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BOEM 2024-002

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U.S. Department of the Interior
Bureau of Ocean Energy Management
BOEM Alaska Region, Anchorage, AK

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January 2024

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Prepared under M20PG00005
By
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U.S. Department of the Interior
Bureau of Ocean Energy Management
BOEM Alaska Region, Anchorage, AK

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Interagency Agreements: This study was funded, in part, by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, through Interagency Agreement Number M20PG00005 with the NOAA Fisheries. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of BOEM, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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CITATION

Kumar, S.V., M. Castellote, and Gill VA. 2024. THE URBAN BELUGA: ACOUSTIC MONITORING IN THE KENAI AND KASILOF RIVERS, ALASKA. Anchorage: US Department of the Interior, Bureau of Ocean Energy Management. 64p. Report No.: OCS Study BOEM 2024-002. Contract No.: M20PG00005.

ABOUT THE COVER

A ST500 in a silo on a dock pile deployment next to a commercial seafood company's floating dock in the Kenai River, Alaska (Sonia Kumar).

ACKNOWLEDGMENTS

Thank you to the Alaska Region of the Bureau of Ocean Energy Management (BOEM) and the Alaska Region of NOAA Fisheries (NOAA) for funding this study. We are indebted to Sean Burril and Cathy Coon (BOEM) for partnering with us and championing this project for funding. We appreciate the help of Barbara Lake and Julie Scheurer (NOAA) with equipment logistics and Dana Whitley (NOAA) with contracts. There are so many people who provided support with field work during the two- year long field season. A huge thank you to everyone who helped with field logistics, including Chris Garner, Curt and Kurt from the City of Kenai, Garrett and Josh Patterson with PacificStar Seafoods, Ron Hyde at the Cannery Lodge, Steven Meadows with Copper River Seafoods, Rogue Wave, and PacStar, Buck Kunz from Mike's Welding, Michael Cota from OBI, Ed Schmitt, Peter Ehrhardt, Randy Vasko who let us use his "What's Up Dock," Teresa Becher, Ben Meyer and Louise Bishop who helped in the initial field site scouting process. Thank you to Kenya Pace for being a great AKUNiTe intern in 2021! We are grateful to Jacob Pelham and Colton Lipka from the Alaska Department of Fish and Game for boat rides, buoy rescues, and good dog company. We certainly would have had a much harder time without the volunteers who helped with field work over the 2 field seasons: Brandon Kellum, Brandon Hoffman, Diane Taylor, Kelly Matthews, Colleen Sinnott, Bhavisha Bhalsod, Mat Thomas, Lindsey Stadler, Carol Fairfield, Cindy McCroskey, Shashi and Sheila Kumar, Shivani Doshi, Courtney Stage, Jacob Reid, Ciara Bismark and Yvonne Weber. Thank you to Greg Messimer for not giving up on the buoy that went rogue and for helping us track it down. Thank you to all the dedicated citizen scientists with the Alaska Beluga Monitoring Program (AKBMP) who tirelessly collected data on both the Kenai and Kasilof Rivers. We appreciate the Alaska Wildlife Alliance for partnering with NOAA at this AKBMP site and to Teresa Becher for coordinating these local efforts and Madison Kosma for her overall coordination of the program. We sincerely appreciate all of the help and guidance Dr. Lara Horstmann provided to S. Kumar throughout this whole process. This work is part of S. Kumar's Master's degree. All work was conducted under National Marine Fisheries Service (NMFS) permit no. 25563.

The urban beluga: acoustic monitoring in the Kenai and Kasilof Rivers, Alaska

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Abstract

Cook Inlet, Alaska, has multiple sources of anthropogenic noise, such as shipping and marine traffic, fishing, oil and gas exploration and extraction, military activities, and coastal development. It is also home year-round to an endangered distinct population segment of beluga whales, the Cook Inlet Beluga (CIB). In the CIB recovery plan, noise was identified as one of the top three threats to their recovery. Historically, CIB utilized all of Cook Inlet but as their numbers decreased from a high of about 1300 to the current 331 whales, their range contracted to upper Cook Inlet (UCI), defined by the National Marine Fishery Service as north of the forelands in the middle inlet. Consequently, research has focused on UCI and less work has been focused on CIB contemporary use in lower Cook Inlet (LCI). This study focused on the Kenai, which has the highest return of salmon in Cook Inlet, and Kasilof rivers. Salmon are the main prey item of CIB in the summer months. Between May - November 2021 and 2022, we acoustically monitored CIB presence and background noise in the Kenai and Kasilof rivers. From September 2021 until April 2022, we acoustically monitored CIB presence outside of the mouths of these same rivers. We recorded numerous occurrences of the acoustic presence of CIB in the Kenai River from late August to early November, and off the mouth of the river from December to March. After staying out of the rivers for the summer, CIB were first heard returning to the Kenai on the 28th and 29th August in 2021 and 2022 respectively. They were not recorded visually in the Kenai River until September 3rd and August 29th of those same years. In stark contrast to the Kenai River, we never acoustically recorded any CIB inside the Kasilof River during the same time period, but did record them off the river mouth in December-March. In fact, the overwinter deployments showed CIB had higher instances of acoustic presence by the Kasilof River compared to the Kenai River mouth locations. Visual observations agreed well with the acoustic results and were statistically correlated in both years, with the majority of sightings occurring in the Kenai River between September and November. Tide height did not significantly affect CIB acoustic presence in the Kenai River; beluga access and spend time inside the Kenai River even through low tides, but in both 2021 and 2022, there was a distinctive seasonal pattern to CIB acoustic presence that was related to the anthropogenic noise intensity of the river. Belugas visited the river after the busy fishing season ended, when noise in the river decreased. The number of minutes belugas were detected significantly decreased the further upriver the F-PODs were located, suggesting a gradual decrease of river habitat use with distance to the mouth, but yet, belugas were acoustically detected in our furthest up river station by the Warren Ames Memorial Bridge, 7.5 river km from the mouth. Our study results support the notion that Cook Inlet beluga whales avoid the Kenai River when there are high levels of anthropogenic noise from fishing related activity from April to the end of August, despite these being the months with highest density of salmon in the river. We suggest seasonal vessel speed limitation measures within the Kenai River in April-May and August-November

when beluga and fisheries activities currently overlap to decrease disturbance and potential boat strike. Additionally, we suggest a revision of the Kenai River fishing regulations for the personal use fishery in July, with an evaluation of new criteria to consider the impacts to the CIB critical habitat.

1. Introduction

Anthropogenic noise has detrimental effects on marine mammals, including an increase in stress, changes in behavior, and auditory masking (Nowacek 2007). Cook Inlet, Alaska has multiple sources of anthropogenic noise, such as shipping and marine traffic, oil and gas exploration and extraction, military activities, and coastal development (Castellote et al. 2019). These waters also provide critical habitat for endangered Cook Inlet beluga (CIB) whales (*Delphinapterus leucas*), which, as with many other marine mammals, are sensitive to underwater noise disturbance (Small et al. 2017, Nowacek 2007). As with other beluga populations, CIB use a wide array of vocal signals to communicate, and sound is their primary sensory modality (Brewer et al. 2023; O'Corry-Crowe 2017). CIB are a genetically distinct and geographically isolated population of endangered beluga whales that reside year-round in the turbid waters of Cook Inlet (O'Corry-Crowe et al. 1997, Hobbs et al. 2015). In 1972, an Alaska Department of Fish and Game (ADFG) survey estimated about 1,300 CIB (Calkin 1989), but there was a sharp decrease in the 1990s due to overharvesting by Alaska Natives, and concerns about the decline of the Cook Inlet stock resulted in a voluntary suspension of the subsistence hunt in 1999 (Mahoney and Shelden 2000). However, despite hopes that the population would rebound once hunting pressure was removed, it continued to drop. By 2008, the population had plummeted to 375 (Hobbs et al. 2015) at which time they were listed as endangered under the U.S. Endangered Species Act.

To monitor the trend and abundance of the CIB population, the National Marine Fisheries Service (NMFS) conducts biennial aerial surveys; the most recent population assessment was published in 2023, estimating the population to be 331 CIB (95% probability interval 290 to 386; Goetz et al. 2023). In 2011, critical habitat was designated for CIB; in 2015, CIB were declared a NOAA Species in the Spotlight (SIS) and a Priority Action Plan outlining five key actions was published (NOAA 2016, 2021); and in 2016, a Recovery Plan (NMFS 2016) was published with 64 recovery actions. Despite all of these efforts, CIB have failed to recover and the reason(s) why are unknown. In the Recovery Plan, ten potential threats to recovery were identified, with three of those identified as a high threat; catastrophic events; cumulative effects of multiple stressors, and noise (NMFS 2016). The SIS Action Plan also highlights how identifying areas where the acoustic environment may no longer be suitable for belugas is a key benefit to CIB recovery (NOAA 2016, 2021).

To understand how different stressors may be impacting the CIB population, it is important to understand the whales' habitat and behaviors. Cook Inlet waters are dynamic, with extreme tidal changes and strong currents. Semidiurnal tides can be 8-10 meters and expose vast mudflats during the low tide (Ezer et al. 2008). Numerous glaciers and rivers feed into Cook Inlet and the basin receives a substantial amount of sediment that gets moved around to different channels (Sharma and Burell 1970). High turbidity makes it difficult to visually locate marine mammals unless they breach the surface, and even then it can be difficult to identify these small cetaceans. Belugas have survived in the silty and icy waters of Cook Inlet because they are considered to have sophisticated hearing and echolocation abilities (e.g. Ridgway et al., 2001; Turl et al., 1987).

The CIB population has experienced a significant range contraction to the Upper Cook Inlet (UCI, defined as north of the forelands in mid inlet), and Rugh et al. (2010) has hypothesized that persistent human impacts, limited prey availability, and predator presence may be explanations for this diminution. Despite declining numbers, CIB show a strong preference for the UCI, possibly influenced by historical behavioral patterns and the trade-off between resource availability and predation risk (Rugh et al. 2010). This range contraction, combined with the lack of emigration or immigration, due to the geography of Alaska and isolation of the Cook Inlet basin, raises concerns about their long-term survival and vulnerability to extinction. There has been many focused efforts to research UCI beluga habitat, specifically during summer time when the population is concentrated in the UCI (e.g., Ashford et al. 2013, Goetz et al. 2012, 2023), but far fewer studies have documented CIB in Lower Cook Inlet (LCI, defined as south of the forelands in mid inlet) habitat, specifically the Kenai and Kasilof rivers, where traditional knowledge indicates historic extensive CIB use of these rivers (Huntington 2002, Dutton et al. 2012).

Dutton et al. (2012) conducted oral history interviews with 214 informants to provide input on knowledge of historical abundance and distribution of CIB in the Kenai Peninsula Borough and prepared a compilation of sightings in the Kenai and Kasilof rivers from the 1940s through 2012. Participants noted that, until the 1980s, seeing belugas in these rivers often coincided with the migration of anadromous fish, including seeing up to 200 belugas foraging near the river mouths (Dutton et al. 2012). Participants also noted a decline in CIB sightings during the 1980s and 1990s, but a few noted that in the early 2000s, there were still small groups observed in the lower Kenai River (Dutton et al. 2012). Huntington (2002) found that traditional knowledge holders have historic accounts of belugas frequenting the Kenai River in the 1930s, between April and November, in groups as large as 50 individuals, and as far as 5 miles from the river mouth. In recent years, it is clear that the presence of beluga in the Kenai River has diminished, with far fewer sightings than historically documented (Ovitz 2019, AKBMP 2023). However, despite a reduction in use, this habitat continues to support critical functions for the survival of the CIB population. McGuire et al. (2020) conducted an analysis of the distribution and habitat use of CIB using photo-identification data between 2005 and 2017, and found that during surveys conducted at the Kenai River, 80% of CIB groups demonstrated foraging behavior and, in addition, calf-rearing behavior was also documented.

The Kenai River is Alaska's most heavily fished river, with commercial, recreational, personal-use, and sport fishing taking place there in the spring and summer (ADFG 2015). The Kasilof River is a smaller but still heavily fished river, just 13 nautical miles south of the Kenai River. There have been opportunistic sightings of belugas in the Kasilof but far fewer dedicated monitoring efforts there, other than efforts by the Alaska Beluga Monitoring Program (AKBMP) (AKBMP 2023). The AKBMP is a community science NOAA Fisheries-led monitoring program that facilitates collaboration between organizations, communities, and individuals to collect standardized shore-based observational data on Cook Inlet beluga whales. Four species of Pacific salmon spawn in the Kenai and Kasilof rivers: sockeye, king, coho, and pink salmon; and the ADFG has sonar sites at both the Kenai and Kasilof rivers to monitor the passage of sockeye salmon throughout peak summer months (ADFG 2015, 2023c). In a diet analysis, Quakenbush et al. (2015) found that salmon represented 67% of the 12 fish species found in CIB stomachs, and yet, CIB are no longer present up the Kenai River during peak salmon runs; they begin to return to the river during the tail end of the sockeye and chinook late-runs, after most of the fishing boats are out of the water (ADFG 2023c, AKBMP 2023). Continuous monitoring of CIB presence in these rivers can help inform the timing of habitat usage and foraging efforts, especially compared to prey availability and anthropogenic activity in the rivers.

Methods to track the presence of CIB can include visual observations (by plane, boat, and on shore), by using passive acoustic monitoring (PAM), by tagging, and by high resolution satellite imagery analysis (NMFS 2016, Castellote et al. 2020, Shelden et al. 2015, Khan et al. 2023). Passive acoustic monitoring (PAM) is a non-invasive way to remotely monitor anthropogenic underwater acoustic sources and marine organisms (Zimmer et al, 2011). Because belugas use a wide variety of vocalizations for social interactions (Brewer et al. 2023) and use echolocation to hunt and navigate, they are a prime candidate for PAM. A noisy environment, like the Kenai River during the height of the fishing season, has the potential to displace CIB due to the physical and acoustic disturbance of all the anthropogenic activity (Small et al. 2017), which could affect the abilities of CIB to communicate with conspecifics, navigate, and locate prey (Vergara et al. 2021). Documenting belugas' acoustic presence is critical for identifying seasonal patterns and preferred foraging locations, especially considering how climate change might be impacting important prey species, like salmon (Castellote et al. 2021, Meyer et al. 2023). PAM can be applied to understanding belugas' acoustic behavior, which is essential for proper interpretation of habitat use, such as determining their preferred foraging locations and seasonal occurrence. PAM can also be applied in assessing the occurrence and levels of anthropogenic noise, and if the sources of this acoustic disturbance are deterring CIB presence from specific areas of their critical habitat.

