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# Beluga Whale Acoustic Monitoring During Pile Driving at the Port of Alaska, 2021

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**Beluga Whale Acoustic Monitoring  
During Pile Driving at the Port of Alaska, 2021**

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## ABSTRACT

Pile driving activities associated with the construction of the petroleum and cement terminal at the Port of Alaska (POA) in Anchorage, Alaska, occurred between April and November during the ice-free season of 2020 and 2021. The POA implemented a comprehensive marine mammal monitoring and mitigation program to reduce potential impacts of pile driving on marine mammals in Cook Inlet, as required by the Marine Mammal Protection Act and Endangered Species Act. During the 2021 open water season, the National Marine Fisheries Service (NMFS) funded a marine mammal passive acoustic monitoring (PAM) project concurrently with the POA monitoring and mitigation program; four moorings were deployed at two stations north and south of the port docks. The aim of the PAM project was to 1) determine if pile driving activities would deter belugas from crossing the port area, and 2) compare visual sightings and acoustic detections to determine the level of missed beluga presence by both monitoring methodologies.

Between 3 June and 6 October 2021, belugas were acoustically detected for a total of 48 days at the north PAM station and 40 days at the south PAM station. Based on a port basin crossing duration of 38 to 96 minutes (1<sup>st</sup> and 3<sup>rd</sup> quartiles of visually observed crossings), 5 of 345 acoustic encounters at each PAM station were attributed to beluga crossings. All five acoustic crossings occurred more than 48 hours after a pile driving event. No acoustic encounters were detected during pile driving events or within 1 hour after an event, suggesting belugas either avoid the port basin during pile driving or remain silent during their crossing. For impact pile driving, the acoustic encounter rate gradually increased with time after a pile driving event until reaching the baseline conditions at > 48 hours from the event. The increase with time for vibratory pile driving was less marked, suggesting belugas may have a lower aversion to vibratory than impact pile driving. Spatial displacement from the port basin could cause the loss of access to habitat farther north in Knik Arm, which is known to be critical beluga foraging grounds from mid-August to late October. We recommend exploring the correlation between the documented spatial displacement by pile driving activities at the port basin and the presence of Cook Inlet belugas in Eagle Bay and Eagle River to test this hypothesis.

When concurrent visual sightings and acoustic detections were compared, only 7 of the 20 sighting groups (sightings with unequivocal acoustic assignment) were acoustically detected. These sightings had a median group size of 10 whales. The 13 sighting groups acoustically missed had a median group size of 3 whales; small groups may be acoustically cryptic when crossing the port basin and more easily missed during PAM efforts. A total of 17 acoustic encounters out of the 31 detections with visual effort were missed visually. The acoustic characteristics of the missed encounters suggest they also consisted of small group sizes. The results from this study suggest that when belugas cross the port basin in small groups they tend to be visually and acoustically cryptic, thus making monitoring and mitigation efforts challenging.



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## INTRODUCTION

Impact pile driving is a method used to install piles for marine and inland water construction projects using high-energy impact or vibratory hammers. The installation of hollow steel piles in this manner can produce extremely high sound levels in the surrounding waters, as well as in the air (Dahl, 2015). In-water pile driving is one of the anthropogenic activities considered to be highly relevant for noise impact to marine mammals (Richardson et al. 1995). During construction of the petroleum and cement terminal at the Port of Alaska (POA) in Anchorage, Alaska, in 2020, multiple 1-inch-thick round steel piles with 24-inch, 36-inch, 48-inch, 72-inch, and 144-inch diameters were driven into the seafloor. A confined bubble curtain system was used, when feasible, to attenuate noise radiation. Median source levels (RMS SPL) at 10 m for these piles ranged from 158.5 to 207 dB re 1  $\mu$ Pa, and mean 10-m peak sound pressure for all pile driving ranged from 195 to 219 dB re 1  $\mu$ Pa (Reyff 2021a, Reyff et al. 2021b). The POA implemented a marine mammal monitoring and mitigation program, as required by NMFS-issued Incidental Harassment Authorizations (85 FR 19294, 6 April 2020) and a Biological Opinion. The maximum distances determined by the sound source verification results to reach potential behavioral harassment of marine mammal species (Level B take) from vibratory pile driving was determined to be 33.1 kilometers (km) from the pile and for impact pile driving 13.6 km from the pile (Reyff 2021, Reyff et al. 2021). In view of these distances, and due to the geographical characteristics of Knik Arm, being a narrow waterway of shorter width than the level B take distances above with the port located at its entrance, there was a concern for temporary habitat abandonment due to the possible displacement effects of the noise disturbance at the entrance of the arm. The NMFS Alaska Region funded visual and passive acoustic monitoring efforts in 2021 to evaluate potential impacts to beluga whales, including temporary habitat abandonment and spatial displacement, from POA construction activities.

