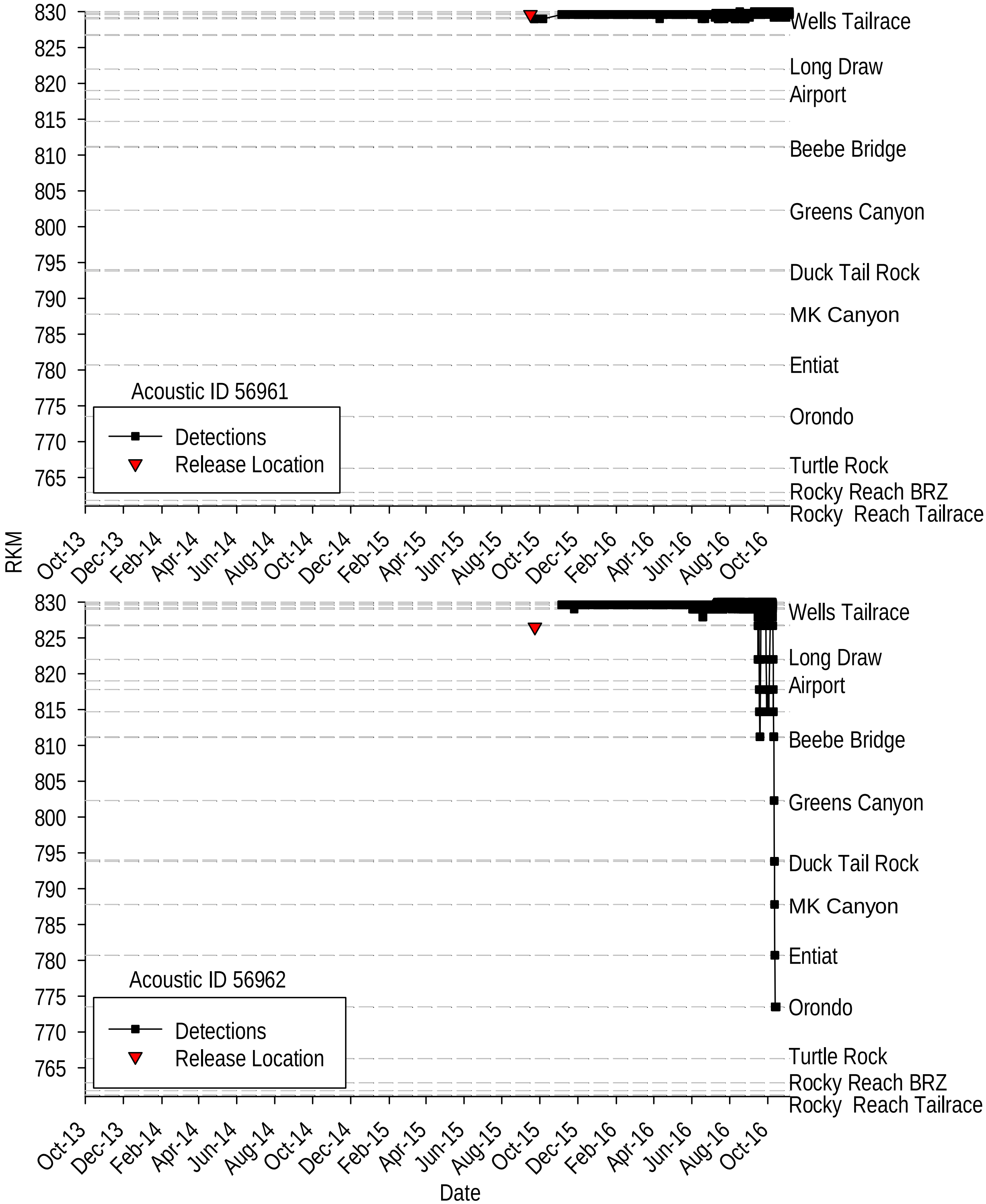
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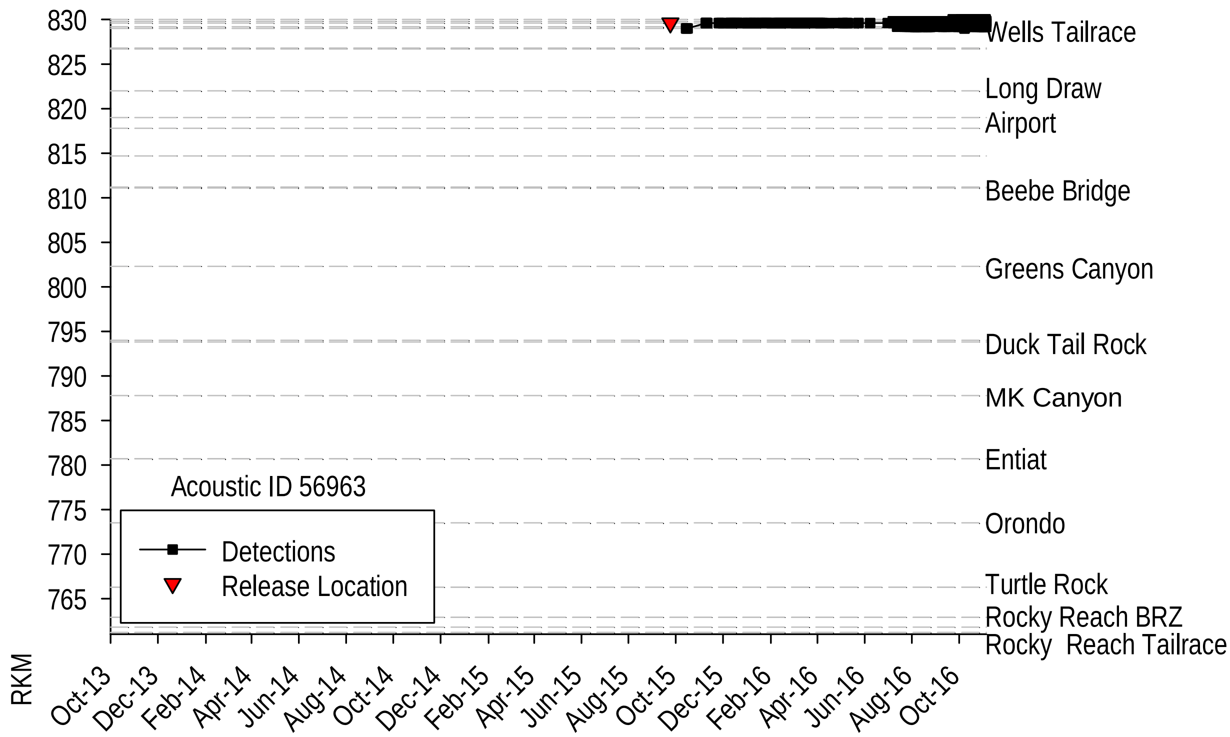
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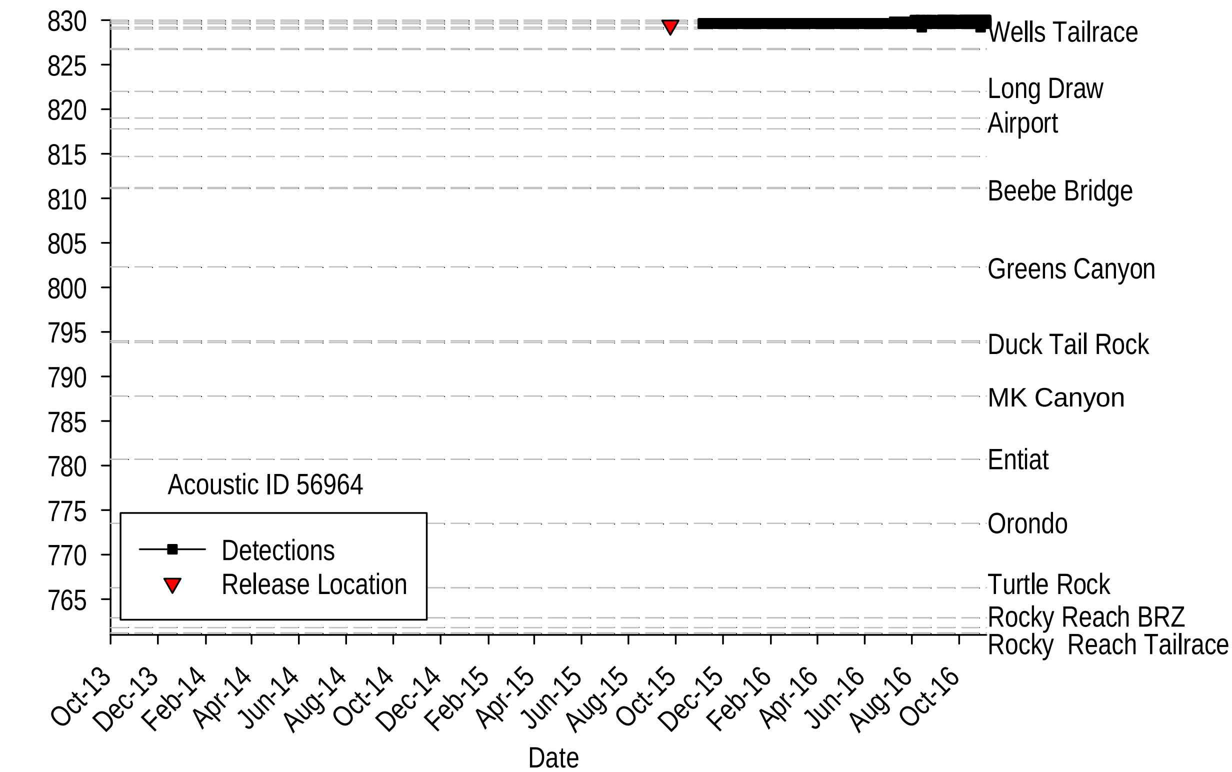
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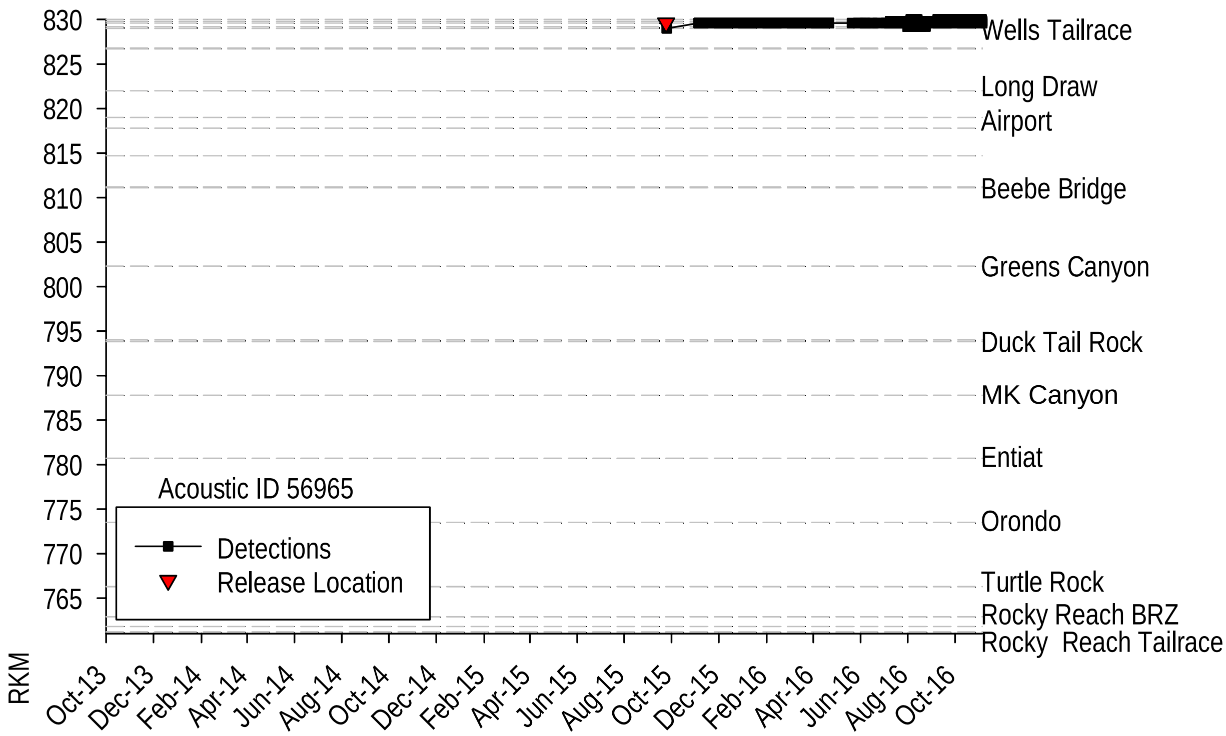