This study utilizes PAM to determine CIB riverine habitat use patterns in the Kenai and Kasilof rivers during the ice-free season, as well as the offshore waters adjacent to these river mouths in winter. These are the two biggest rivers that feed into the east side of lower Cook Inlet (LCI), and are important foraging habitat for CIB (NMFS 2008). We also used PAM to catalog anthropogenic noise occurrence and its intensity in the Kenai and Kasilof during the ice-free season and discuss how that may have impacted use of the rivers by CIB. Our research aims to identify inter-annual variation of CIB acoustic presence in the Kenai and Kasilof rivers between two years, 2021 and 2022. This study is a companion study to Castellote et al. 2023 in which Cook Inlet beluga whales were monitored using acoustics in pristine rivers and bays with presumed low disturbance on the relatively undeveloped west coast of LCI.

2. Methods

2.1 Study area

The sampled area encompassed about 7.5 km from its mouth to the furthest upstream station for the Kenai River and just over 2 km for the Kasilof River. For Kenai River, this segment hosts the majority of the commercial fishing activity, processing plants, docks where fish are unloaded, buoys where tender vessels are moored, as well as the only boat launch ramp maintained by the city of Kenai. The monitored segment of Kasilof River also hosts several docks and processing plants, but in general, due to it being a smaller size, this river is not as busy. There is no designated boat ramp leading to the lower part of the river, so in order to access the river, people have to use the boat launch at the Sterling Highway, approximately 13 km upriver, or launch from either the north or south shorelines.

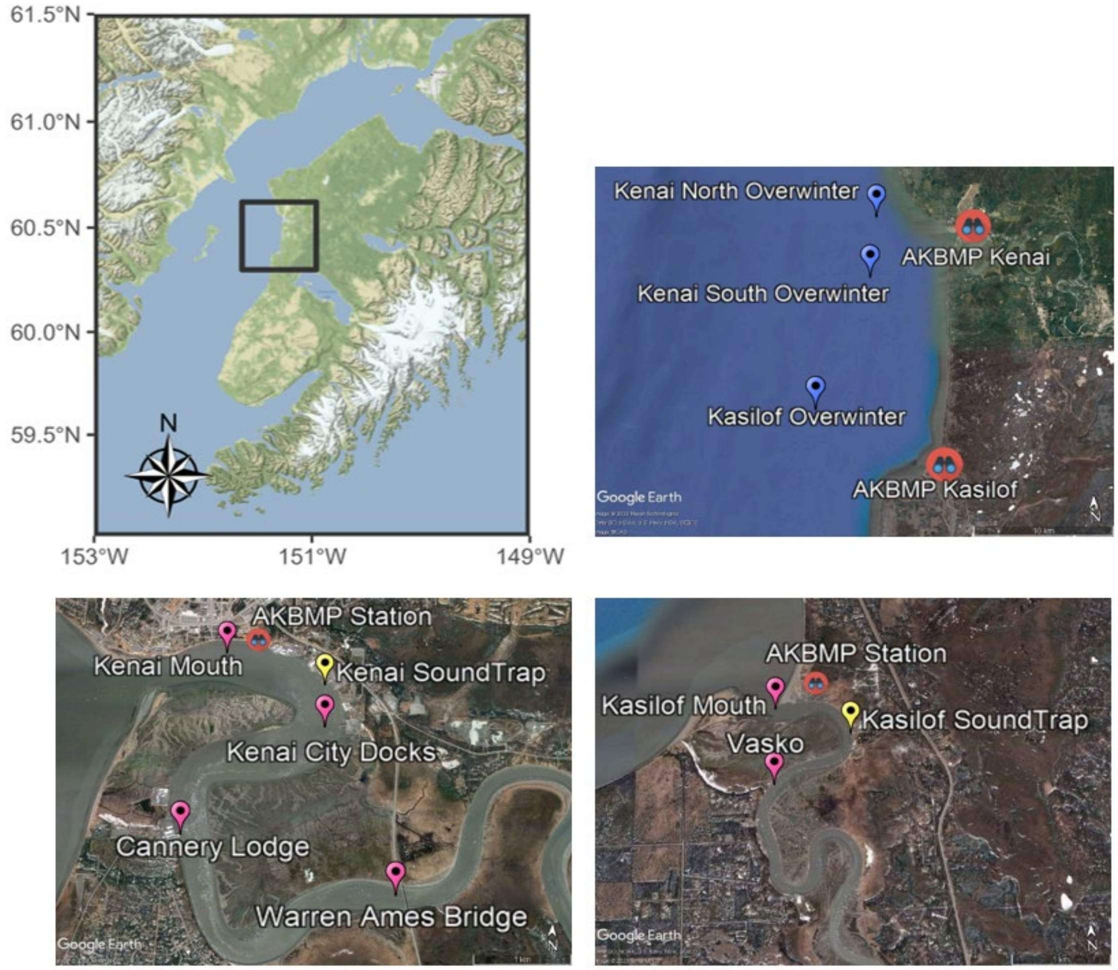

Figure 1: Top left - Map of Cook Inlet, Alaska, depicting the study area. Top right: overwinter deployment locations of moored PAM devices. Bottom left: Kenai River passive acoustic monitoring (PAM) device deployment locations during the ice-free season (May - November). Bottom right: Kasilof PAM deployment locations during the ice-free season. Pink and blue location markers indicate echolocation loggers (F-PODs) and yellow location markers indicate sound recorders (SoundTraps). Alaska Beluga Monitoring Partnership (AKBMP) visual survey observation stations are also included in each study site map.

2.2 In river instrument deployment

During the open water seasons in 2021 and 2022 (approximately May - November), we deployed two different types of passive acoustic monitoring devices in the Kenai and Kasilof rivers: 1) Echolocation loggers (F-POD, Chelonia Ltd, UK), used to continuously scan frequencies between 20 kHz to 160 kHz to detect CIB echolocation signals, and 2) autonomous sound recorders (SoundTrap ST-500 STD and ST-600 STD, Ocean Instruments, New Zealand), to record background noise in the areas where beluga presence was monitored. The SoundTraps were set to record continuously at a sample rate of 48 kHz, generating concatenated five-minute files. The locations of these instruments were selected to collect a representative sample of the anthropogenic noise occurring in the lower section of the river, near the mouth, where most human activity is concentrated for both rivers.

Initial deployment of the instruments was heavily dependent on the absence of sea ice in the river, as well as the availability of safe deployment locations within the river (Table 1). Ideally, each detector would have been attached to a dock piling at a fixed depth only accessible during a strong negative low tide, to be serviced a few times per season to retrieve data and ensure that the device was still properly secured, not buried by sediment, or damaged by boats. Unfortunately, there are not very many structures that fit these criteria within the first three river miles and the tide fluctuation in that region is so extreme, that often even the deeper sections of those structures are exposed during average low tides or have the potential to be directly and physically impacted by boat activity. The differences between deployment and recovery times of the different devices (Table 2) are due to the accessibility and availability of different structures in the river.

2.2.1 2021: Kenai

In 2021, we deployed four PAM devices in the Kenai River (Figure 1, Table 1). Three F-PODs were deployed at location sites labeled 'Kenai Mouth' (KNM), 'Kenai City Docks' (KCD), and 'Cannery Lodge' (CL). These instruments log any odontocete echolocation activity, and for CIB it has been estimated that detection range is roughly 900 m (Castellote et al. 2016). The dates of deployments are listed in Table 2. Between June and mid-August, the KNM F-POD was attached to a commercial fishing mooring buoy that was deployed and utilized by one of the seafood processing companies on the Kenai River; the anchors on these buoys are very heavy and are safe against the extreme tides (Appendix A, Figure 1a). It was secured ~ 3 feet under the buoy, on the chain leading to the anchor, with an aluminum bracket that was specially welded to encase the F-POD. Care was taken to avoid rattling noise by the chain on the bracket. The KCD F-POD was secured on a smaller and lighter 15-inch buoy. With help from the City of Kenai, we developed a deployment system that will be referred to as the 'standard deployment' for the remainder of this report (Appendix A, Figures 2a, 3a). The buoy had two attachments. One attachment was approximately five feet of ⅜ inch galvanized steel chain which hung vertically from the buoy, and the other was an approximately 30-foot polypropylene leaded mainline, tied off to 10 feet of ⅜ inch galvanized steel chain, which was attached to a 16lb Danforth anchor. Hose clamps were used to secure the F-POD to the tail end of the vertically deployed chain. The KCD F-POD remained in this deployment during the entire duration of the 2021 field season. The KNM F-POD was changed to the standard deployment after the commercial fishing buoys were removed from the river in mid-August and remained in the standard deployment through the remainder of the sampling period. The CL F-POD was attached off the side of a floating dock at the Cannery Lodge, using a specially welded aluminum bracket that was bolted to the dock, permanently maintaining the F-POD hydrophone at three feet below the water's surface (Appendix A, Figure 4a). This F-POD was removed at the end of September when the floating dock was removed from the river. All of the instruments in the Kenai and Kasilof rivers were typically serviced every two to four weeks to ensure the devices were still in the correct locations, functioning properly, and free from debris, however, some of the devices were serviced less regularly due to the location and nature of the deployment.

The Kenai SoundTrap (KNS, sound recorder) was deployed on the side of one of the commercial seafood company's floating docks on June 7th. A special aluminum bracket was used to encase it and was bolted to the edge of the dock, permanently maintaining the SoundTrap at two feet below the water's surface (Appendix A, Figure 5a). Unfortunately, when the device was being serviced on August 3rd, it was clear that the instrument had encountered some boat collisions, as the device had leaked and was destroyed (Appendix A, Figure 6a). We were able to recover some data from the memory card but the device stopped working nearly three weeks into an eight week deployment. This instrument was replaced and attached to a dock piling at a different commercial seafood company dock, approximately 250m upriver from the initial deployment, using hose clamps to secure it to the structure (Appendix A, Figure 7a). This proved to be a better location than the floating dock, as it was protected from watercraft activity. Since this new deployment was on a dock piling, the sound recorder was only accessible during certain negative low tides.

2.2.2 2021: Kasilof

We deployed three PAM devices in the Kasilof river in 2021 (Figure 1, Table 1) and the dates of deployment are listed in Table 2. Two F-PODs (echolocation loggers) were deployed at sites labeled 'Kasilof Mouth' (KSM) and 'Vasko' (VD), and one SoundTrap (sound recorder) was deployed at a location site labeled 'Kasilof SoundTrap' (KSS).

The KSM F-POD was deployed on a commercial fishing buoy from June to August 28, at which point it was changed over to the standard deployment until it was removed from the river on September 30. The VD F-POD was hose-clamped to one of the dock pilings of a privately owned dock during a negative low tide (see Figure 1 for locations, Appendix A, Figure 8a). The Kasilof SoundTrap was deployed on one of the commercial seafood company's docks, secured with a special welded bracket (Appendix A, Figure 9a). Although deploying on a dock piling is ideal, the base of that dock, unfortunately, was frequently exposed during low tides, meaning this sound recorder was off periodically. No other locations could be identified to deploy this particular device that year.

Table 1: Deployment locations and programming settings of each passive acoustic monitoring station in the Kenai and Kasilof rivers in 2021 and 2022, and changes in station location.

Site Name	Kenai SoundTrap (KNS)	Kenai Mouth (KNM)	Kenai City Docks (KCD)	Cannery Lodge (CL)	Warren Ames Bridge (WAB)	Kasilof SoundTrap (KSS)	Kasilof Mouth (KSM)	Vasko (VD)
Type of PAM	SoundTrap	F-POD	F-POD	F-POD	F-POD	SoundTrap	F-POD	F-POD
Location A	60.54844°, -151.22639°	60.55156°, -151.24712°	60.54362°, -151.22578°	60.53202°, -151.25258°	60.52681°, -151.21086°	60.38299°, -151.28649°	60.38505°, -151.3009°	60.37780°, -151.30194°
Location B	60.54986°, -151.22923°	60.54946°, -151.25693°	N/A	60.53499°, -151.25386°	N/A	60.38178°, -151.28681°	60.38599°, -151.29074°	60.37869°, -151.30038°
2021 Deployment Setup	Floating dock (A) to dock piling (B)	Commercial fishing buoy (A) to standard deployment (A)	Standard deployment	Floating dock (A)	N/A	Dock piling (A)	Commercial fishing buoy (A) to standard deployment (B)	Dock piling (A)
2022 Deployment	Dock piling (B)	Standard deployment (B)	Standard deployment	Standard deployment (B)	Standard deployment	Dock piling (B)	Commercial fishing buoy (A) to standard deployment (B)	Commercial fishing buoy (B) to standard deployment (B)
Date of Change	8/10/2021	5/1/2022	N/A	5/2/2022	N/A	7/12/22	8/28/2021, 8/21/2022	6/14/2022
Distance between A and B	~250m upriver	~600m downriver	N/A	~400m upriver	N/A	~130m upriver	~600m upriver	~80m downriver

Table 2: Summary of deployment dates and success rate at each of the passive acoustic monitoring sites in the Kenai and Kasilof rivers during the 2021 and 2022 ice-free seasons. BPD = beluga positive day, BPD = beluga positive minute.

PAM Location	**Kenai Sound Trap (KNS)**		**Kenai Mouth (KNM)**		**Kenai City Docks (KCD)**		**Cannery Lodge (CL)**		**Warren Ames Bridge (WAB)**	**Kasilof SoundTrap (KSS)**		**Kasilof Mouth (KSM)**		**Vasko (VD)**	
Year	2021	2022	2021	2022	2021	2022	2021	2022	2022	2021	2022	2021	2022	2021	2022
Date Deployed	Jun 7	May 3	Jun 21	May 2	Jun 15	May 2	Jun 18	May 2	Aug 20	May 24	Jul 12	Jun 18	Jun 17	Jun 23	Jun 15
Day Removed	Nov 7	Oct 24	Nov 7	Oct 21	Nov 8	Oct 21	Sep 28	Oct 23	Oct 23	Sep 24	Oct 24	Sep 30	Oct 23	Sep 19	Oct 21
Data Gaps	6/26 - 8/11, 9/8, 9/19 - 9/21	5/17 - 5/19, 6/17 - 9/8	7/18 - 7/25, 8/18 - 8/30	9/8 - 10/21	0	5/2 - 5/20, 7/13 - 8/20, 10/7 - 10/21	0	7/24 - 8/20	0	7/20 - 8/6	8/11 - 9/7	8/28 - 8/31	8/18 - 9/16	6/23 - 7/27	8/18 - 9/12
Total Days Running	106	89	118	112	146	101	102	151	65	106	75	98	85	54	104
BPD	N/A	N/A	46	0	47	21	10	28	12	N/A	N/A	0	0	0	0
BPM	N/A	N/A	2831	0	3025	1647	247	1017	185	N/A	N/A	0	0	0	0

2.2.3 2022: Kenai

In 2022, the KNM and CL F-PODs were transitioned to the standard deployment setup (Appendix A, Figure 3a). The KNM F-POD started on a 16 lb Danforth anchor but after it was dragged into the ocean during a very high tide, it was upgraded to a 40 lb Danforth anchor and we moved the location closer to the south bank of the river and slightly upstream, ~600 m away from the 2021 location. Locations and dates of the changes to all PAM devices are listed in Table 1. We decided not to deploy on the Cannery Lodge floating dock in 2022 because of the truncated deployment period. Instead, we put it on a standard deployment system, ~400m from the 2021 location. The KCD F-POD was deployed in the same location as 2021 and on August 20th, using hose clamps, a 10 lb weight was added to the F-POD chain to maintain the instrument in its optimal vertical position, even when exposed to strong currents. In addition, a new sampling station with a fourth F-POD was stationed slightly downstream from the Warren Ames Memorial Bridge (WAB), using the standard deployment setup; this station is about four nautical miles (7.5 kilometers) upriver from where KNM was deployed (Figure 1). A permit was issued by the Alaska Department of Natural Resources for deployment in the Kenai River Special Management Area (KRSMA) since this deployment location falls under that management area. This F-POD was deployed on August 20, 2022 and all of the F-PODs in the Kenai were removed from the river between October 21-23, 2022 (Table 1). The KNS SoundTrap was re-deployed on the same dock as it was during the latter part of the 2021 field season.