## METHODS

### Passive Acoustic Moorings

We used four low-profile moorings designed to resist the harsh environmental conditions of Cook Inlet (Castellote et al. 2016). Each mooring contained two passive acoustic instruments: an acoustic recorder (Soundtrap ST-500HF, Ocean Instruments NZ) to detect beluga social signals and an echolocation logger (F-POD, Chelonia Ltd.) to detect beluga echolocation clicks. Both instruments were housed within a syntactic foam package with an acoustical release (VEMCO Ascent AR, Innovasea Systems Inc.). The mooring package was connected to a 160 pound (lb) anchor with 5 feet (ft) of 3/8-inch diameter anti-strumming Vectran line (Fig. 1). The acoustic recorder (ST-500) was programmed to sample on a continuous basis in the range 10 Hz to 24 kHz. The echolocation logger (F-POD) scanned on a continuous basis to log the occurrence of high frequency short impulsive signals in the range of 20 to 160 kHz, which are typically used by odontocetes such as beluga whales for echolocation purposes.

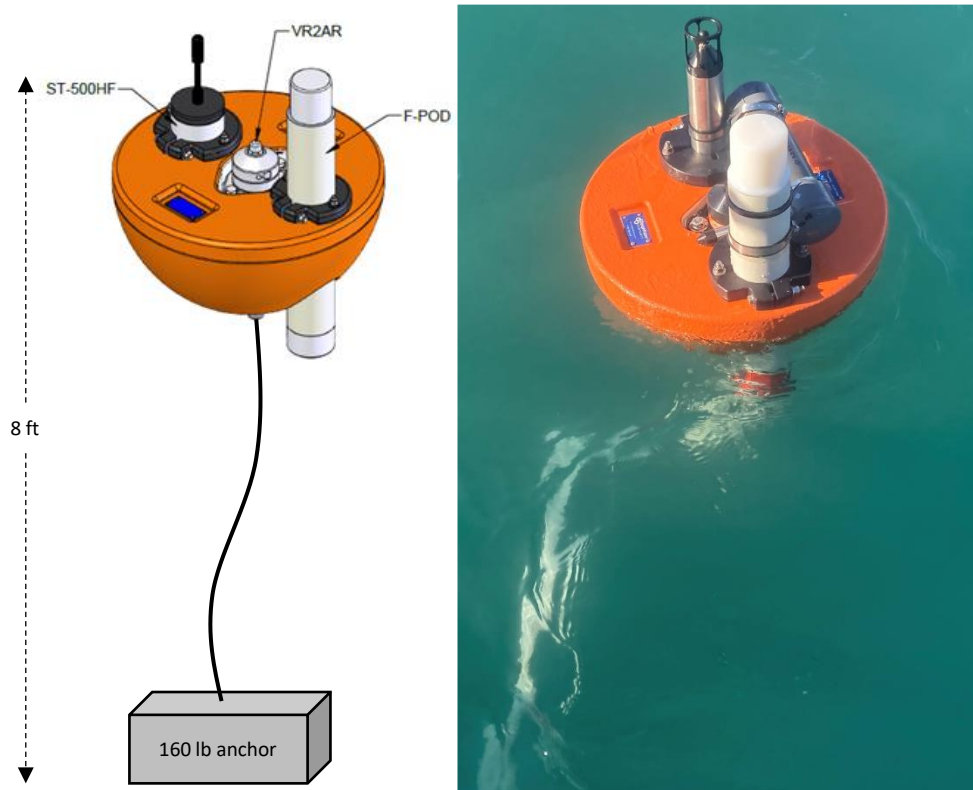


Figure 1. -- Schematic of the low-profile syntactic foam mooring configuration containing a VEMCO Ascent-AR acoustical release, a F-POD echolocation logger, and a ST-500HF acoustic recorder.

### Mooring Deployment Sites

Moorings were deployed in pairs to a depth of 15 to 18 m at mean lower low water (MLLW) with a distance of 274 m between each other at two passive acoustic monitoring (PAM) stations. One PAM station was located at the south side of the port docks, near the entrance to Knik Arm, and the other was located at the north side near Cairn Point (Fig. 2). This configuration allowed for maximum detectability at each station (four instruments concurrently sampling), higher chances of recovering at least one mooring per station, as well as facilitating the analysis of movements across the port area by comparing the timing of detections between the south and north PAM stations (see data analysis).