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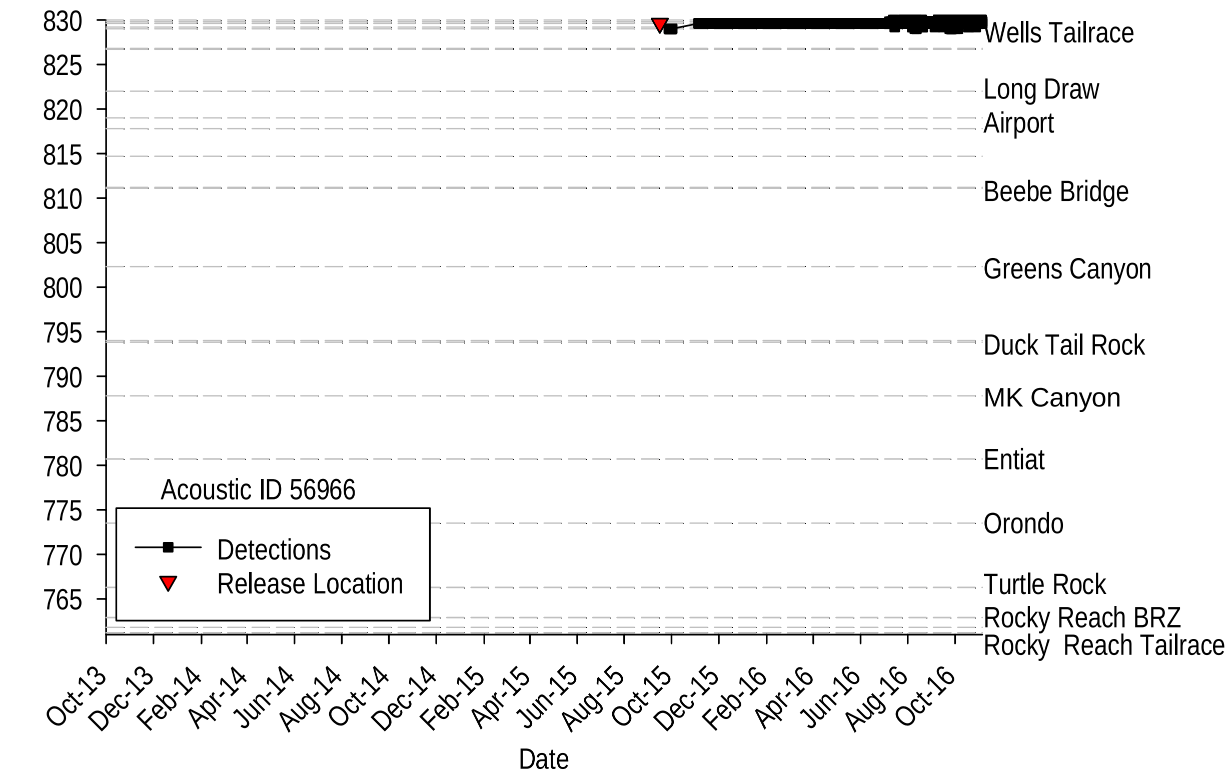