2.2.4 2022: Kasilof

In 2022, the KSM F-POD was initially deployed on a commercial fishing buoy on June 18th and on August 20th, at the end of the commercial fishing season, when that buoy was removed from the Kasilof River, we re-deployed it at the same location using the standard deployment method. The currents in the Kasilof River seemed to move this particular F-POD around a lot, but never more than ~500m. On August 24th, we added a second 14 lb Danforth anchor to the deployment system and a 10 lb weight was added to this device, as we did with the KCD F-POD.

During this field season, instead of attaching the VD F-POD to the Vasko Dock dock piling, we attached it to a commercial fishing buoy ~80m downriver from the dock piling used in 2021. On August 18th, we transferred this F-POD to the standard deployment method at the same location. This F-POD station was also exposed to strong river currents, so on September 11th, we added a second 14 lb Danforth anchor, as well as 15 feet of ⅜ inch galvanized steel proof coil chain at the bottom of the system, to make it more resistant to the river current conditions.
The sound recorder designated for this location, the Kasilof SoundTrap (KSS), was not functioning properly at the beginning of the field season, so we upgraded to a SoundTrap ST-600 model which has the same specifications as the previously used ST-500 and therefore equivalent, though it was not deployed until July 12 (Table 2). This sampling station was moved to a different commercial seafood company dock, ~130m from the 2021 station (Table 2, Appendix A, Figure 10a). This location was chosen because the dock piling sits slightly lower in the river and thus the KSS would not be exposed to air as much as it was in the 2021 field season. Sound recording in the Kasilof River ended on October 24th.

2.3 Overwinter Instrument Deployment

During the overwinter period of 2021 to 2022, two low profile acoustic moorings were deployed in September 2021 near the mouth of the Kenai River, and one near the mouth of the Kasilof River and were recovered in May 2022 (Figure 1). These moorings contained an F-POD, a DSG-ST sound recorder (Loggerhead Instruments Ltd.), and an acoustical release (Edgetech PORT) to recover the mooring package after deployment. Moorings were designed to withstand the high currents, high concentration of vegetative debris in the water column, and high sedimentation rate of Cook Inlet (Castellote et al. 2016).

2.4 Visual Observation

2.4.1 Observations by the Alaska Beluga Monitoring Program:

The Alaska Beluga Monitoring Program (AKBMP, https://akbmp.org/) is a community science NOAA Fisheries-led monitoring program that facilitates collaboration between organizations, communities, and individuals to collect standardized shore-based observational data on Cook Inlet beluga whales. From mid-March through late-May and mid-August through late-November, trained volunteers conduct visual surveys for beluga whales at the Kenai and Kasilof rivers. Each session is scheduled for two hours; in the Kenai, sessions typically start an hour after low tide, and in the Kasilof, volunteers have the option to monitor during either the low or high tides. Environmental conditions are recorded at the start of each session and human activity, such as watercraft presence, aircraft overhead, and other noisy activities that might affect beluga behavior. Monitors also made note of other marine mammal species they saw during the surveys. If belugas were observed during the monitoring session, behaviors were recorded, including suspected feeding, traveling, milling, and predator avoidance, to name a few. The visual surveys at the Kenai typically took place at the Spur View Picnic Ground (Figure 1), a bluff that overlooks the river entrance and upriver, towards the second bend in the river. It has a good vantage point and it was possible to see both the mouth of the Kenai River and over to the second bend in the river, between the Kenai City Docks and the Cannery Lodge.

2.4.2 Observations for anthropogenic disturbance:

Visual observations were collected in 2021 and 2022 on a weekly basis in order to document anthropogenic activity in the Kenai City Docks section of the river throughout the PAM deployment period; these will be called ‘boat surveys’ from here on (Appendix A, Figure 11a). Survey times were randomly chosen with no consideration for tide period. Observational surveys lasted 2 hours, and aimed at documenting the number and types of boats within sight in the river. Boat categories used included commercial fishing boats, transporter skiffs, tenders associated with seafood companies, and personal use vessels which primarily included participants in the dipnet fishery (Appendix A, Figures 12a, 13a, 14a, 15a). Every ten minutes during the survey, the number of boats was counted, and any additional anthropogenic activity was noted. During the commercial fishing season, commercial boats often leave the river or re-enter the river, depending on the status of the fishery at that time. Documenting changes every ten minutes allows for the variation in boats during those two hours. At the end of the survey, the number of boats per watercraft category were averaged to get a boat value for that survey.

2.5 Data Analysis

2.5.1 Beluga acoustic presence

F-POD data was processed with the dedicated software F-POD.exe (v 4.5.2023), following Castellote et al. (2016), where all algorithm-based (KERNO-F classifier v1.0) echolocation detections were manually validated to exclude false detections or correct misclassified detections. The total number of beluga positive minutes (BPM, any minute with at least one echolocation detection) per day was tallied and heat maps and line diagrams showing how BPM/day changed throughout the deployment period between F-POD locations were generated. Beluga positive hours (BPH) and beluga positive days (BPD) were also tallied and used as comparisons. A BPH and a BPD was an hour or day, respectively, in which there was at least one BPM. The overall beluga presence per monitored station was computed as beluga detection rate. Thai metric is calculated as the total number of beluga positive minutes divided by the total number of minutes sampled.

2.5.2 Anthropogenic noise intensity

Data from the sound recorders were visually inspected using Raven 1.6.5 (K. Lisa Yang Center for Conservation Bioacoustics, Cornell University), where a spectrogram was generated with a 30-minute duration, and 96000 Hz in bandwidth. Each spectrogram window was visually assigned a categorical value from a noise scale, ranging from low noise (1), medium noise (2), and loud noise (3) (Figure 2). The first thirty minutes of every hour were visually assessed for noise in a spectrogram and classed in one of the three categories. These noise classes were then compared to beluga presence and absence to determine if there is a correlation between anthropogenic noise and beluga use of the river.

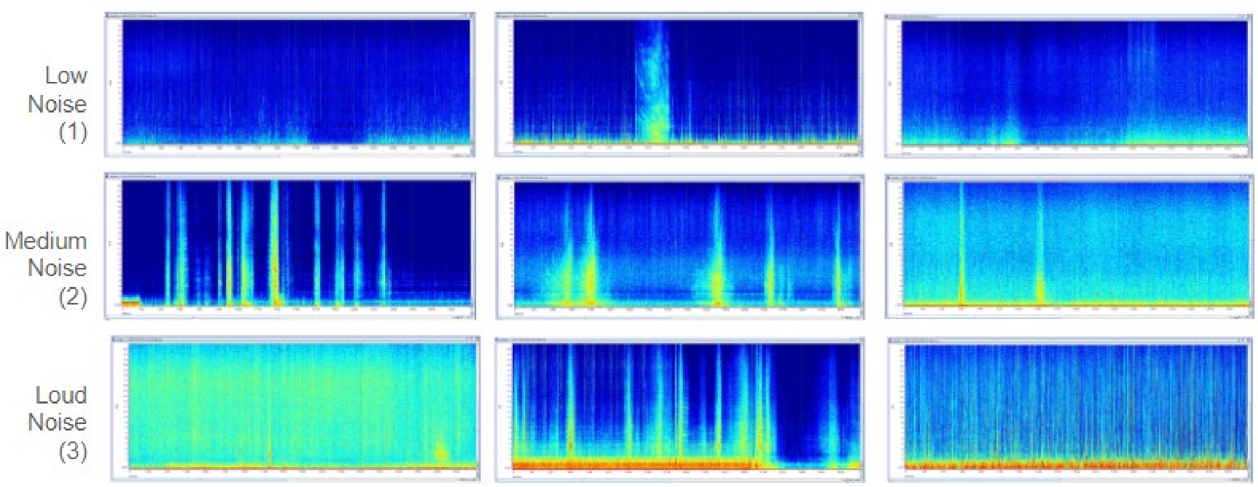

Figure 2: Three spectrogram examples (30 minutes long and 96 kHz sample rate, 512 FFT, Hanning window, 75% overlap) for low noise condition (upper), medium noise condition (middle), and high noise condition (lower) in Kenai River, AK, representing the three categories of anthropogenic noise intensity in the river during the sampled periods.

2.5.3 Visual observations vs PAM comparison

To assess the association between acoustic and visual observations for beluga presence, we utilized a Chi-squared test of independence, using the 'chisq.test' function in R statistical software 2023.09.1 (R Core Team 2021). Our data consisted of binary variables representing the presence (1) or absence (0) of belugas per day as detected by each observation method. We only used days that had data from both methods. Upon establishing the significance of the association with the Chi-squared test, we further quantified the strength of this association using the Phi coefficient, a measure suitable for binary data. The Phi coefficient is calculated as the square root of the Chi-squared statistic divided by the sample size, providing a value ranging from -1 to 1, where values close to +/-1 indicate a strong association, and values near 0 suggest a weak or no association.

2.5.4 Binomial Generalized Linear Model

The relationship between beluga acoustic presence and absence and environmental covariates was evaluated using a binomial generalized linear model specified with a logit link (R Core Team 2022).

For the analysis of beluga acoustic presence/absence, time was discretized into 30-minute observational intervals each hour between May and November and treated as independent observations, during which presence/absence was determined.

Tide level: Hourly tidal data from water gauges in Nikiski, AK, about 14 miles north of the Kenai River, were used to assess the influence on tides on beluga presence (NOAA Tides & Currents 2022).

Seasonality: The day of year was also included in the analysis to assess seasonality of CIB presence in the rivers.

Location within the river: Location of the F-POD monitoring stations

Noise intensity: Noise level category as described above.

The logistic regression model was specified as follows:

Logit (CIB Presence/Absence) ~ factor (Noise Scale Category) + Average Tide + Day of Year + factory (Location of F-POD in the River)

To assess the significance of the Noise Scale variable in our logistic regression model, we performed an Analysis of Deviance to compare nested models with and without the Noise Scale variable included, to determine whether this additional predictor significantly improves the model fit. Two logistic regression models were compared:

Model 1 included the location of the F-POD (2021: Kenai Mouth, Kenai City Docks, and Cannery Lodge; 2022: Kenai City Docks, Cannery Lodge, Warren Ames Memorial Bridge), the day of year, and the average tide as predictors.

Model 2 extended Model 1 by including the Noise Scale variable. A chi-squared test was used to evaluate the significance in deviance between the two models.

We also performed an Analysis of Variance (ANOVA) test to determine if there were statistically significant differences in the day of year across the different Noise Scale levels, using the 'anova' function. A Tukey's HSD test was used for post-hoc analysis to compare each pair of scale levels.

2.6 Overwinter moorings

F-POD data from the overwintering moorings was processed following the same methodology described for the in-river F-POD data.

3. Results

3.1 Gaps in sampled periods

During both field seasons, we experienced a high occurrence of equipment failure, both field and office equipment. Reasons for data loss include internal hardware issues with F-PODs, boats colliding with and impacting the PAM devices, a hard drive failure, mooring systems failing to maintain position due to exposure to extreme currents, or by getting entangled with debris and being dragged down river. One notable data gap occurred when the 2022 KNM F-POD mooring failed to stay in place and drifted out of the mouth into the inlet around August 20th, about a week before belugas were first detected at the KCD F-POD (Table 2). This mooring was eventually found and recovered at the conclusion of the field season. We periodically received reports from one of the AKBMP volunteers of a partially submerged buoy that was only visible during certain low tides several thousand meters outside the mouth of the river. However, we were unable to track down a boat operator who was comfortable navigating the extremely shallow waters of the mouth of the Kenai River until the very end of the field season, data was recovered but there were no beluga detections logged on the device.

There are also two significant data gaps with the KNS SoundTrap. There are no data between June 26th, 2021 and August 11th, 2021 due to boats colliding with the device and damaging it as it was attached to the side of a floating dock. In 2022, there are no data between June 17th and September 8th, due to equipment and hard drive failure causing data loss. As such, there are no data from SoundTraps in July during either year (Table 2).

3.2 Kenai beluga acoustic detections

During the 2021 PAM deployment, we logged 472 days of data between three F-PODs and one SoundTrap in the Kenai River and 258 days of data between two F-PODs and one SoundTrap in the Kasilof River, for a total of 730 days between the two sites. In 2022, we logged 518 days of data between four F-PODs and one SoundTrap in the Kenai River and 264 days of data between two F-PODs and one SoundTrap in the Kasilof River, for a total of 782 days between the two sites (Table 2). In 2021 there were 101.77 BPH (4.24 BPD) and in 2022 there were 47.48 BPH (1.97 BPD, Figure 3).

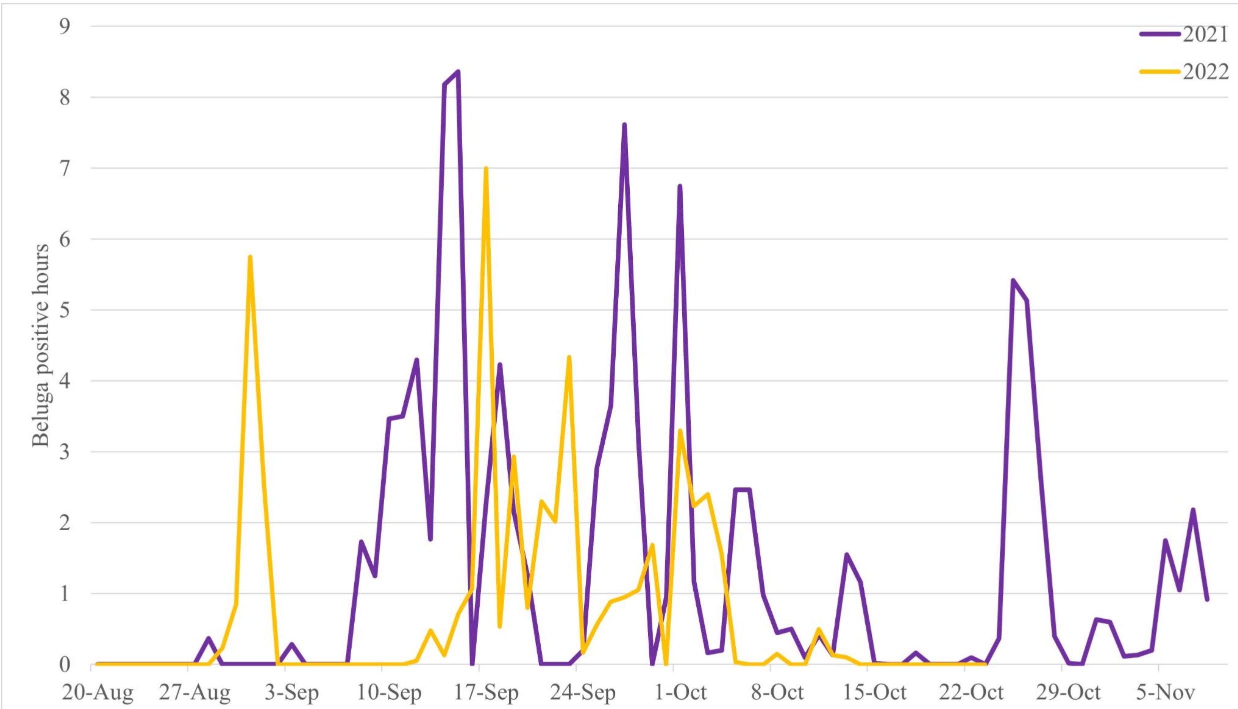

Figure 3: Beluga positive hours per day throughout the ice-free PAM sampled period in 2021 and 2022.