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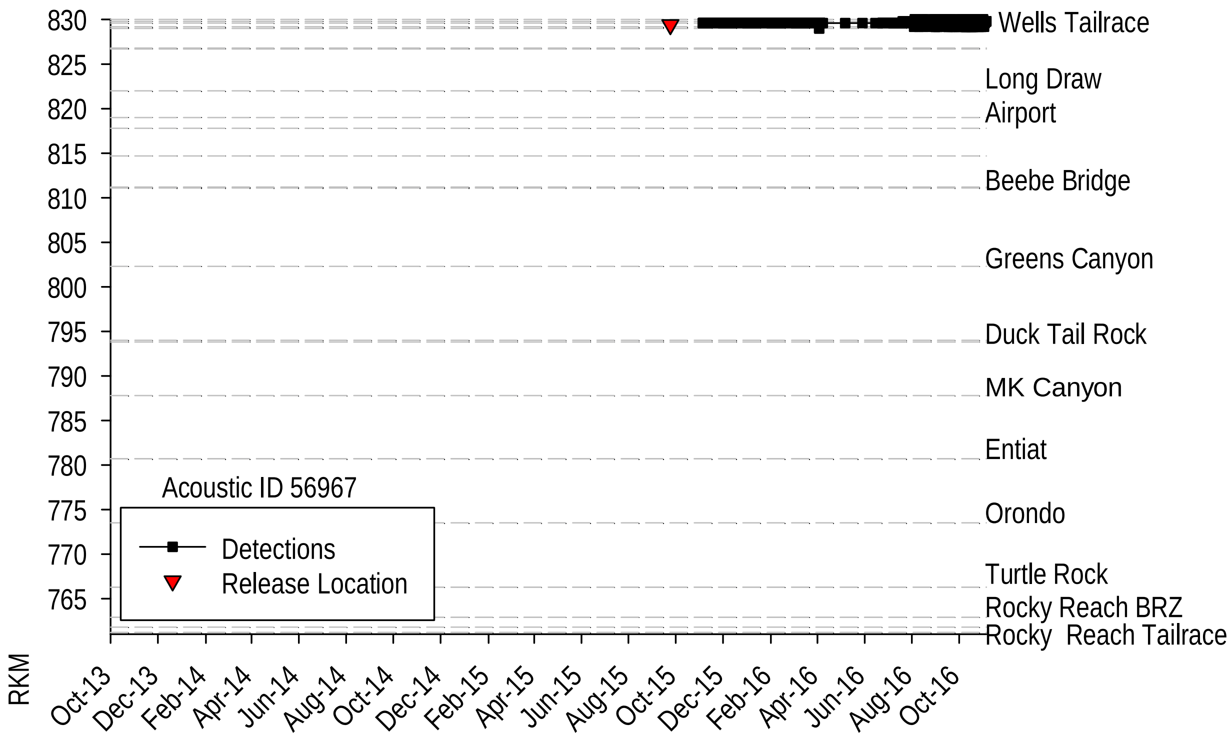
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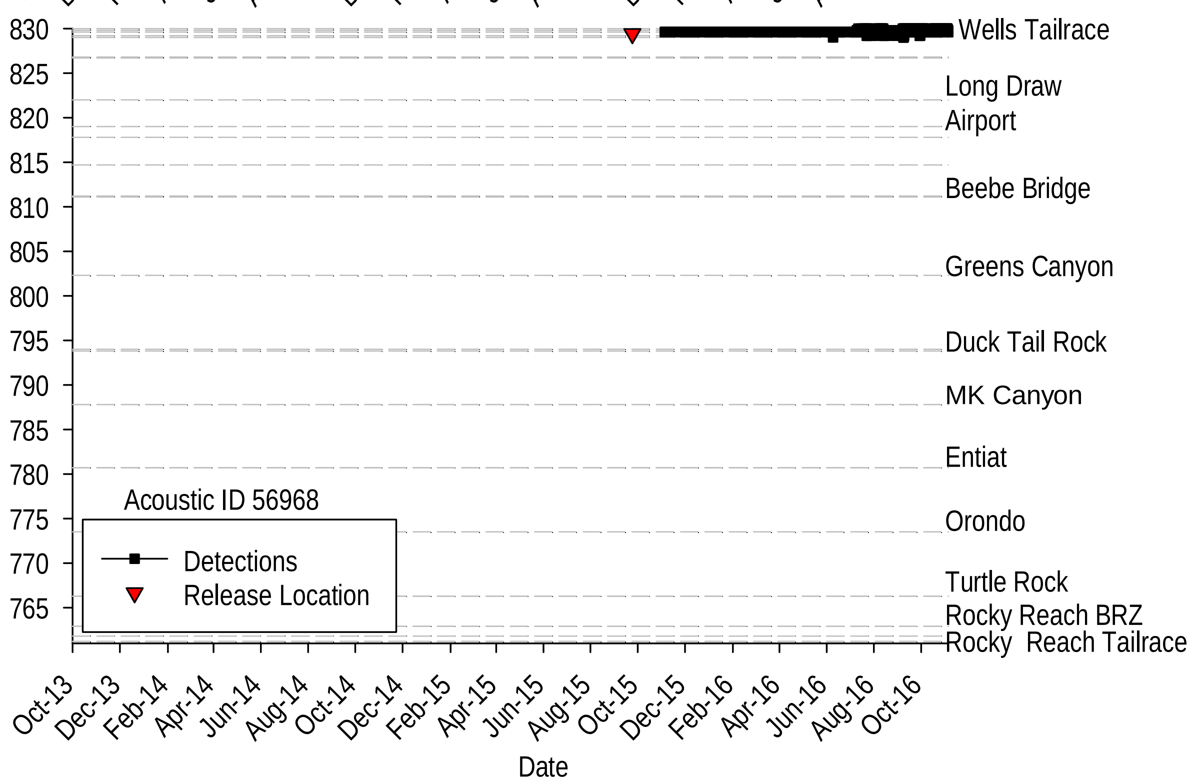
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