There were differences in detection rates between F-PODs in each river, and between the two years of the study (Figure 4). Out of all of the F-PODs, the 2021 Kenai Mouth F-POD had the highest detection rate at 1.67%. The 2022 Kenai Mouth F-POD had the lowest detection rate at 0% because, though it was deployed in May and logged data until mid-August, the mooring system failed and we lost the device before CIB returned to the river in the fall.

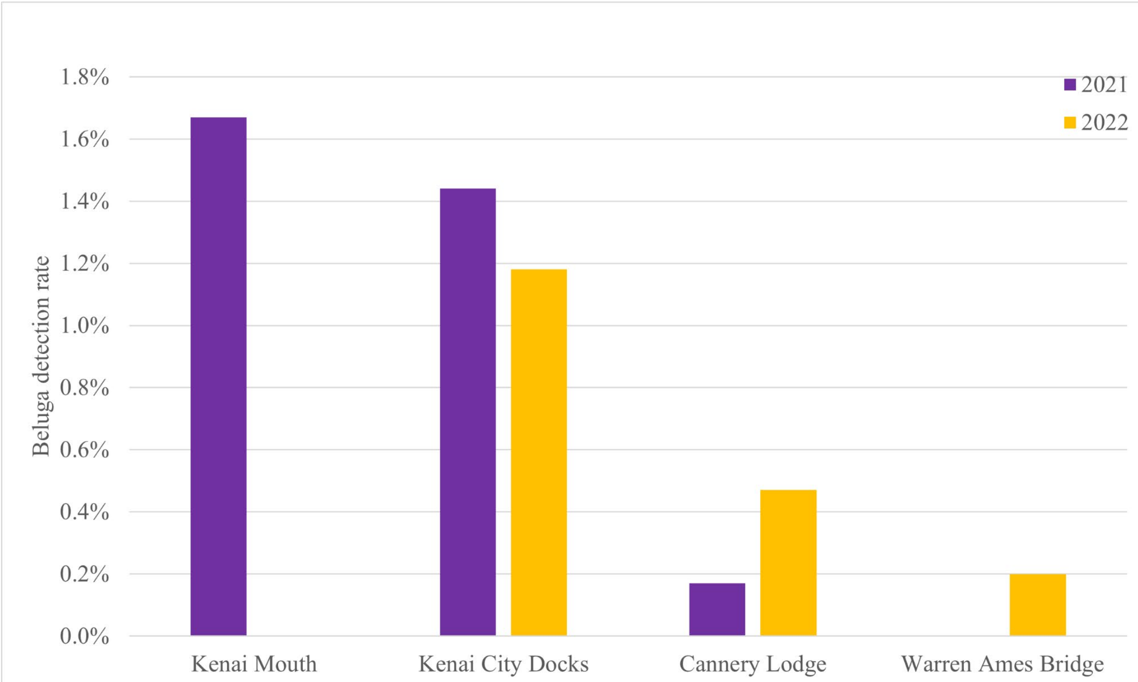

Figure 4: Beluga detection rate between each F-POD in the Kenai River during the 2021 and 2022 ice-free PAM deployment.

In 2021, belugas were first detected in the Kenai River at the KCD F-POD on August 28th and visually by AKBMP monitors on September 3 (Figures 5, 6). The day with the highest number of daily detections from all three devices was on September 15th, with 502 BPM registered. Belugas were detected for 1 out of 31 days in August, 19 out of 30 days in September, 20 out of 31 days in October, and 6 out of 8 days of deployment in November. Between August 31st and September 27th, all three F-PODs were successfully running. Of the 16 BPD within that time frame, belugas were detected at all three F-PODs for six days. During the other 10 days, detections only occurred at the KNM F-POD and the KCD F-POD, but not at the further upriver CL F-POD.

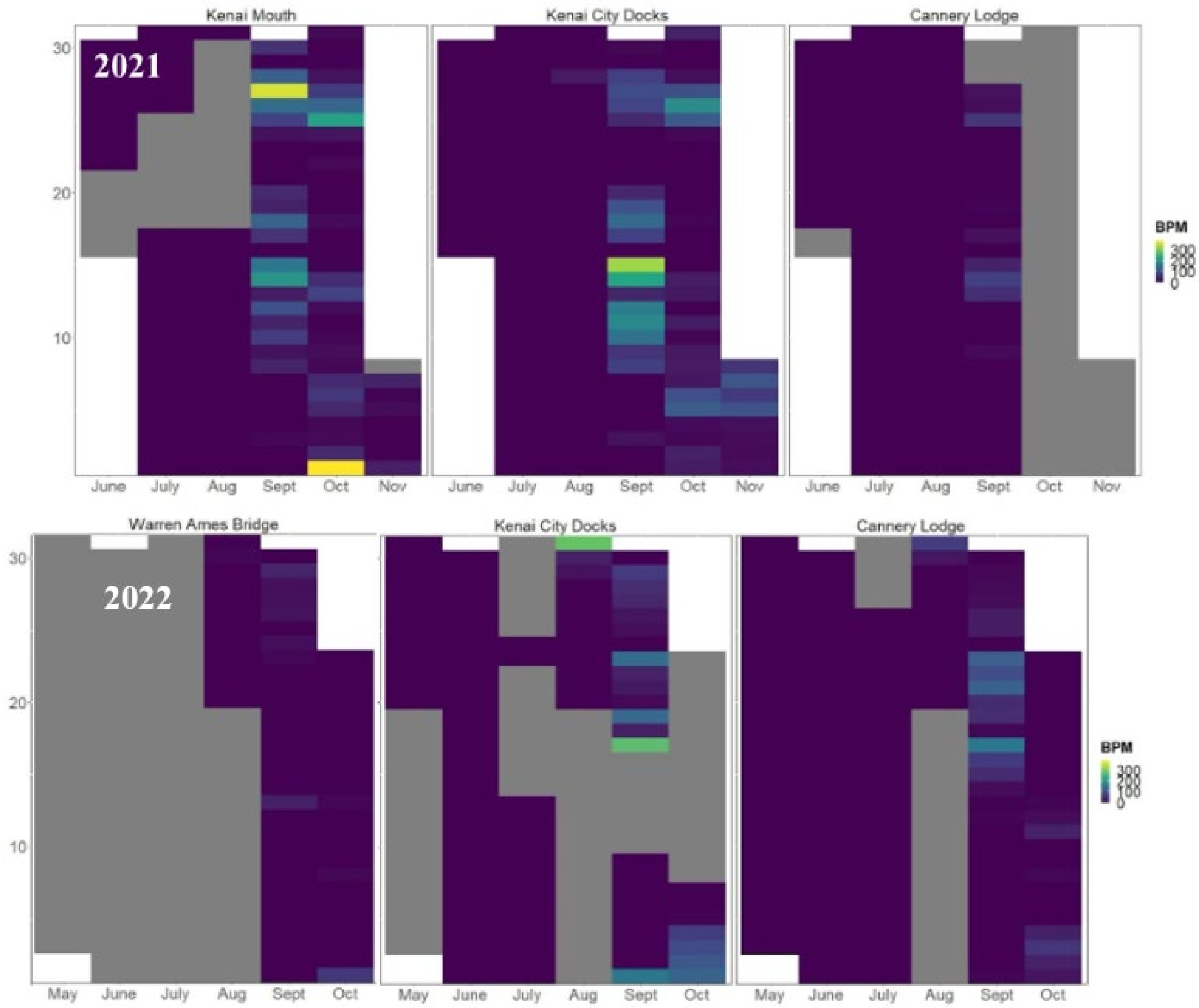

Figure 5: Beluga positive minutes (BPM) per day by month in 2021 and 2022 at the F-PODs in the Kenai River. Gray regions represent off effort periods. Please note that the months listed on the y axis are not the same between the two years.

In 2022, the F-PODs were deployed in the Kenai River over a month earlier than in 2021, shortly after the river was free of ice. The AKBMP documented sightings of belugas in April and May and we were hoping to acoustically document spring river usage (AKBMP 2023). However, the last CIB visual observation was on April 27, just 5 days before we deployed the PAM devices. Belugas were first detected in the Kenai River at the KCD F-POD on August 29th and visually by AKBMP monitors on the same day (Figure 7). The day with the highest number of detections from all the devices was September 17th, with 420 BPM registered (2.53 BPH). The highest number of detections on one F-POD was on August 31st at the KCD, with 278 BPM, in just over 4.5 hours. Belugas were detected for 3 days in August, 19 days in September, and 9 days in October and were detected at all F-POD locations, except for KNM. Outside of the KNM F-POD, the WAB had the lowest beluga detection rate out of the 2022 F-PODs. Between August

20th and September 9th, and September 17th and October 7th, the KCD, CL, and WAB F-PODs were all successfully running. Out of those 41 days, there were 22 BPD, with belugas detected at all three locations for eight days, and only at the KCD and CL F-PODs for 11 days. Between the two years, the highest number of BPM logged was on October 1, 2021 at the KNM station, with 380 BPM, 6.34 DPH.

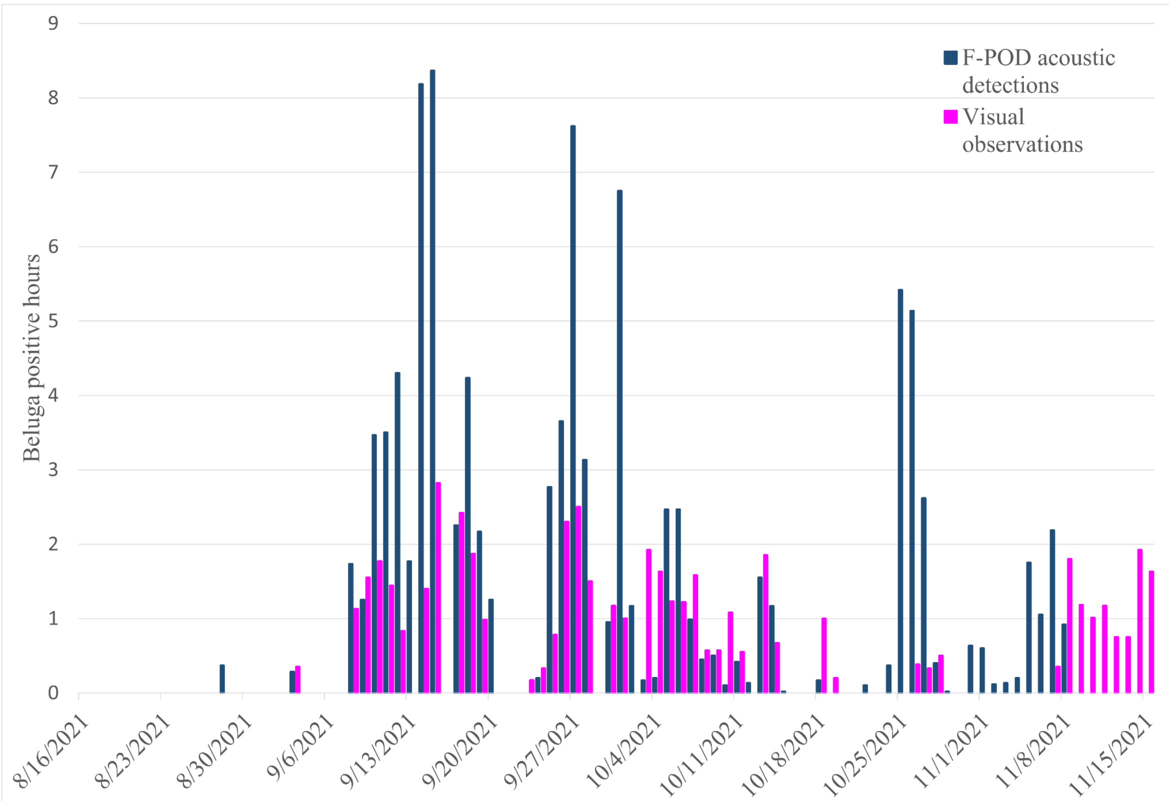

Figure 6: A comparison of beluga positive hours in Kenai River between the 2021 F-POD acoustic detections and AKBMP visual observations.

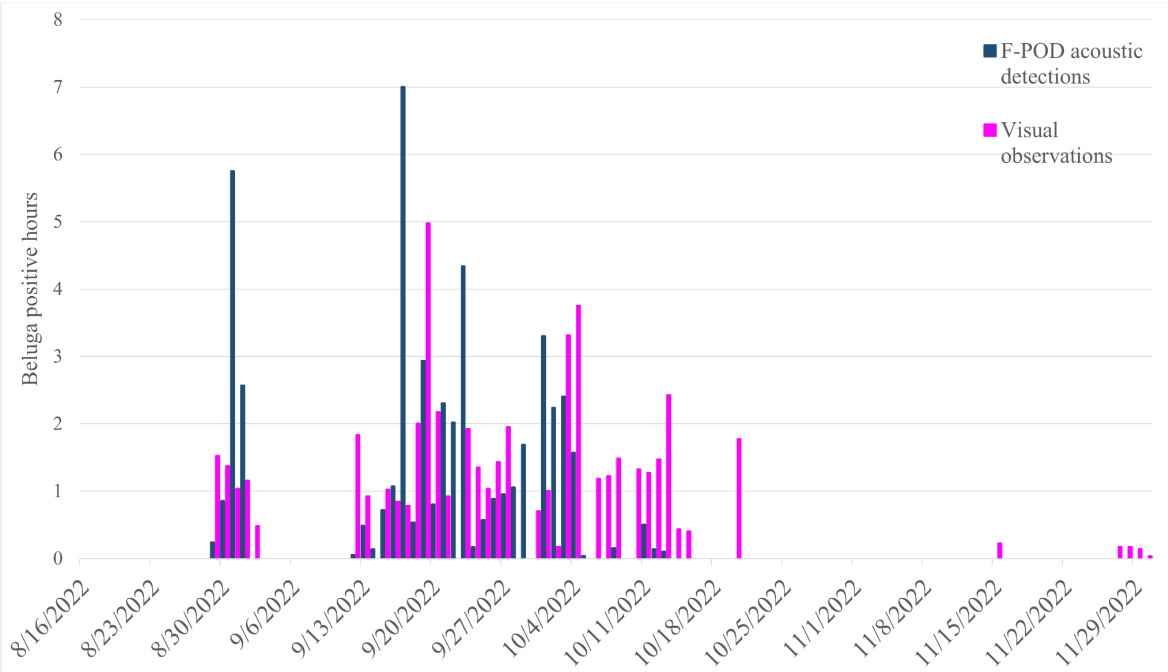

Figure 7: A comparison of beluga positive hours in Kenai River between the 2022 F-POD acoustic detections and AKBMP visual observations.