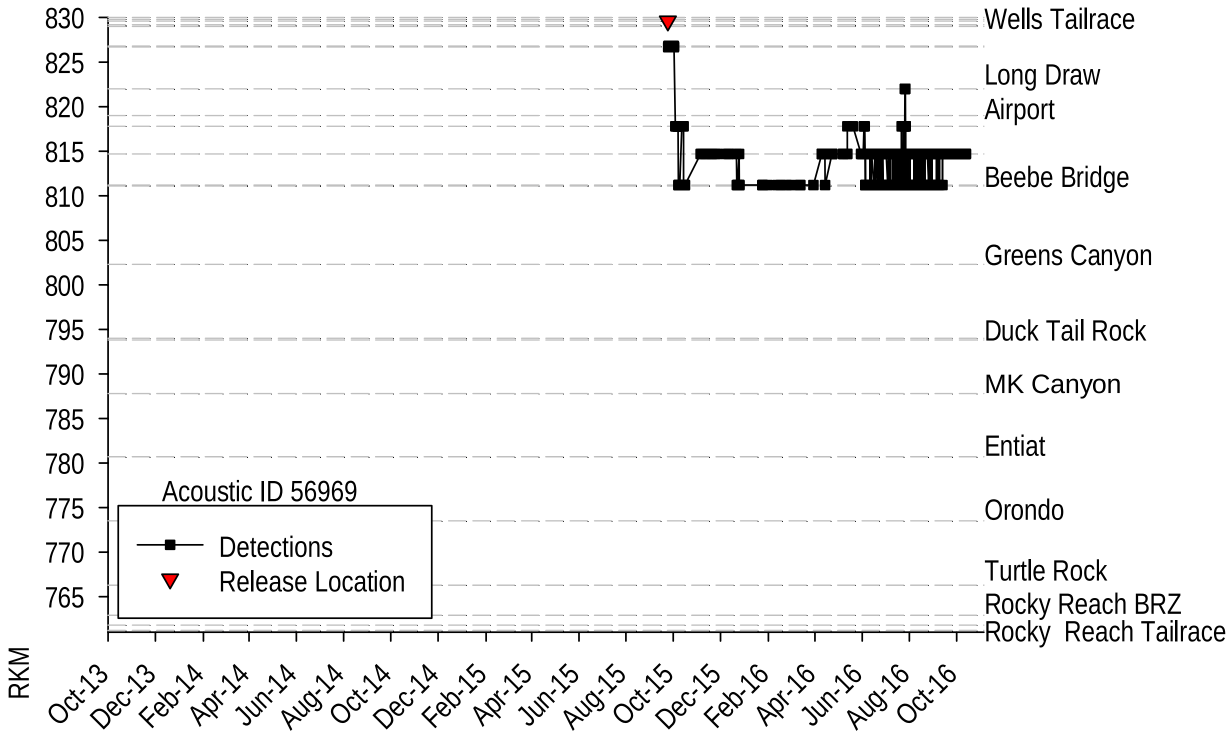
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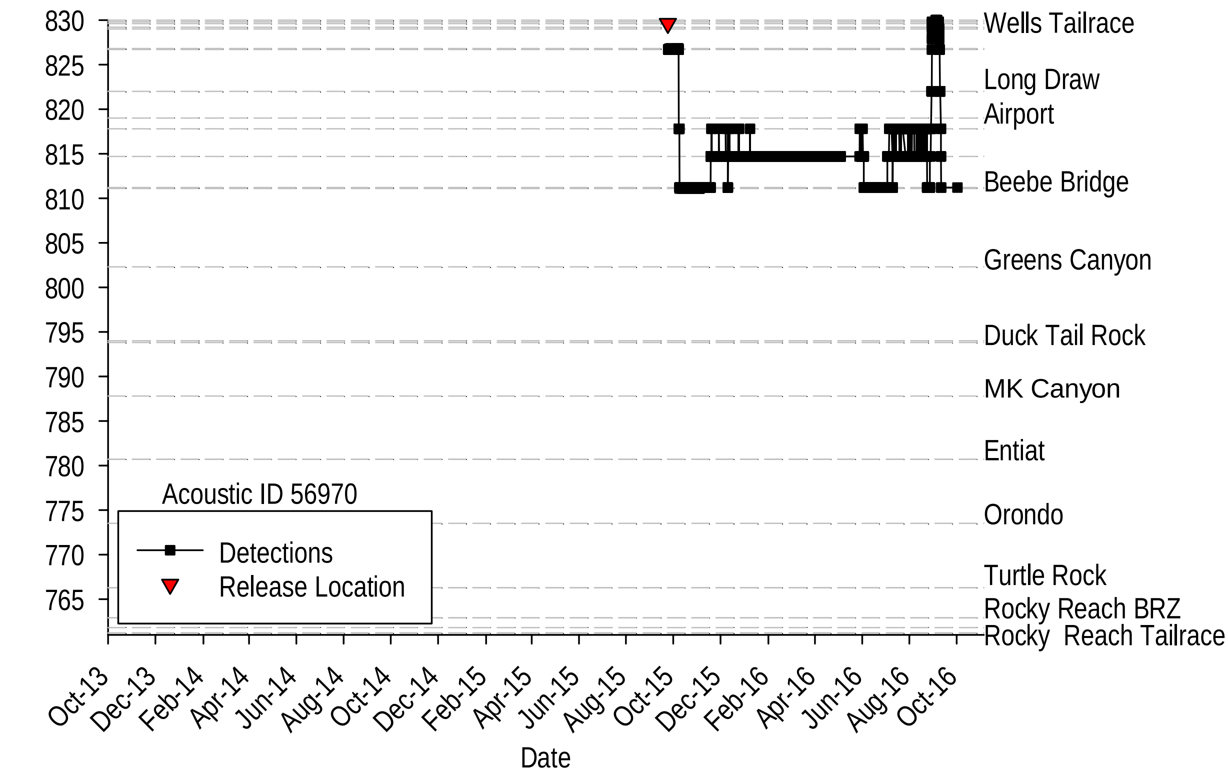
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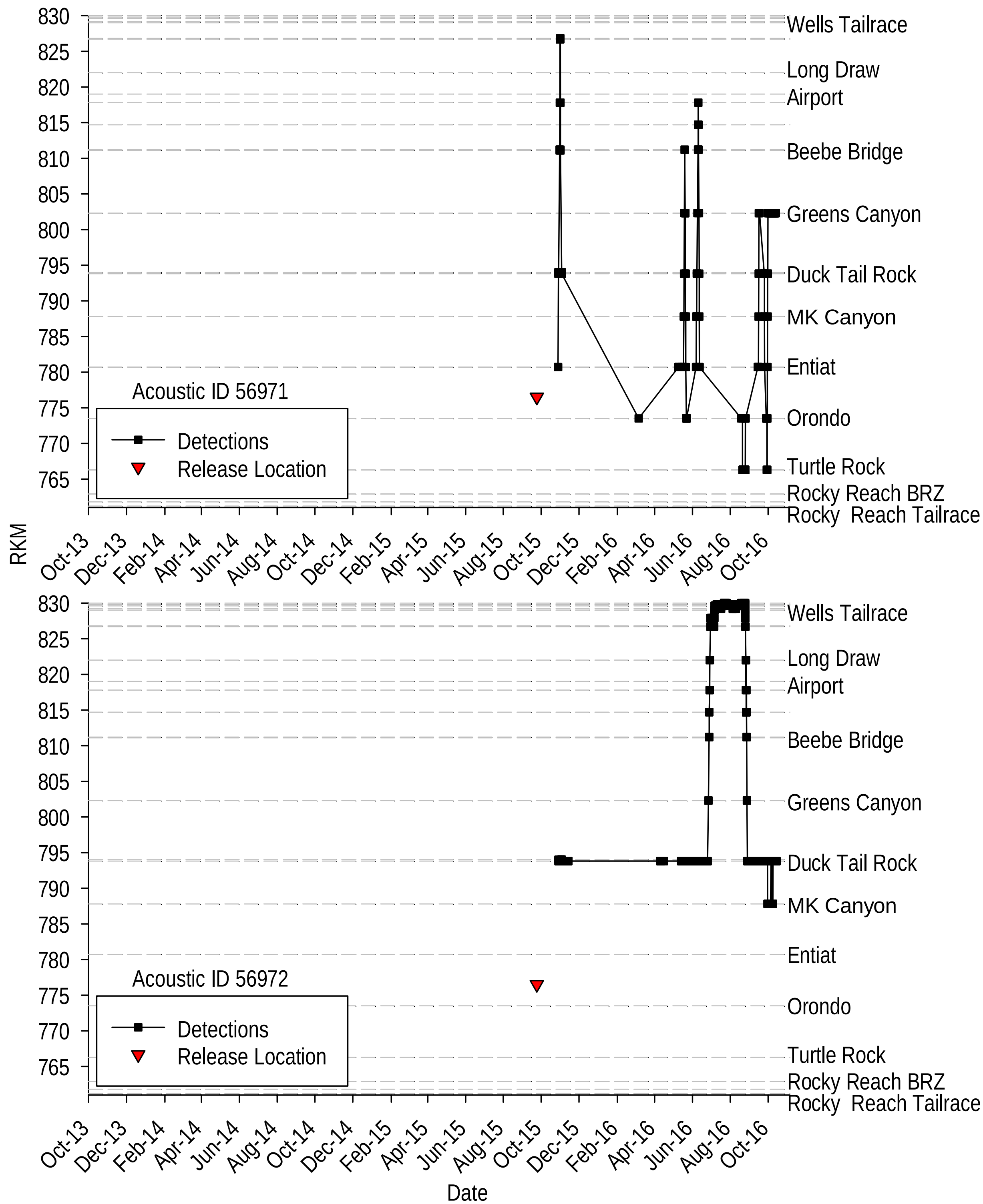