3.3 Kasilof beluga acoustic detections

There were no beluga acoustic detections in the Kasilof River during the ice-free season in 2021 or 2022.

3.4 Visual vs. acoustic observations

In 2021 and 2022, the AKBMP team conducted visual surveys in both the Kenai and the Kasilof in spring, from March through May, and in the fall, from mid-August to mid to late November (Table 3). 134 and 121 surveys were completed in the Kenai River in 2021 and 2022, respectively. 51 and 31 surveys were conducted in the Kasilof River in 2021 and 2022, respectively. In the Kenai River, belugas were sighted during 50% of all surveys conducted in both 2021 and 2022.

	Kenai				Kasilof			
Season and year	**Spring 2021**	**Fall 2021**	**Spring 2022**	**Fall 2022**	**Spring 2021**	**Fall 2021**	**Spring 2022**	**Fall 2022**
Survey period	Mar 15 - May 29	Aug 15 - Nov 15	Mar 16 - May 15	Aug 16 - Nov 29	Mar 28 - May 31	Aug 15 - Nov 8	Mar 18 - May 16	Aug 15 - Nov 14
Number of visual surveys	60	74	50	71	37	14	19	12
Surveys with CIB	26	41	26	35	0	0	3	0
Surveys without CIB	34	33	24	36	37	14	16	12
Beluga sighting rate	43.3%	55.4%	52.0%	49.3%	0.0%	0.0%	15.8%	0.0%

Table 3: A summary of the Alaska Beluga Monitoring Program 2021 and 2022 visual monitoring surveys in the Kenai and Kasilof Rivers.

In the 93 days between August 15, 2021 and November 15, 2021, the AKBMP team conducted 74 visual surveys at the Kenai River, surveying 79.6% of the 2021 fall monitoring season. In the 108 days between August 14, 2022 and November 29, 2022, the AKBMP team conducted 71 surveys at the Kenai River, surveying 65.7% of the 2022 fall monitoring season. The fall 2022 AKBMP visual survey season extended later than the fall 2021 season. Over half of surveys in fall 2021 and spring 2022 resulted in CIB visual detections (Table 3). There were no CIB observations in the Kasilof River in neither the 2021 monitoring season nor the fall 2022 season, but three out of 19 surveys documented CIB in the spring 2022 season.

Throughout the fall 2021 AKBMP visual monitoring season, a total of 52.15 hours of CIB visual BPH were recorded. In fall 2022, AKBMP documented 51.3 visual BPH. Both visual and acoustic efforts overlapped between August 15th, 2021 and November 8, 2021, although visual surveys continued for another week after the PAM devices were removed from the Kenai River (Figure 6). During the overlap time, visual surveys documented 43.74 BPH and acoustic surveys recorded 101.77 BPH, using data from all three F-PODs.

In fall 2022, AKBMP visual and acoustic efforts overlapped between August 14th and October 21st, although visual surveys continued through November 30th (Figure 7). During this overlap time, visual surveys documented 50.57 BPH and acoustic surveys recorded 47.48 BPH, using data from the KCD, CL, and WAB F-PODs.

The Chi-squared tests indicated a statistically significant association between acoustic and visual observational methods for detecting beluga presence in 2021 ($\chi^2 = 0.61$, $p < 0.05$) and in 2022 ($\chi^2 = 0.59$, $p < 0.05$). The calculated Phi coefficients for both years suggest a moderate positive association between the two methods. When belugas are detected (or not detected) by one method, they are likely to be detected (or not detected) by the other method, as well.

3.5 Visual observations for anthropogenic activity

During our boat surveys, we documented changes in the numbers of different types of boats utilizing the river throughout the PAM deployment period. In Kenai, we conducted 51 surveys in 2021 between May 4th and September 17th and 29 surveys in 2022 between May 5th and October 18th. Commercial fishing boats were documented in 49 surveys in 2021 (96%, Figure 8) and during 20 surveys in 2022 (69%, Figure 9). The number of personal use watercraft increased between July 13, 2021 and July 31, 2021. In 2022, we only conducted one survey during that time but the total number of boats on that day, July 23, was the highest number of boats documented during the 2022 season, at 176 vessels; 71 commercial fishing boats, seven transporter skiffs, one commercial fishing tender, and 97 personal use boats, used for the dipnetting fishery. July 23, 2021 hosted the highest number of boats recorded during both seasons, with 314 vessels, 103 commercial fishing vessels, six transporter skiffs, three commercial fishing tenders, and 200+ personal use boats. In 2021, belugas were observed during four boat surveys, on September 9th, 10th, 14th, and 17th (Figure 8). In 2022, belugas were observed during three boat surveys (Figure 9). On October 12, 2022, belugas were spotted during the AKBMP visual survey, at a time that was outside of the boat survey (Figure 9). The number of commercial fishing boats gradually decreased from the beginning of August through the first week of September, when only a handful of commercial fishing boats remained in the river. The dipnet fishery in the Kenai River concludes on July 31st each year, so the number of watercraft in the river significantly decreases after that date.

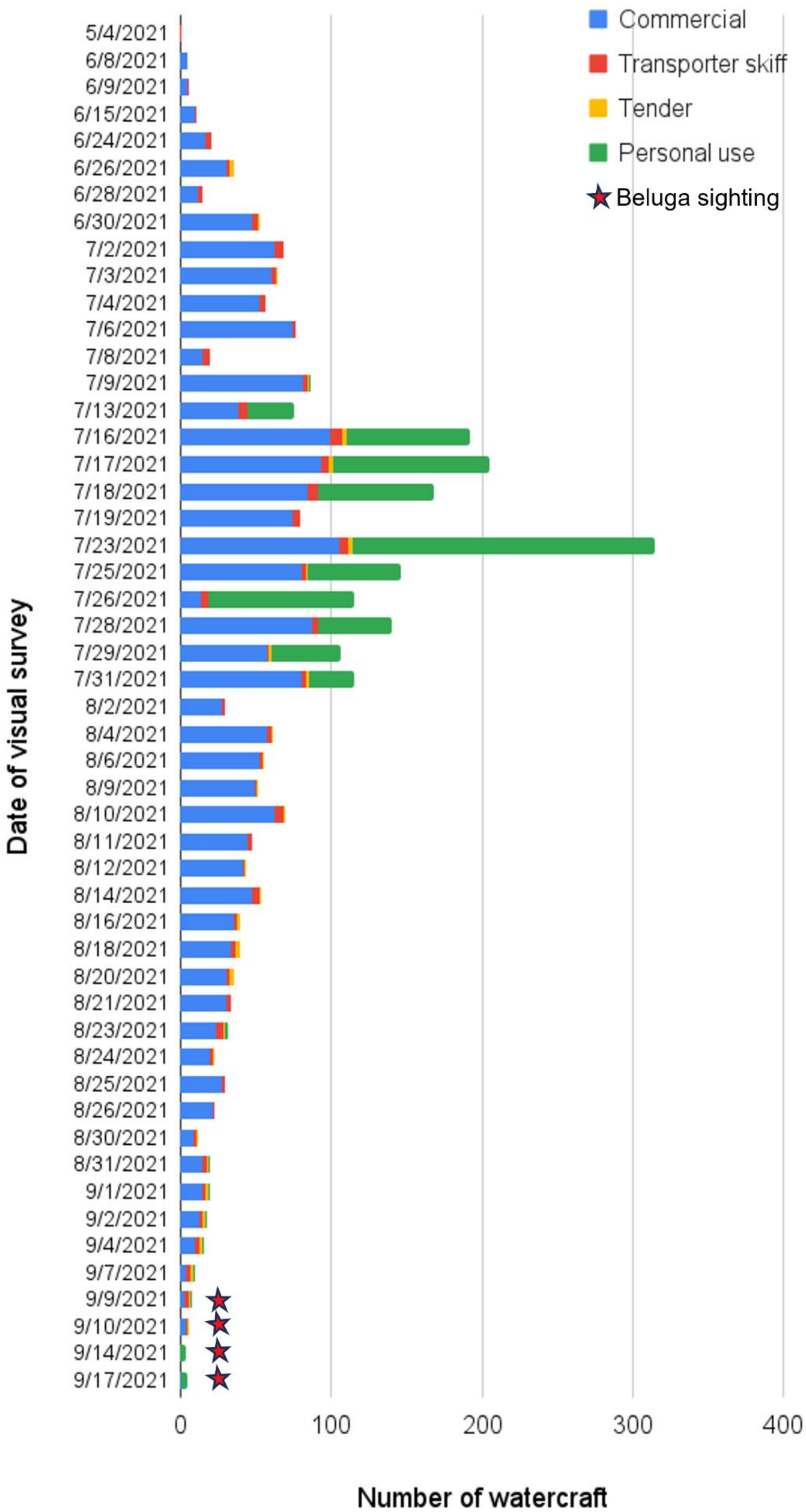

Figure 8: A summary of the 2021 boat visual surveys in the Kenai River. Note that the survey dates are not uniformly spaced and were conducted randomly. Red stars indicate beluga sightings during the survey.

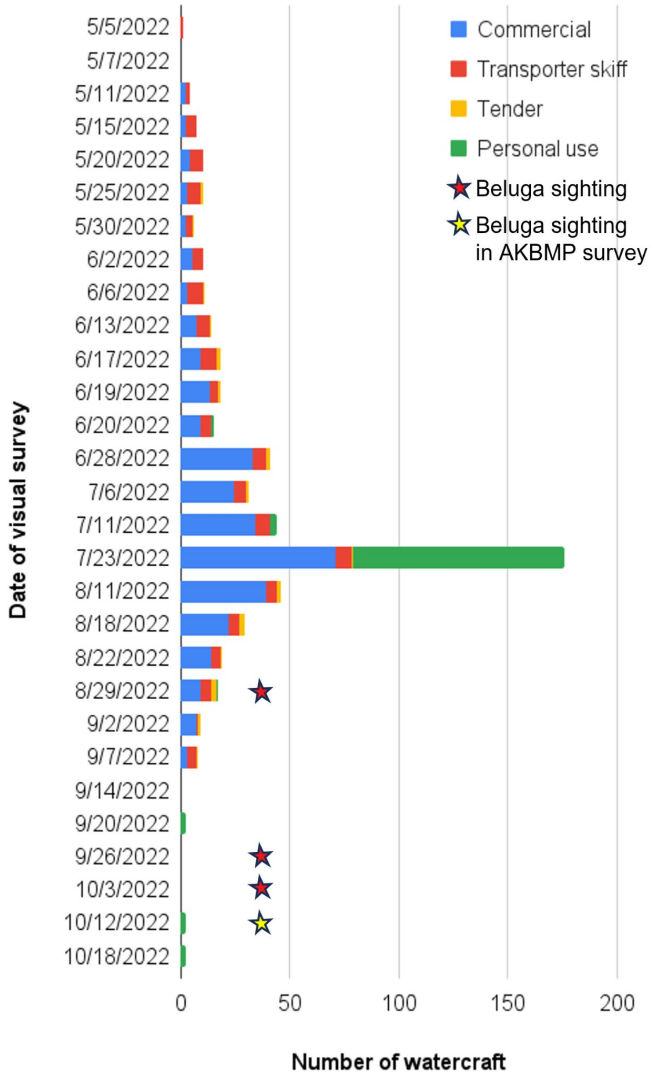

Figure 9: A summary of the 2022 boat visual surveys in the Kenai River. Note that the survey dates are not uniformly spaced and were conducted randomly. Red stars indicate beluga sightings during the survey. Yellow stars indicate beluga sightings during the AKBMP survey.

3.6 Beluga relationship to noise and tide in the Kenai River

In 2021, there were 14 BPM that occurred during Noise Scale 3 in 2021, at a rate of 6.0% among all observations at the Noise Scale 3, but zero detections in this category in 2022 (Table 4, Figure 10). In general, there were far fewer observations in Noise Category 3 in 2022, with 232 observations in 2021 compared to 99 observations in 2022. The lowest noise category, 1, had the highest rate of detection between the three noise categories, with a detection rate of 17% in 2021 (Table 4 and Figure 10).

Table 4: A comparison between the total observations in the Kenai River at each Noise Scale level between 2021 and 2022.

Kenai	**Noise Scale 1**		**Noise Scale 2**		**Noise Scale 3**	
Year	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
Total observations	1752	1658	409	328	232	99
BPM	298	119	28	5	14	0
Detection rate	17.0%	7.2%	6.8%	1.5%	6.0%	0.0%

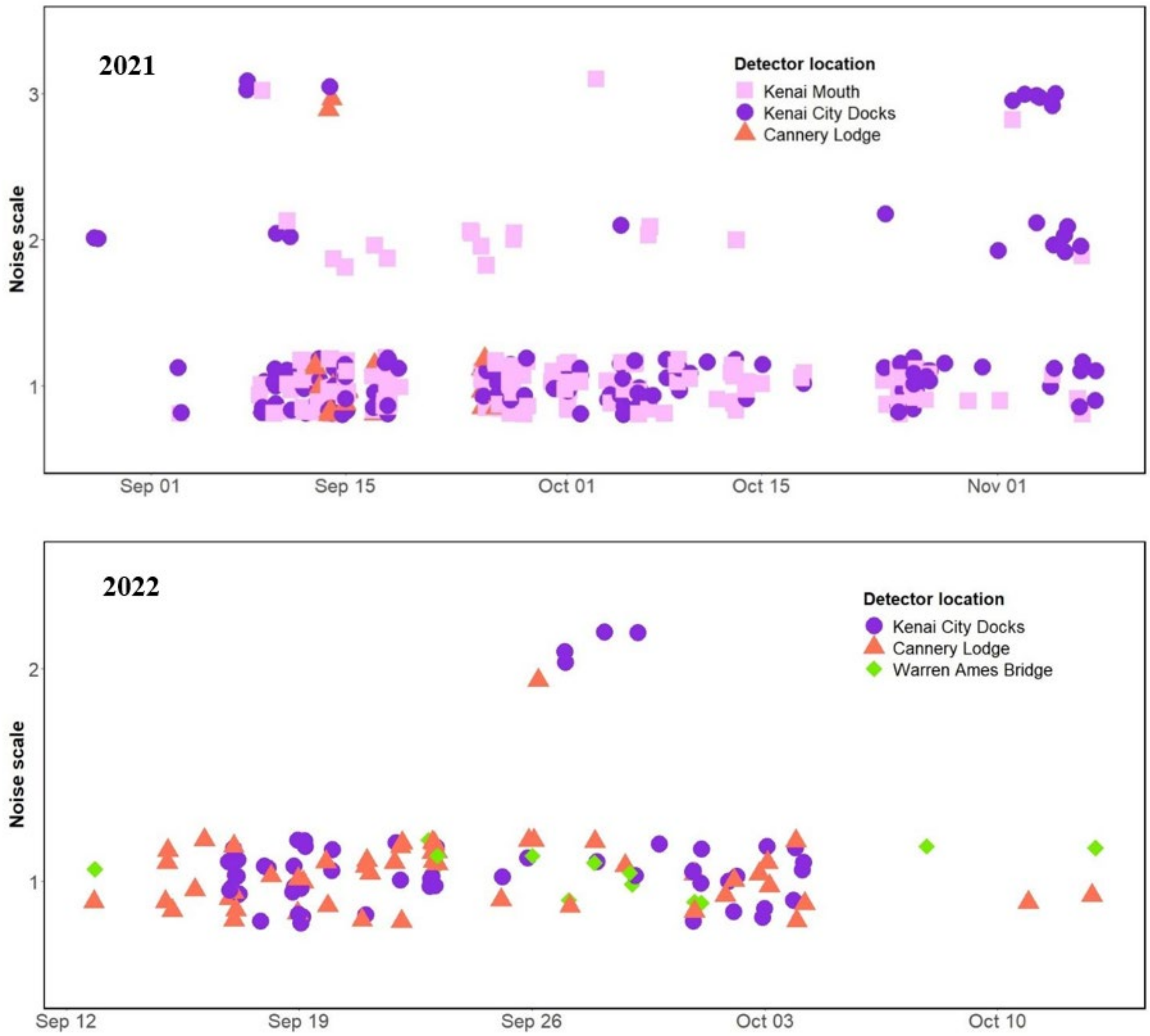

Figure 10: The comparison between beluga acoustic detections in the Kenai River in 2022, as registered by the F-PODs and anthropogenic and environmental noise as recorded by the SoundTrap and categorized into three different noise categories with 1 representing low noise, 2 representing medium noise, and 3 representing loud noise. There were no beluga detections during the loud noise category, so the y-axis of the plot only represents the low and medium noise categories.

3.7 Generalized linear model results

The generalized linear model applied to the 2021 dataset showed that Noise Scale 2 and Noise Scale 3 both showed negative associations with detections, implying lower odds of detection compared to the baseline of the Noise Scale 1 category (as shown in Figure 10, Table 5). Both are statistically significant. The average tide variable has a negative coefficient, meaning that the lower the tide, the lower the detection rate, however, this value was not statistically significant (Figure 11). The day of year variable shows a positive and significant association, suggesting an increase in the odds of beluga detection as the year progresses (Figures 5, 11). The Cannery

Lodge F-POD, which was furthest upriver in 2021, shows a significant negative association with detections, while the Kenai City Docks F-POD, although a negative association, is not statistically significant.

The results of the Analysis of Deviance (Table 6) indicate a significant reduction in residual deviance when moving from Model 1 to Model 2 (ΔDeviance = 33.932, $p < 0.01$). The inclusion of the Noise Scale variable in Model 2 significantly improves the model's fit compared to Model 1, which does not include the Noise Scale variable.

The ANOVA test (Table 7) to determine if there were statistically significant differences in the day of year across the different Sound Scale levels showed the p-value was <0.01, which is highly significant. Day of year has a strong effect on Noise Scale levels.

Each Tukey's HSD test pairwise comparison between levels (1vs2, 2vs3, 1vs3) revealed statistically significant differences. Different times of the deployment period were associated with each of the three different Sound Scale levels. The mean differences are negative values, suggesting that higher observations of Sound Scale 3 tended to be earlier in the deployment period compared with Sound Scale 2 and Sound Scale 1.

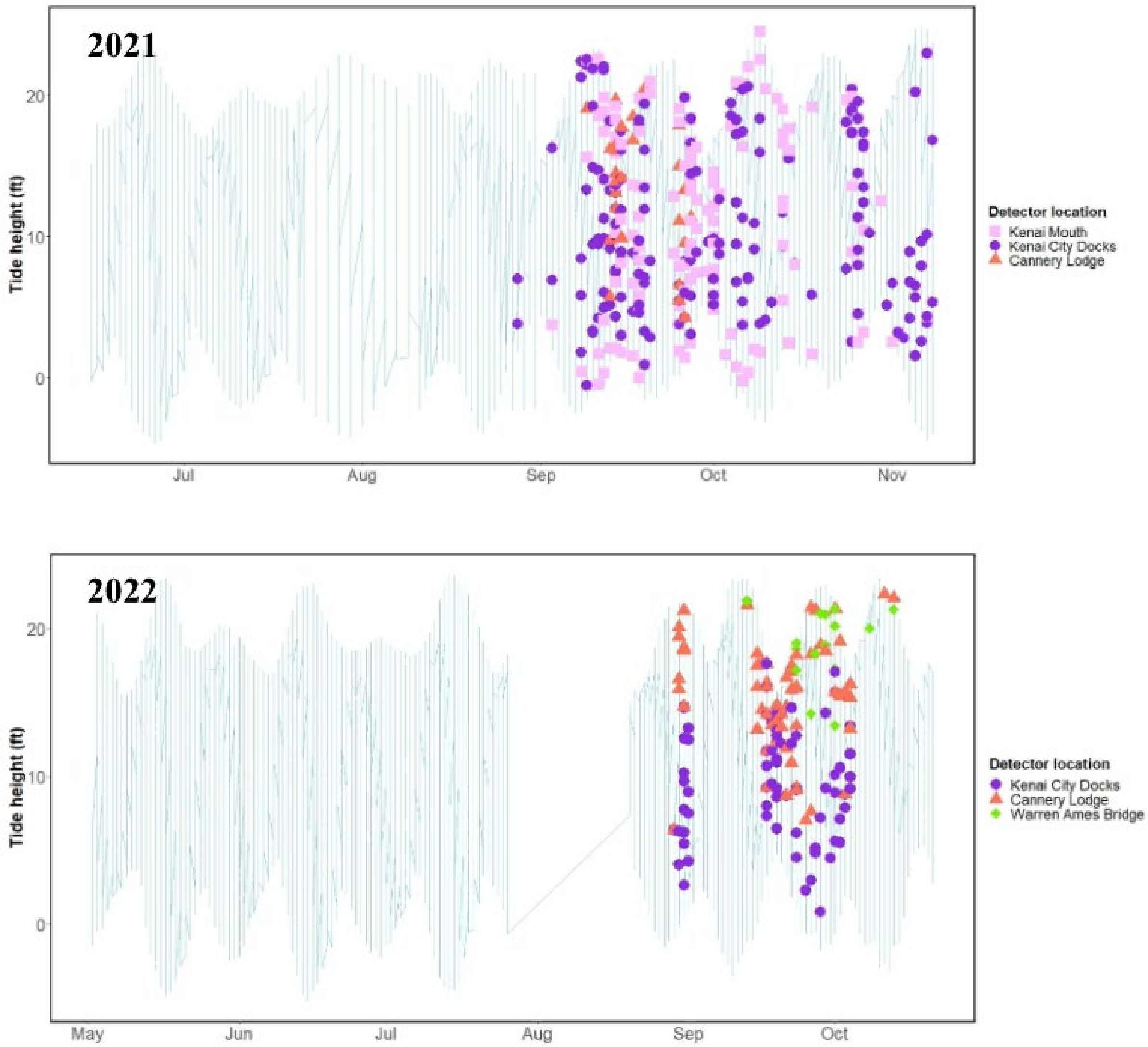

Figure 11: A comparison of tide height and F-POD beluga acoustic detections in the Kenai River.

Table 5: Results of the 2021 generalized linear model for F-PODs in the Kenai River.

Coefficient	**Estimate**	**Std Error**	**z value**	**Pr>|z|**
Intercept	-5.759	0.590	-9.762	<2e-16 ***
Noise Scale 2	-0.924	0.206	-4.490	7.12e-06***
Noise Scale 3	-0.990	0.290	-3.409	0.001***
Average Tide	-0.013	0.010	-1.369	0.171
Day of Year	0.002	0.002	6.6145	3.75e-11***
Kenai City Docks	-0.161	0.119	-1.349	0.177
Cannery Lodge	-1.106	0.228	-4.843	1.28e-06***

Table 6: Results of the 2021 Analysis of Deviance test in the Kenai River.

	Residual Degrees of Freedom	Residual Deviance	Differences in Degrees of Freedom	Deviance	Pr(>Chi)
Model 1 (Reduced)	5357	2397.5	-	-	-
Model 2 (Full)	5355	2363.6	2	33.932	4.284e-08***

Table 7: Results of the 2021 Analysis of Variance test in the Kenai River.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Pr(>F)
Scale	2	367,089	183,544	1403	<2e-16 ***
Residuals	5,359	7,012,968	1.309	-	-

Table 8: Results of the 2021 Tukey's honestly significant difference post-hoc test in the Kenai River.

Comparison	Mean Difference	Lower Confidence Interval	Upper Confidence Interval	Adjusted p-value
2-1	-12.295	-15.389	-9.201	< .01
3-1	-24.939	-28.785	-21.093	< .01
3-2	-12.644	-17.188	-8.099	< .01

In 2022, there were no beluga acoustic detections logged at the Kenai Mouth F-POD, so we removed that factor from the generalized linear model to better interpret the results and the Kenai City Docks F-POD was designated as the intercept (Table 9). Noise Scale 2 exhibits a significantly negative relationship with detections, indicating lower odds of beluga detection compared to the baseline category of Noise Scale 1. Noise Scale 3 exhibits a positive, very insignificant relationship with detections; this is due to the fact that there were no detections in this noise category. The average tide shows a positive and significant relationship, suggesting that higher tides are associated with increased odds of CIB acoustic detection. The day of year variable indicates a significant positive effect, with increasing day of year being associated with higher odds of detection. The Cannery Lodge F-POD and the Warren Ames Memorial Bridge F-POD both demonstrate significant negative relationships with detections compared to the Kenai City Docks F-POD.

The Analysis of Deviance shows a significant decrease in residual deviance when moving from Model 1 to Model 2 (ΔDeviance = 10.552, $p < 0.01$, Table 10). The inclusion of the Noise Scale variance in Model 2 significantly improves the model's fit compared to Model 1, which does not include the Noise Scale variable.

We ran an ANOVA and a Tukey's Honestly Significant Difference (HSD) test to determine if there was a relationship between the day of year and the noise levels, and how the noise levels compared with each other. The ANOVA demonstrated that there is a statistically significant difference between day of year and the Noise Scale levels (Table 11). A Tukey's HSD test showed that there was a significant difference in detection between certain scales (Table 12). Specifically, the mean detection rate at scale 2 was significantly lower than that at scale 1 ($p<0.001$), and the mean detection rate at scale 3 was also significantly lower than at scale 1 ($p<0.01$). However, there was no significant difference in detection rates between scales 2 and 2 ($p= 0.565$). These results suggest that the Noise Scale significantly impacts detection rates.

Table 9: Results of the 2022 generalized linear model for F-PODs and noise in the Kenai River.

Coefficient	**Estimate**	**Std Error**	**z value**	**Pr>|z|**
Intercept	-9.150	0.870	-10.517	<2e-16 ***
Noise Scale 2	-1.040	0.475	-2.191	0.028*
Noise Scale 3	-14.160	441.285	-0.032	0.974
Average Tide	0.063	0.018	3.579	0.0003***
Day of Year	0.023	0.003	7.440	1.01e-13***
Cannery Lodge	-0.911	0.204	-4.472	7.73e-06***
Warren Ames Bridge	-2.154	0.301	-7.151	8.61e-13***

Table 10: Results of the 2022 Analysis of Deviance test in the Kenai River.

	Residual Degrees of Freedom	**Residual Deviance**	**Differences in Degrees of Freedom**	**Deviance**	**Pr(>Chi)**
Model 1 (Reduced)	4170	944.08	-	-	-
Model 2 (Full)	4168	933.53	2	10.552	0.005**

Table 11: Results of the 2022 Analysis of Variance test in the Kenai River.

Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F value**	**Pr(>F)**
Scale	2	76035	38017	10.07	4.34e-05***
Residuals	4172	15,753,496	3776	-	-

Table 12: Results of the 2022 Tukey's honestly significant difference post-hoc test in the Kenai River.

Comparison	Mean Difference	Lower Confidence Interval	Upper Confidence Interval	Adjusted p-value
2-1	-9.179	-15.330	-3.029	0.001
3-1	-14.333	-25.079	-3.587	0.005
3-2	-5.154	-17.021	6.713	0.565

3.8 Overwinter results

Between September 21, 2021 and April 5, 2022, three F-PODs were moored outside the mouths of the Kenai and Kasilof rivers. Moorings were recovered in May 2022 but instruments stopped logging earlier due to depleted power or full memory. The Kenai North F-POD sampled 132 days; the Kenai South F-POD sampled 194 days; and the Kasilof F-POD sampled 179 days (Table 13, Figure 12). The Kasilof F-POD had the highest number of BPM between the three sites.

Table 13: Summary of the 2021-2022 overwinter PAM deployment outside the mouths of the Kenai and Kasilof rivers.