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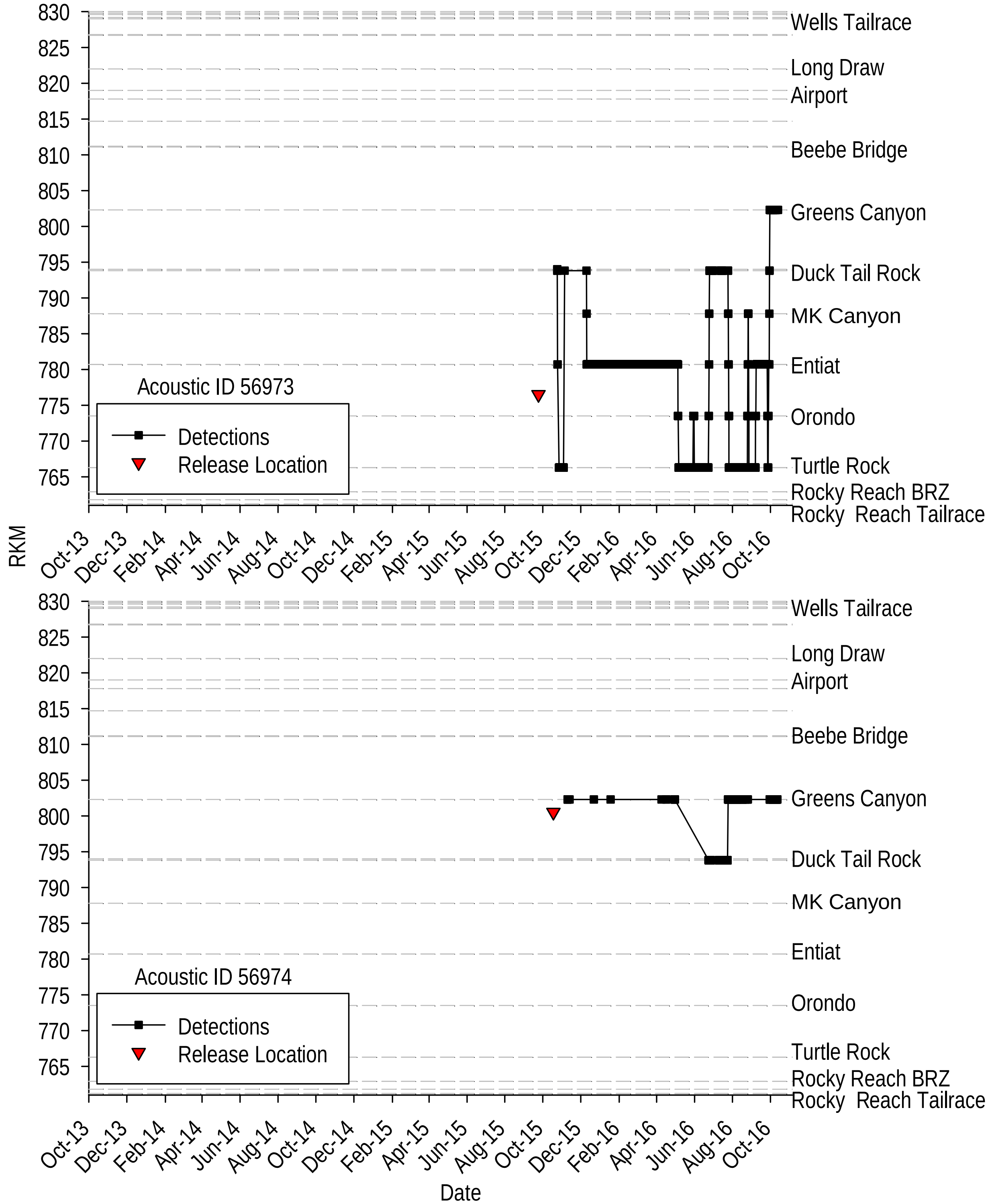
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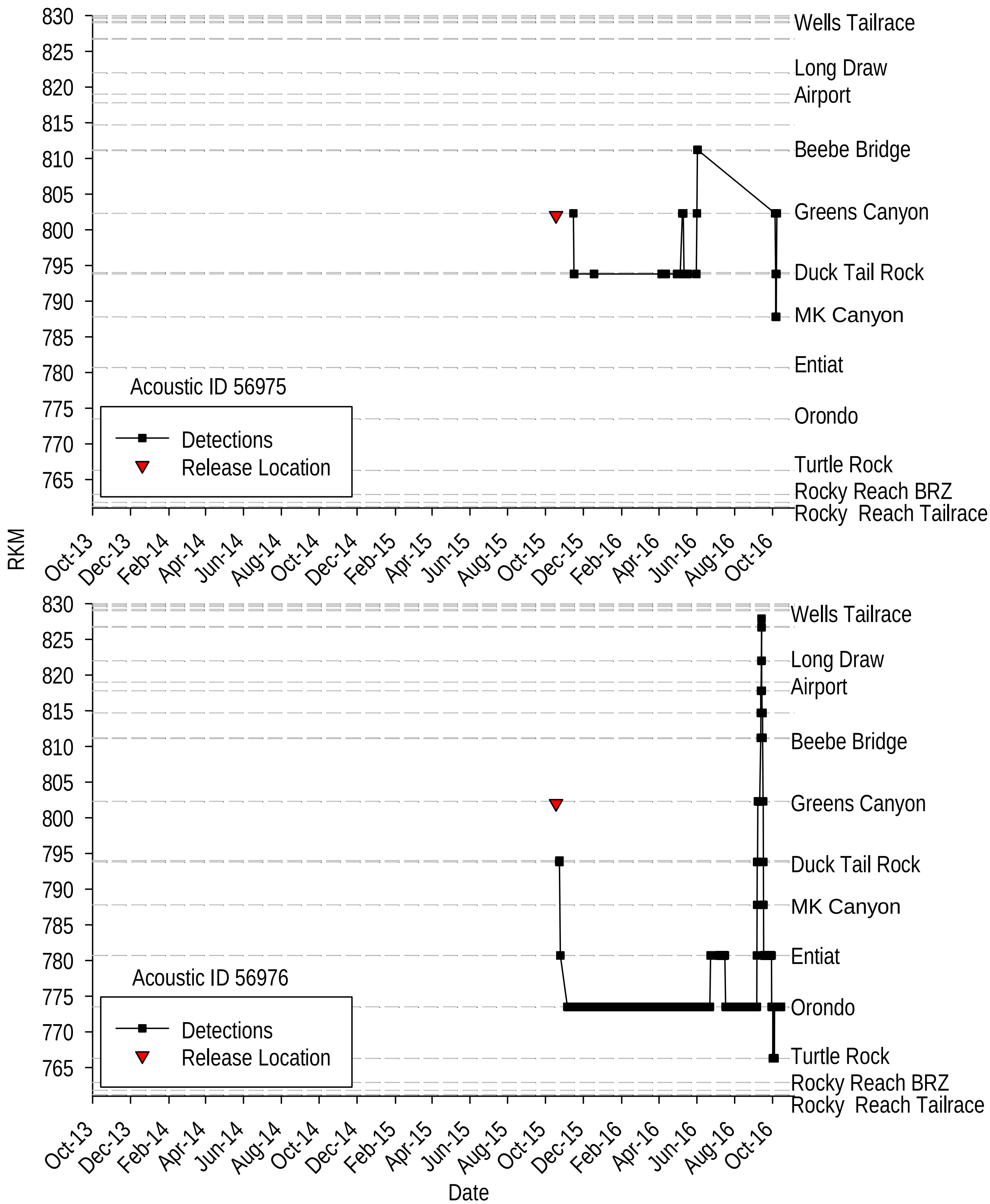

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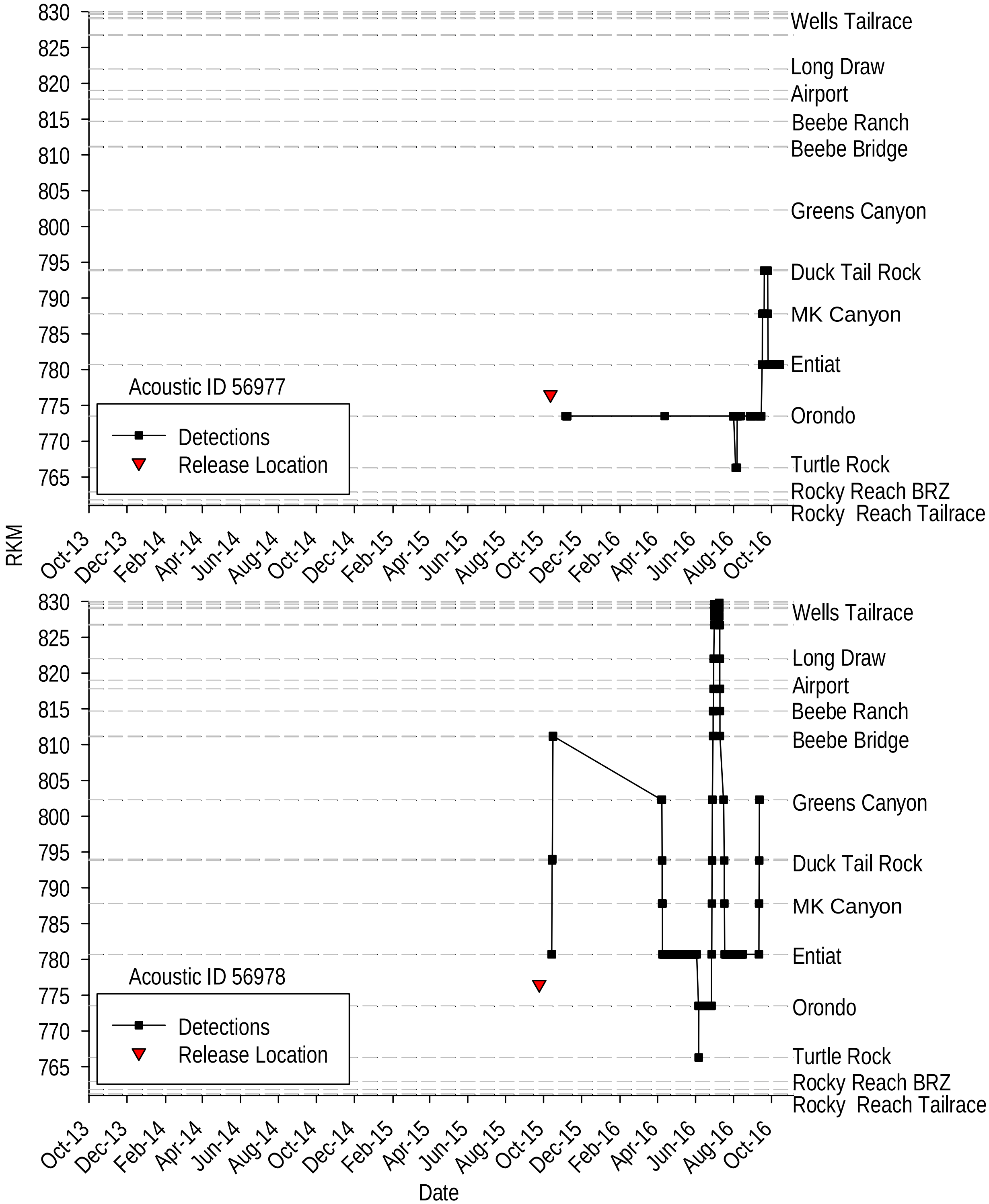
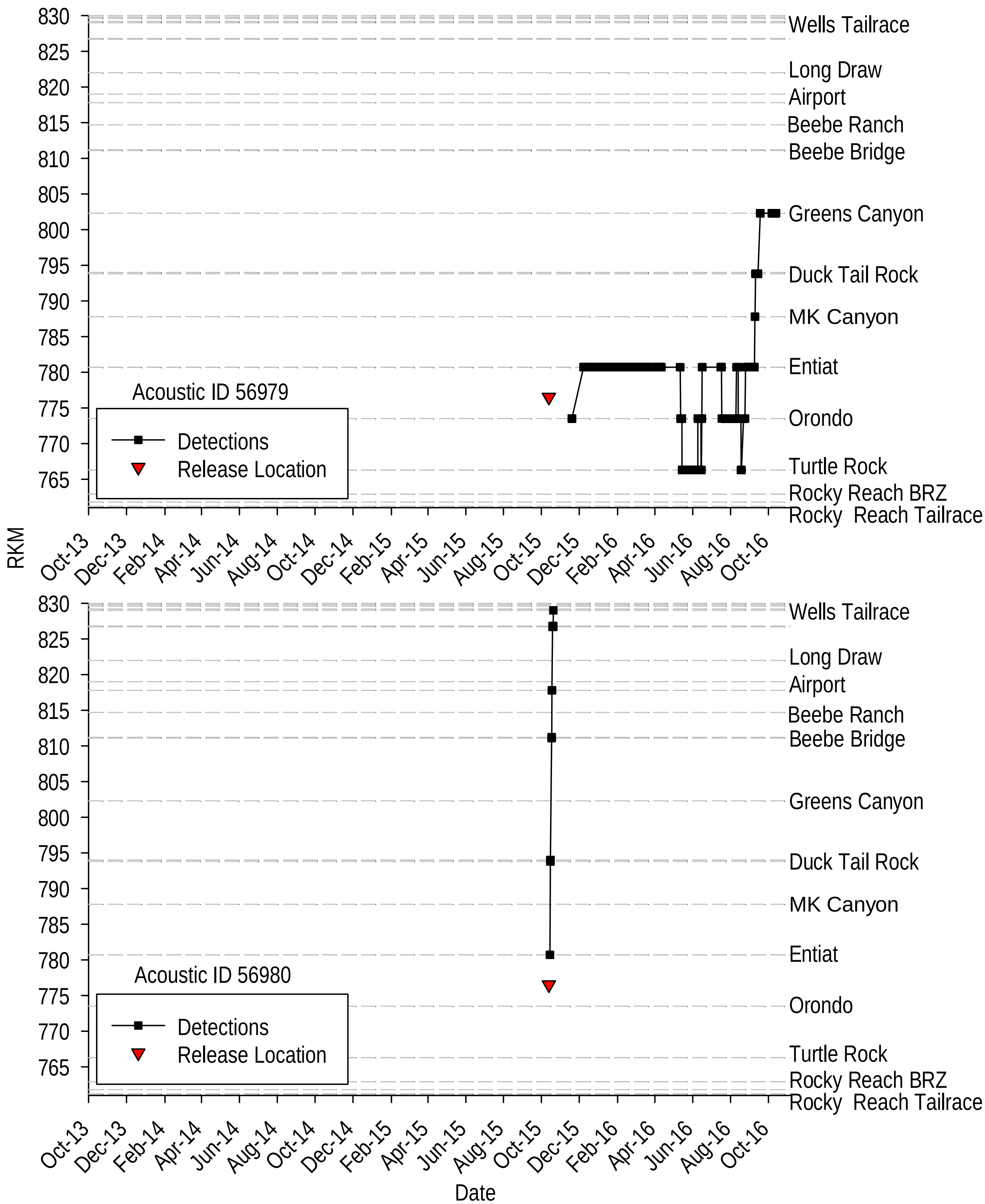