Deployment Location	Kenai North F-POD	Kenai South F-POD	Kasilof F-POD
Start	Sep 24, 2021	Sep 23, 2021	Sep 21, 2021
End	Feb 3, 2022	Apr 5, 2022	Mar 21, 2022
BPD	1	6	9
BPM	4	110	149

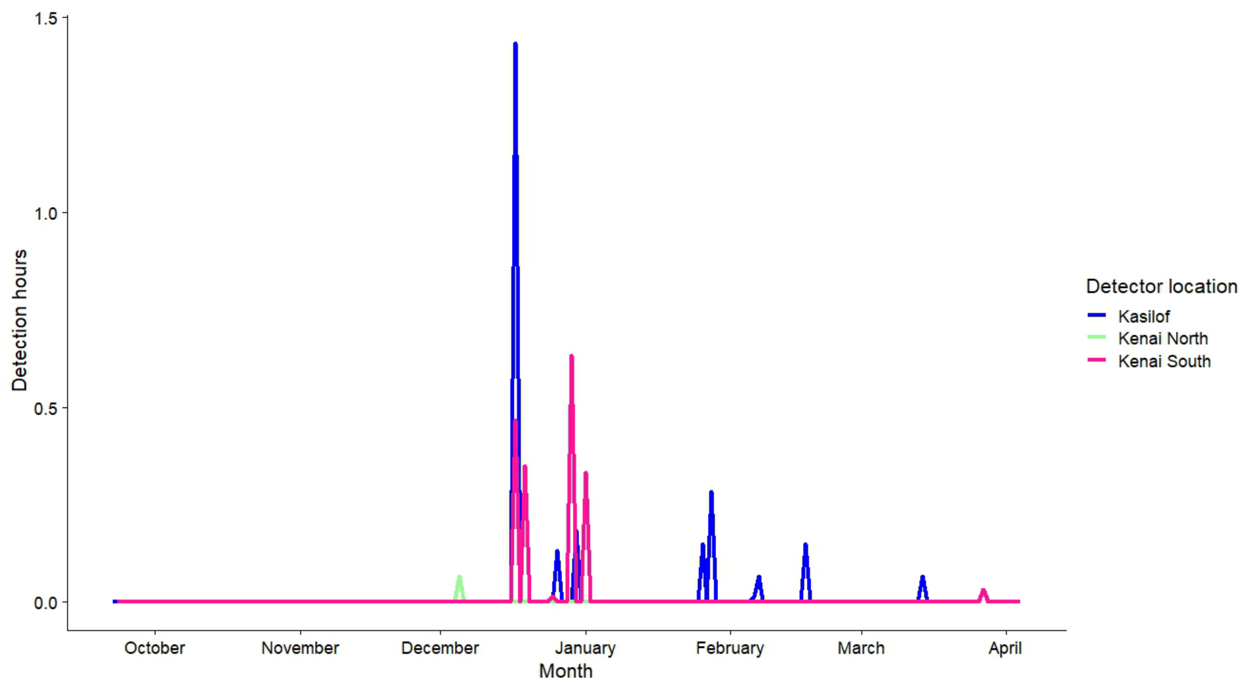

Figure 12: The number of beluga positive hours at each of the three 2021-2022 overwinter PAM sites outside the mouths of the Kenai and Kasilof rivers.

4. Discussion:

4.1 Field work fails and data gaps

In both years, we faced a multitude of challenges while conducting this study. Cook Inlet can be an extremely difficult place to conduct PAM-based research (i.e., Lammers et al. 2013, Castellote et al. 2016) and the Kenai and Kasilof Rivers were no exception. There are extreme tides, fast moving current, vegetative debris flowing downstream entangling in moorings, ice presence early or late in the season, silty waters corroding electronic equipment, and treacherous mudflats.

In 2022, when we converted all of the F-PODs to the standard deployment system, we thought simplifying the accessibility of the devices would make them easier to service. It also offered better protection from potential boat collisions, since buoys are a clear obstacle in the river. While they were easier to service and we did not face boat collisions with our F-PODs, we also noticed that the Danforth anchors did not always hold the mooring system in place, even at locations where we had little to no issues the previous year. There were quite a few times when we would have to reset the mooring location, due to the currents displacing it. This happened even when additional anchors and weight were added to the anchoring system. The bathymetry of the river is constantly changing; sediment accumulation fluctuates with the strong currents and the increasing discharge throughout the summer due to snow and glaciers melt, with mean discharge levels peaking between June and September (Shoen et al. 2017). The strong river currents and extreme tides shape sediment distribution and bring debris, including entire tree trunks and large vegetation, down the river. In addition to destabilizing the mooring system, the discharge and heavy sediment loads also have the potential to bury anchors or instruments strapped to the lower ends of piles. Little PAM work has been done on glacial river systems elsewhere, and for beluga, we are only aware of work done in Eagle River in Knik Arm, Cook Inlet. JBER Conservation Department has over a decade of experience monitoring beluga using F-PODs, and similar challenges occur in their river system every season (USAF 2015). Nevertheless, despite the field challenges and data gaps, we were able to successfully describe beluga occurrence and its relationship with underwater noise for both seasons.

4.2 CIB acoustic presence

Because CIB were never detected acoustically within the Kasilof River all further discussion on in-river belugas presence will pertain only to the Kenai River hereafter. The differences between the overall beluga presence between 2021 and 2022 at the Kenai City Docks (Figure 4) can be explained by the equipment failures we experienced with the 2022 F-POD, and by the slightly shorter field season; we recovered instruments on November 7th and 8th in 2021 and between October 21st and October 24th in 2022 due to the earlier impending ice buildup in 2022. Additionally, the differences in beluga presence between 2021 and 2022 at the Cannery Lodge can be explained by the 2022 CL deployment extending until October 23, unlike the 2021 CL F-POD deployment, which ended on September 28.

CIB were identified at all three F-POD sites in 2021 and all sites except for the Kenai River Mouth site in 2022, beginning in late August. We designed the study sites to have PAM stations in different locations within the first three river miles in the Kenai River (and first river mile in the Kasilof River) to allow for the ability to assess belugas' preference of location within the river during various times of year and within certain periods of the tidal cycle. It is possible that certain parts of the river provide more beneficial foraging habitat due to various features within the river, however, due to the inconsistency in sampling between the two years, we were unable to make that determination. The 2021 results showed that there was no significant difference between detections at the Kenai Mouth F-POD and the Kenai City Docks F-POD; this could indicate that belugas are more likely to turn around before getting to the Cannery Lodge or spend more time between the mouth of the Kenai and the Kenai City Docks. Unfortunately, with the lack of data from 2022 at the mouth, a full assessment of CIB preference at different sites cannot be completed between the two years. But overall, results highlight how beluga presence is reduced with an increase in distance to the mouth. There were more detections at the Cannery Lodge F-POD site in 2022. This could be due to the different placement of the F-POD in 2022; in 2021, the device was situated on the side of a floating dock. When servicing the device, it was not uncommon to encounter boats tied up to the dock. We do not have noise data that far upriver, but it is possible that the boats physically and acoustically masked beluga detections from that F-POD. The 2022 CL F-POD location was in the river channel and thus CIB would have to pass directly by it, echolocating towards it, if they were swimming upriver. The addition of the Warren Ames Memorial Bridge F-POD increased the detectability of CIB further upriver than the 2021 field season and there was 1 day (October 1st) where we had detections there for nearly an hour.

4.3 Anthropogenic disturbance and noise

The Upper Cook Inlet commercial salmon fishing season typically runs between mid-June through mid-August, though the seafood processing companies and commercial fishermen start preparing and utilizing the river in early May and remain in the river until early September (NOAA 2023). In 2022, ADFG issued nearly 1300 drift and set gillnet limited entry fishing permits for UCI; 567 drift gillnet permits and 731 set gillnet permits (ADFG 2023a). The fishery yielded a harvest of 1.7 million salmon in 2021 and 1.4 million salmon in 2022 (ADFG 2022).

The commercial salmon fishery in Kenai River has a strong seasonal footprint. In early May, the commercial seafood companies operating in the region begin to set out their mooring buoys in the river for commercial fishermen to anchor onto between openers (Appendix A Figure 12a). A "commercial fishing opener" refers to a specific, regulated time period during which commercial fishing activities are legally permitted in a designated area. These openers are primarily established by the Alaska Department of Fish and Game and are based on various factors, including species conservation, ecological sustainability, and stock assessments. Although the duration of the drift gillnet openers is usually from 7am to 7pm, they can be extended until 10pm.

Buoys extend from the mouth of the river, past the Kenai City Docks, right until the river bends towards the Cannery Lodge (Figure 1). As May progresses, fishermen begin putting their boats in the water to prepare for the upcoming fishing season. Our boat surveys reflect that gradual increase in boat presence in May (Fig. 8 and 9). Commercial fishers essentially use the rivers as boat harbors throughout the season. During the commercial fishing season, there can be anywhere from 1 to upwards of 100 commercial boats anchored on the mooring buoys in the Kenai River (Figures 8, 13, Appendix A, Figure 12a). After an opener, fishing vessels offload their catch at one of the several commercial seafood processing company docks that are located adjacent to the river or on one of the several tenders that anchor within the river, close to the mouth. Although the season ends in mid-August with the bulk of the fleet ending in-river presence, commercial fishing vessels were still documented in the river until mid-September in 2021 and 2022 (Figures 8, 9). There was some overlap between CIB, the last remaining commercial boats in the river, and the seafood processing companies removing buoys from the river during this fall shoulder season (Appendix A, Figure 15a).

In addition to the commercial salmon fishery, there is also a heavily utilized Cook Inlet personal-use salmon dip-netting fishery that takes place in the Kenai River, Kasilof River, Fish Creek, and Susitna River. In the Kenai River, the fishery is open between July 10th to July 30th, and in the Kasilof River it is open June 25th through August 7th. During this time, thousands of people descend upon the rivers, whether dip-netting from the banks or fishing from various types of watercraft within the rivers (Figures 8, 9, Appendix A, Figure 16a). This fishery regulation was modified in 1996 when it allowed dipnetting from boats and skiffs, and in 2008, regulation on the type of outboard was implemented, in an attempt to reduce hydrocarbon contents in the water (ADFG 2023d). Since 1996, the permits issued for Cook Inlet personal use fisheries have increased dramatically. In 2022, there were 28,402 permits issued for the Cook Inlet personal use fishery; ADFG reported that 286,213 salmon – sockeye, chinook, coho, pink, and chum – were harvested in the Kenai River and 162,527 salmon in the Kasilof River (ADFG 2023b). In 2021, there were 26,444 permits issued and 332,659 salmon harvested in the Kenai and 101,159 salmon harvested in the Kasilof (ADFG 2023b). This is in stark contrast to the number of permits issued in 1996, 14,576, and the number of salmon harvested in the Kenai and Kasilof rivers that year, 107,627 and 11,701, respectively (ADFG 2023b). The number of salmon harvested in the Kasilof River is 14 times greater in 2022 than it was in 1996, compared with the Kenai River, which just had an increase of 2.7 times the amount of salmon harvested in 2022, compared with 1996. Although the harvest in this fishery is directly related to run size and timing of the fish, the increase of users of that fishery plays a large part in the increased harvest since the fishery first started in 1996. Considering the trend in boat presence in the Kenai River throughout the season, the dipnet fishery generates a spike in July over a period where the commercial fishery is at or near its maximum number of vessels in the river.

Unfortunately, during both years, we were unable to obtain SoundTrap data from July in the Kenai River due to equipment destruction and loss. This is the most congested, and thus noisiest, month of the year, since commercial fishing, sport fishing, and personal use fishing all take place during this time. In 2022, the Kenai SoundTrap data gap extended from June 17th through September 8th, a time frame that encompasses the height of anthropogenic activity and noise. It seems highly likely that we would have had many more observations in the Noise Scale 3 level if we had been able to obtain this data. Our results still show that CIB are statistically more likely to be in the Kenai River during periods of lower noise intensity (Figure 10 and Tables 4, 5, 9), and including noise data during the busiest part of summer would have likely strengthened that relationship. For the 2021 data, the ANOVA and Tukey's HSD test performed to assess differences between the day of year and the Noise Scale levels did show that Noise Scale 3 occurred more frequently earlier in the deployment period than Noise Scale 2 and Noise Scale 1 during both deployment times, despite the data gaps (Tables 7, 8). There was a parallel increase in the number of boats in the river (Figures 8, 9) and the increment in the noise scale (Tables 8, 9) from late May until September, therefore, this period sustains a high level of anthropogenic disturbance, both the physical presence of vessels and the acoustic disturbance associated with mooring and idling within the river, entering and exiting the river, and tangential activity on the river banks.

During these times – June, July, and most of August – the F-PODs in both the Kenai and Kasilof did not log any CIB detections (Figure 5). In 2021, the first acoustic beluga detection in the Kenai River occurred a week and a half after the end of the commercial fishing season, with consistent detections only occurring several weeks later, by September 8th (Figure 5). Beluga are known to be sensitive to anthropogenic noise disturbance, and it has been hypothesized that the noise and physical disturbance of the fishery activity in the Kenai River might displace beluga from this important habitat, at least early in the season when vessel activity starts to ramp up (Castellote et al. 2018). Beluga disturbance by noise and vessel presence has also been reported in many other areas of Alaska and non-US Arctic waters, in particular for populations that endure hunting pressure (Finley et al 1982; Halliday et al. 2019; Kendall et al 2013; Krasnova et al. 2002; Lesage et al. 1999, Martin et al. 2022, Anderson 2017).

This shoulder season, where noise occurrence is beginning to drop, would be a beneficial time period to implement heightened restrictions in the river. For instance, implementing a speed limitation zone for boaters from the mouth of the Kenai River until Cunningham Park, located upriver from Warren Ames Memorial Bridge, from mid-August to November. This would not only reduce the risk of a boat colliding with a whale, but it would also decrease the intensity of acoustic disturbance as outboard and inboard motors running at lower rpm emit lower noise levels (Leaper, 2019). This could also be implemented in the spring, in April and May, the other shoulder season with overlapping beluga presence and increase in noise when boats start to be used in the river in preparation for the season (Castellote et al. 2018), and when noise intensity is beginning to increase as the commercial fishing season begins. These time periods where there is an inverse relationship between noise levels and beluga presence are important to highlight from a conservation perspective, as they would be cost effective periods for reducing the overall duration of the fisheries related acoustic disturbance in this part of the critical habitat, known for its historical foraging importance (Huntington 2002, Dunton et al. 2012). Additionally, during the convergence period of the commercial fishery and personal use dipnetting, any mitigation proposed measure should consider disturbance as a whole. A spike in small vessels is generated by the dipnetting activity, as the regulation for this personal use accommodated boat-based operations started in 1996. Since then, there has been a stark increase in permit users. We suggest a thorough review of the boat-based dipnet personal use fishery and its increasing environmental impact. A cap on boat numbers, type of propulsion, speed, time in the river are factors that could be considered in an effort to make beluga habitat more habitable. While commercial fishery boats are in the river at the same time their number and activity is much lower. In fact, most of them are just at anchor in comparison to the various dipnet watercraft which are running up and down the river 6am to 11pm for three weeks in July. The current dipnet fishery regulation prohibits the use of old 2-stroke outboards as these have been associated with the highest emissions of hydrocarbons in the water (in the form of unburnt fuel). However, 2-stroke direct fuel injection (DFI) outboards are permitted. These might emit a lower level of unburnt fuel, but sound emissions are equivalent for DFI or non-DFI 2-stroke outboards, and significantly higher than 4-stroke outboards, as the main source of underwater noise here is the blade cavitation and exhaust expelled underwater. CIB habitat disturbance should be considered in a revision of the Kenai fishing regulations in a way that would have a low impact to the economy. It is important to highlight that the Kenai and Kasilof rivers present the highest habitat value in summer, during the peak of the salmon spawning runs, as seen by the historical accounts of CIB in this area. Furthermore, Kenai and Kasilof river mouths are included in the designated critical habitat for CIB, and specifically for the Kenai River, critical habitat includes the in-river waters up to the Warren Ames Memorial Bridge (76 FR 20180). As such, and in view of the suggested spatial displacement that our results support, fisheries related disturbance should be considered as a management priority. The current fisheries regulations in the Kenai River do not consider the effects of this activity on CIB critical habitat.