Appendix A- 37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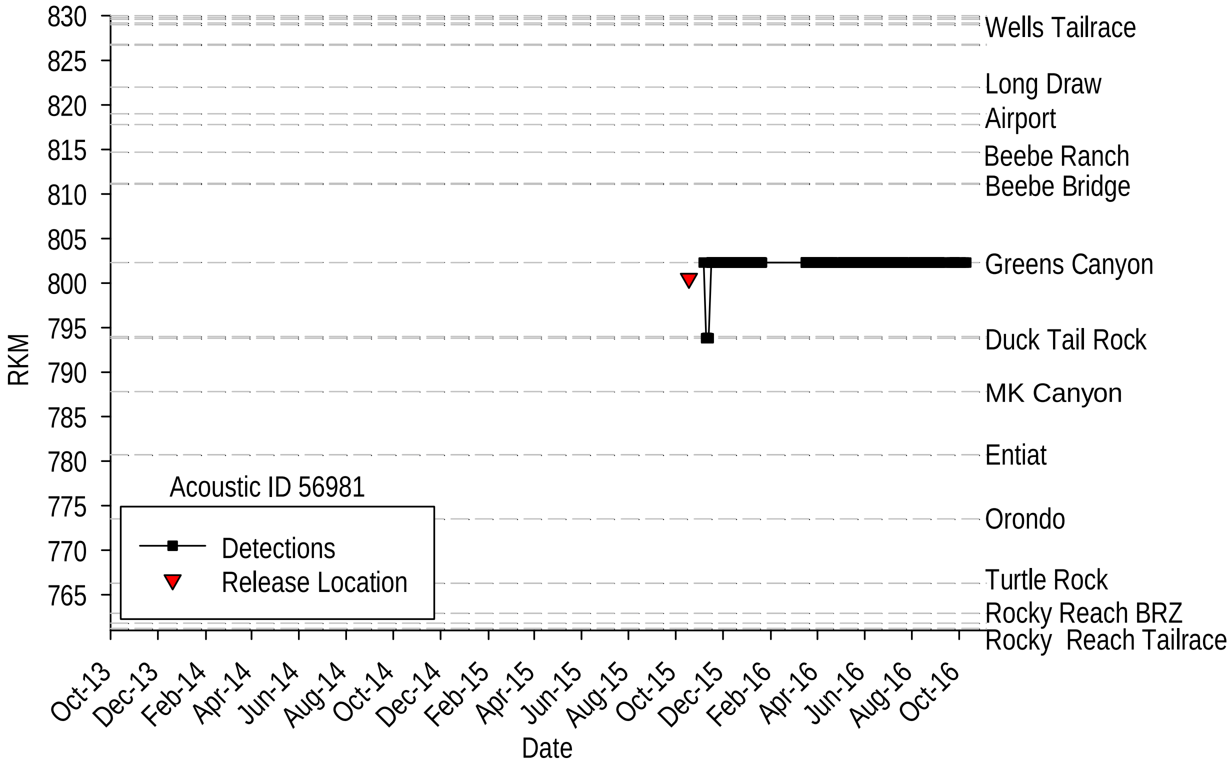

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APPENDIX B

Determining the Detection Model for Survival Analysis

Prior to conducting the main survival analyses, a sub-analysis was conducted to determine an appropriate detection model that could be used in the survival investigation. A simplified survival model was used to compare and rank different detection models. The survival model used a constant long-term survival rate for all release groups (β_0), with a simple offset $(R_{i,t})$ that allowed short-term survival to vary from long-term survival. The survival model used was of the form:

$$\text{logit}(\phi_{i,t}) = \beta_0 + R_{i,t}.$$

A total of 20 different detection models were considered for predicting the probability of individual i being captured on sampling bout t (Table B-1). Models looked at the impact of sampling method (i.e., incidental, targeted, and random), the setline configuration used (i.e., length, hook type and number), sampling effort

Table B-1. Model ranking results from the detection model analysis.

	Detection Model	npar	AICc	ΔAICc	Weight	Deviance
14	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + year_t{:}M_t{:}H_t{:}\log(A_{i,t})$	35	39168.06	0.00	1.00	3210.88
16	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + M_t{:}H_t{:}\log(A_{i,t}) + M_t{:}H_t{:}\log(E_t){:}\log(A_{i,t})$	33	39183.07	15.01	0.00	3229.90
13	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + M_t{:}H_t{:}\log(A_{i,t})$	27	39186.34	18.29	0.00	3245.19
19	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t{:}\log(E_t) + M_t{:}H_t{:}\log(A_{i,t})$	19	39277.61	109.55	0.00	3352.48
18	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t{:}\log(E_t) + H_t{:}\log(A_{i,t})$	16	39282.88	114.82	0.00	3363.76
15	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + M_t{:}H_t{:}\log(E_t){:}\log(A_{i,t})$	27	39416.38	248.32	0.00	3475.23
11	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + H_t{:}A_{i,t}$	24	39476.90	308.84	0.00	3541.76
12	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + M_t{:}H_t{:}A_{i,t}$	27	39478.16	310.10	0.00	3537.01
20	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t{:}\log(E_t) + M_t{:}H_t{:}\log(A_{i,t}){:}\log(E_t)$	19	39522.28	354.22	0.00	3597.16
10	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + \log(A_{i,t})$	22	39524.49	356.43	0.00	3593.35
9	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t) + A_{i,t}$	22	39619.06	451.01	0.00	3687.93
17	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t{:}\log(E_t) + \log(A_{i,t})$	14	39655.33	487.27	0.00	3740.21
7	$\text{logit}(p_{i,t}) = M_t + H_t + year_t{:}M_t{:}H_t{:}\log(E_t)$	21	39672.01	503.95	0.00	3742.87
8	$\text{logit}(p_{i,t}) = M_t + H_t + year_t + M_t{:}H_t{:}\log(E_t)$	18	39787.30	619.25	0.00	3864.18
6	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t{:}\log(E_t)$	13	39794.73	626.67	0.00	3881.61
5	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t{:}E_t$	13	39891.69	723.64	0.00	3978.58
4	$\text{logit}(p_{i,t}) = M_t + H_t + M_t{:}H_t$	10	41074.83	1906.77	0.00	5167.72
3	$\text{logit}(p_{i,t}) = M_t{:}year_t$	12	41801.33	2633.27	0.00	5890.22
2	$\text{logit}(p_{i,t}) = M_t$	5	43669.42	4501.37	0.00	7772.32
1	$\text{logit}(p_{i,t}) = \beta_0$	3	43708.70	4540.64	0.00	7815.60

(along with log transformed effort), sturgeon age (along with log-transformed age), and year-to-year effects (both random differences and temporal trends). Sampling 'bouts' were defined as a sampling session that featured a unique sampling method and setline configuration combination.

Model 1 was the null model that used a constant capture probability for all individuals across all sampling bouts. Model 2 allowed capture probability to vary by the sampling method (M_t; i.e., incidental, targeted and random) used in a given sampling bout. Model 3 extended Model 2 by allowing the capture probability for a sampling bout to vary by year for each sampling method used ($M_t\colon year_t$) in order to accommodate for effort differences among years. Model 4 extended Model 2 by introducing setline configuration as another explanatory variable (H_t); interactions between sampling method and setline configuration were also included in this model ($M_t\colon H_t$). Models 5 and 6 refined Model 4 by allowing the capture probability to be related to the sampling bout effort (E_t). The metric of effort used the number of setlines deployed in the 2013-2016 sampling bouts, and the total number of sampling days for the 2011-2012 sampling bouts (due to the lack of setline information for the two first years; note that 2011-2012 exclusively used the 'incidental' sampling method). Models 5 and 6 also considered whether or not to log transform the effort metric. Due to the strong support for log-transforming the effort metric (ΔAICc > 10; Model 5 versus 6) only the log transformed effort metric was included in remaining models.

Models 7 and 8 looked at how the effort relationship varied with year. Model 7 extended Model 6 by allowing the sampling method and setline configuration effort relationship to differ by year, while Model 8 kept the same effort relationship each year, but allowed the overall capture probability to vary from year to year. Model 9 extended Model 7 by introducing considerations of age selectivity ($A_{i,t}$), where the age of individual i on sampling bout t was used as a proxy measure for size. Model 10 considered whether log-transforming age was more appropriate. Model 11 extended Model 9 by allowing the age selectivity relationship to vary by setline configuration, and Model 12 extended Model 11 by allowing the age selectivity relationship to vary by sampling method *and* setline configuration. Model 13 extended Model 12, but log-transformed age. Model 14 extended Model 13, but allowed the age selectivity relationship to vary by year. Model 15 extended Model 13 by allowing effort to interact with the age selectivity relationship (methodological combinations that preferentially capture more individuals can be expected to result in higher capture probabilities under higher effort regimes). Finally, Model 16 extended Model 15 by including an additional interaction term for the age selectivity relationship.

Estimating the year-to-year difference in the methodology-by-effort relationship required a large number of model parameters, which can contribute to convergence problems for some survival models of interest. As such, Models 17 to 20 kept the basic model structure of Models 10, 11, 13, and 15, respectively, but used a constant methodology-by-effort relationship.

Model ranking results favored Model 14, the most complex detection model, but this model showed estimation problems in practical use. Model 16 and 13 were the next top supported models that did not have estimation problems in practical use. Model 13 was within 3.28 AICc units of Model 16, and could be considered a plausible alternative, especially given that it used 5 fewer parameters. However, most analyses converged using Model 16, so the higher ranked model was used.