4.4 Visual and acoustic presence

The Alaska Beluga Monitoring Program documented their first fall 2021 visual observation of CIB in the Kenai River on September 3rd, six days after belugas were acoustically detected on August 28th (Figure 6). In 2022, however, volunteers first observed belugas on the same day that the F-PODs first registered beluga detections, August 29th (Figure 7). In both 2021 and 2022, there was a significant positive relationship between the days that belugas were visually detected in the river compared with when they were acoustically detected. However, in 2022, the results demonstrated that the relationship between positive hours from the visual surveys and the acoustic sampling was slightly weaker than 2021; there could be several explanations for this. Since the Kenai River Mouth F-POD is at the entrance of the river, and thus the first PAM device that would record CIBs when accessing the river but not necessarily venturing upriver, lacking these data severely limits the comparison for the 2022 season. Additionally, there were data gaps in the Kenai City Docks PAM station in August, September, and October, which reduces the effort overlap between the two sampling methods in one of the most important periods for beluga presence. In general, however, there is a significant correlation between the two methods when assessing general CIB usage of the Kenai River.

In both years, there were periods when the visual observation positive hours exceeded the acoustic detection hours. One possible explanation for this is that during the visual surveys, observers recorded the start and end times of belugas being in view in a stretch of river that one F-POD can't fully cover, due to a bend in the river. If belugas swim around the bend but come back into view later, the whole time period is recorded, not just when the observers had direct eyes on the whales. Therefore, visual "encounters" could include hours with whales in the river but beyond the acoustic range of the F-PODs. Additionally, observers begin logging visual observations when whales are still in the Inlet, prior to their actual arrival at the river. Because high frequency sound, such as beluga echolocation clicks in the range 20-160 kHz, is affected by strong propagation loss (Urick, 1983), belugas outside the mouth of the river are too far to be detected by the F-POD at the river mouth.

Both methods of observing belugas have their advantages and disadvantages. Some advantages of PAM include the ability to continuously monitor belugas, the ability to monitor belugas even if they rarely surface or behave cryptically, as long as they remain vocally active, and the fact that there are no daylight limitations for PAM. However, using PAM in Cook Inlet, as mentioned above, can have serious challenges due to the unforgivable environment. Conducting visual observations bypasses the potential for equipment failure and loss, and observations can occur even when ice is in the river, a factor that challenges long-term acoustic monitoring in the rivers. In 2021, AKBMP conducted visual surveys in the Kenai River for 7 days after the F-PODs were removed from the river and logged beluga activity on each day. In 2022, volunteers extended the visual monitoring season by an additional 53 days, with 23 sessions logged during that time, and belugas were sighted during 13 sessions. This is valuable data for understanding the seasonal distribution and river usage of this endangered species, information that could not be easily collected by PAM, due to the environmental restrictions of winter fieldwork. However, visual surveys are limited by daylight hours, favorable weather conditions, and availability and interest of volunteers. It should also be noted that community science programs, like AKBMP, can be a great tool for bringing awareness of local flora and fauna to the general public. Engaging with the community while simultaneously working towards conservation measures is not always something that acoustic monitoring can accomplish. Urbanized rivers can be monitored by visual effort due to the accessibility of observation stations, but this does not work for remote locations such as the Tuxedni and Chinitna rivers where PAM becomes the only option.

Even though the acoustic presence of CIB decreased further upriver, it would be interesting to know how far CIB venture up the Kenai, and how often. Because of the correlation between acoustic and visual CIB presence, using a combination of PAM and visual observations could alleviate the need to have PAM so close to the river mouth, in an area that is unpredictable and prone to equipment loss or failure. Knowing how far upriver should be considered beluga habitat would be helpful guidance for how far upriver a hypothetical speed limited zone should extend, if measures were implemented to reduce disturbance for CIB in the Kenai River.

4.5 Absence of beluga detections in the Kasilof River

One of the notable results from this work is that CIB were not acoustically detected within the Kasilof River in either 2021 or 2022, despite having been documented as using the river historically (Dunton et al. 2012). More recently they have been recorded during three AKBMP spring monitoring sessions and one fall season session (AKBMP 2023) and on a NOAA aerial survey in April (V. Gill unpublished data), as well as recent opportunistic sightings from members of the public (V.Gill pers comm). It's possible that since the Kasilof is narrower than the Kenai, belugas find it more difficult to navigate around vessels in the river and are deterred from entering it even outside of the busiest part of the year. The Kasilof River has very interesting bathymetry; the river looks completely different during high tide than at low tide. During the low tide, there is a single deep channel that extends into the Inlet, surrounded by mudflats, and the mouth of the river appears to be much further into the body of Cook Inlet than it appears outside of the low tide. At the beginning of the commercial fishing season the Coast Guard deploys navigational markers to indicate where the deep channel is, so fishermen don't strand on the shallow mudflats. Perhaps this peculiar bathymetry constrains the accessibility of river habitat to just the deeper channel in the flats, and belugas are less tolerant to boat presence, and more prone to stranding in habitat that is this shallow if disturbed. It is possible that the sediment and mud built up around the Kasilof has changed throughout the years and made it less suitable for CIB movement. Research into the change of sediment build up in glacially fed Cook Inlet rivers may help answer some of these questions. Additionally, the Kasilof River salmon runs end before the Kenai River runs. Further research should also examine the differences in prey type and availability between the two rivers; perhaps the Kenai has more preferred prey species in greater abundances and is easier to navigate to. Last, killer whale predation pressure has a strong effect in habitat preference for beluga (Sergeant and Brodie 1969; Kovaks 2011) and could also contribute to the observed differences in beluga presence. There were three days of overlap between spring AKBMP surveys and PAM effort by the Kasilof overwinter mooring, however, there were no beluga detections with either method, therefore it cannot be assessed if belugas acoustically detected near the mouth of the river also entered the river system.

4.6 Overwinter moorings

Although the overwinter moorings are labeled with 'Kenai' and 'Kasilof,' they were not placed within the river channels but in Cook Inlet in close proximity to the river mouths due to the minimum required depth to avoid ice interaction throughout the winter. The overwinter results are notable because CIB appear to favor locations near the Kasilof River over the Kenai River. Belugas were more likely to be detected passing the Kasilof River in the period October to May than at either of the two F-PODs moored near the Kenai River during the same period. Kasilof beach is a popular location for spring surf fishing from the shore especially April-May (ADF&G

YouTube channel[1]). In particular, sport fishers are looking to take advantage of halibut that have migrated nearshore at this time of year. Halibut usually are a deep-water fish, but in certain locations, like Kasilof beach, they come into shallower water after baitfish in spring. In addition, early spring Cook Inlet king salmon make their way along the shoreline to spawning waters in east LCI rivers. On a NOAA aerial survey for belugas several CIB were seen around the mouth of the Kasilof on 7 April 2021 (Gill unpublished data). In addition, there have been several opportunistic observations of CIB in and around the Kasilof in the late winter/early spring (NOAA unpublished data). AKBMP data also has observations of CIB around the Kasilof in the spring; 25, 27, 29 April 2022 (https://akbmp.org/updates/). NOAA has numerous opportunistic sightings over the past decade, from Deep Creek to Kenai, of belugas transiting along the nearshore in the spring. This distribution is reflected in the overwinter acoustic data as more detections were obtained in the mooring south of the Kenai mouth than north of the mouth (Figures 1, 12). Flatfish and king salmon are a known prey item for belugas (Quakenbush et al. 2015) and it is possible CIB are taking advantage of these seasonal nearshore prey resources. Traditional Ecological Knowledge from the area suggests they are (V. Gill pers. comm). This may be a key foraging area for belugas coming out of winter before the spring eulachon spawning runs begin in the rivers.

4.7 Comparison to previous CIB distribution research

Our work builds on existing literature of CIB distribution in the Kenai and Kasilof rivers (Huntington 2002, Dunton et al. 2012, Goetz 2018, Ovitz 2019), acoustic detections (Castellote et al 2020), and visual observations (AKBMP 2023, and by way of photo-identification, McGuire et al. 2020). Huntington (2002) and Dunton et al. (2012) used traditional ecological knowledge to show that historically, CIB utilized the Kenai River between April and November which is almost opposite to their temporal use now. Our research, along with visual surveys conducted by AKBMP, shows that whales no longer swim up the river during that entire time frame, instead, utilizing the river in the spring (AKBMP 2023) and in the fall (late August - November). McGuire et al. (2020) also observed a spring/fall pattern in the Kenai River during photo-identification surveys; in addition, they documented calf-rearing behavior in the Kenai River and showed that there is a strong correlation between CIB presence and salmon runs. However, our research shows that CIB no longer travel up the Kenai River during peak salmon runs; they begin to return to the river during the tail end of the sockeye and chinook late-runs, but the beginning of coho and pink salmon entry (ADFG 2022). It is possible that this phenological change was brought on by a gradually increasing anthropogenic disturbance over the past few decades, but accessing the river later than peak fish runs might have detrimental impacts to CIB diet. Warmer water temperatures brought on by climate change will likely influence juvenile salmon growth (Meyer et al. 2022). These same authors modeled the growth of juvenile salmon in the Kenai River watershed under various climate change simulations and found that chinook and coho salmon are predicted to decrease their summer growth rate as water temperatures warm, likely impacting the diet and health of CIB. However, since CIB have altered their seasonal presence in the Kenai River, it is possible that they are targeting other fish

[1] https://www.youtube.com/watch?v=rFVhbDwLCTc

species outside of the busy summer months.

Goetz et al. (2018) looked at the distribution of CIB by using satellite tags. They affixed tags to 18 whales between 1999 and 2002 and using tag data August 20, 2001 to March 9, 2002, they reported one tagged whale near the Kenai and Kasilof rivers from January to March and documented opportunistic sightings in the area in August, September, October, and November. December, March, and April each had just 1 opportunistic sighting. Although the tagged whale was not tracked near the Kenai River between August and November, the winter usage of the Kenai area is consistent with our overwinter observations (Goetz et al. 2018).

This study builds on passive acoustic monitoring work that Castellote et al. (2020) conducted between 2008-2013 who maintained a beluga echolocation logger and a sound recorder outside the mouth of the Kenai River, in addition to 12 moorings in other parts of Cook Inlet, to get a better understanding of CIB year-round distribution patterns and foraging occurrence throughout their critical habitat. Castellote et al. (2020) showed slightly different results than this study; CIB were recorded on the Kenai River PAM devices between the end of January through the end of April; there were no detections from May through December. Although this is somewhat surprising, it is not unexpected. Similar to the overwinter mooring location in this study, the year-round PAM mooring in the Castellote et al. (2020) study was situated in Cook Inlet, as opposed to within the confines of the river. Their research shows weekly mean averages of daily beluga positive hours between 0.5 hours to around two hours at different times between January and April in 2009, 2010, and 2011, in contrast with our results with only one day exceeding a half an hour of acoustic presence. These differences are most likely related to the fact that only echolocation detections were considered in this study, with a shorter detection range, than the combination of echolocation and social signals from sound recordings in Castellote et al. (2020). But overall, the 2009-2011 beluga seasonal presence off the mouth of the Kenai River described by Castellote et al. (2020) in January to April, is in close similarity to our overwinter 2021-2022 results with presence only in the months of December to March.

It would be beneficial to explore the possibility of maintaining acoustic monitoring in the river throughout the winter period, or at least deploy the passive acoustic monitors as soon as the river is free of ice and retrieve these prior to the first freeze. The ability to capture beluga presence and anthropogenic and environmental noise prior to the fishing season will give us a better understanding of the baseline for background noise, and how anthropogenic noise changes during the ice-free months. Ideally, the devices would be placed in the river year-round because there are periodic reports of belugas in the river throughout the winter and more consistent visual reports in March and April, during the time that ice is less prevalent in the river (AKBMP 2023). Deploying the PAM devices in tandem with visual surveys might be the best way to continue monitoring the presence of the CIB in the Kenai River.

5. Conclusions

Historically belugas used the Kenai and Kasilof rivers year round. However, our acoustic study demonstrates CIB now only utilize the Kenai River and vicinity between late August and March, and off the Kasilof River between December and March. We could not verify acoustic presence within the rivers November to March due to ice constraints. Citizen science data (AKBMP) and opportunistic sightings also show that CIB are also seen in both rivers and outside vicinity in the early fall through spring but not in the summer. Our acoustic detections were statistically correlated to visual observations conducted by citizen scientists (AKBMP) indicating that both methods are useful but if cost and expertise is an issue visual observations are an effective way to track beluga presence in these rivers. In our study belugas only used the river when boat activity and noise was at its lowest and salmon runs waned. According to Local Knowledge, this change in temporal usage seems to have started occurring in the 1990s. Where belugas once took advantage of these prolific salmon runs in the Kenai, it appears they now avoid the river despite their preferred prey species being abundant. Noise and disturbance sharply peak in July for three weeks during the personal use dip net fishery which targets the height of the sockeye run, a fishery that began in 1996. We suggest implementing vessel speed limitations in the lower part of the Kenai River in April-May, and August-November, to benefit CIB usage of this habitat. We also suggest a thorough review of the fishery activities in the Kenai River and their impact on Cook Inlet belugas and their critical habitat. Both humans and CIB rely on the Kenai River and finding a balance between the needs of these two entities is essential.

6. References

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Appendix A

Photographs of field sites and deployment setups

Figure 13: Welded bracket housing F-POD attached to commercial fishing mooring buoy.

Figure 14: Kasilof River standard deployment configuration.

Figure 15: Standard buoy deployment on a boat-less day at the Kenai Mouth F-POD site.

Figure 16: Cannery Lodge floating dock deployment, June 2021.

Figure 17: Kenai River ST500 floating dock deployment, June 2021.

Figure 18: Damaged ST500 from the Kenai River floating dock deployment, August 2021.

Figure 19: New Kenai ST500 deployment, August 2021 with floating dock for perspective.

Figure 20: Hose clamp F-POD deployment on the Vasko Dock in the Kasilof River, June 2021

Figure 21: Kasilof ST500 dock piling welded bracket deployment, June 2021.

Figure 22: ST600 hosed clamped to a dock piling in the Kasilof River.

Figure 23: Boat surveys on the Kenai River, September 2021.

Figure 24: Commercial fishing boats in the Kenai River, August 2022

Figure 25: Commercial fishing boats and skiffs in the Kasilof River, August 2022.

Figure 26: Commercial fishing tender with transporter skiff and commercial fishing boats in the background.

Figure 27: Belugas (ripples in the water) overlapping with commercial transporter skiffs and commercial fishing boats at the end of the commercial fishing season, September 8, 2021.

Figure 28: Dipnetters in the Kenai River July 2022; orange standard deployment buoy in foreground.

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