Marine mammal monitoring during port construction activities indicate beluga whales have a preference for near shore waters when utilizing Knik Arm (i.e., Markowitz and McGuire 2007, Cornick et al. 2011; 61North\_Environmental 2022). Our analysis was designed in conjunction with the visual monitoring effort occurring at the port in 2021 (61North\_Environmental 2022, Easley-Appleyard and Leonard in prep.); the passive acoustic moorings were placed on the east side of the Arm closer to the monitoring platforms.



Figure 2. -- Locations of the four observer stations (red) and the four passive acoustic moorings (yellow) deployed at the North and South PAM stations near the Port of Alaska docks, Knik Arm, Cook Inlet, AK.

### Data Analysis

F-POD data were processed with the dedicated software FPOD.exe version 3.11.23 (Tregenza 2020) using the default settings: “Hi” and “Mod” train filter for high and moderate click train quality, “NBHF” for narrowband high frequency, “Other cet” for other cetaceans than NBHF, “Sonar” for depth sounder and other sonar systems as species classifier, and default train values, except for the “high sp confidence only” as this could reject short or distant beluga click trains. All detections were manually validated with a time resolution of 100 milliseconds (ms), which typically gives a 2 to 3 minute (min) review screen window (depending on the display size). Porpoise click trains are normally attributed to NBHF signals by the software classifier. Beluga click trains could be incorrectly classed as NBHF in some instances where sound propagation could attenuate the lower frequency end of beluga click trains, or when noise masks the lower frequency end of click trains (Castellote et al. 2016). The manual validation analysis eliminated multiple false detections caused by noise from tidal currents or vessel noise, which were easily recognized by the broad frequency coverage and lack of coherence in temporal scale, peak frequency, and amplitude.

Using the whistle and moan detector in PAMGuard software version 2.01.03 (<https://www.pamguard.org/>) and following the configuration detailed in Zhong et al. (2020) allowed for semi-automated detection of beluga social signals (i.e., calls and whistles). The whistle and moan detector was set up with a relatively low detection threshold (8 dB) to reduce the risk of missing beluga signals (at the expense of triggering false detections due to mooring noise or anthropogenic noise). PAMGuard detection results were manually validated through visual and aural inspection of spectrograms in PAMGuard Viewer Mode and labeled as either true or false detection.

Beluga whale presence was estimated on a minute basis; any minute in which a beluga echolocation click train, call, or whistle was detected, by either data from ST-500HF or F-POD, was categorized as a detection positive minute (DPM). A DPM could include a single type of beluga whale signal or up to all three types (echolocation, calls, and whistles), and could include signals at different rates (e.g., single call or many calls). This DPM approach reduced the likelihood of overestimation when quantifying beluga whale presence (e.g., avoided using the number of signals detected as a metric of presence). DPMs were grouped into acoustic encounters, and a series of DPMs with silence gaps < 60 minutes between each other were considered as a single encounter.

### **Visual sightings**

The visual observations were collected from 26 April to 17 October 2021 as described by 61North\_Environmental (2022) and Easley-Appleyard and Leonard (in prep.). Teams of visual observers were located at two to four stations along the southern shoreline of Knik Arm (Fig. 2). Observations were made from elevated platforms equipped with 7x50 binoculars, large-aperture binoculars (e.g., 25x), and digital Topcon DT-205 theodolites. Theodolites were linked directly to laptop computers to allow direct input of sighting time and location data into a database. Observers collected data on days with and without pile driving activity at the port.

### **Calculating port basin crossing durations**

Port basin crossing duration was calculated from a selection of beluga sightings. The selection was based on two criteria:

- 1) Beluga groups that did not merge or split while crossing the port basin (i.e., change in group size).
- 2) Beluga groups that did not overlap in time with other groups within acoustic range of the moorings.

Visual criteria were needed because our study design did not allow acoustic localization of sound sources, and it was not possible to resolve the ambiguity in the detection assignment when more than one group of whales was present within acoustic detection range.

The track trajectories of visual groups that met the above criteria were identified and groups were considered to have crossed the port basin when their tracks crossed a perpendicular line to shore at both the North and South PAM stations (Fig. 2). The time of the theodolite location of the first beluga of the group crossing the north and south lines was used to calculate the median and the 25<sup>th</sup> and 75<sup>th</sup> percentile duration of the port basin crossings for all the selected track trajectories.

### **Linking South and North PAM station detections**

Previous studies have shown that belugas primarily transit through this area of Knik Arm (Markowitz and McGuire 2007, Cornick et al. 2011, 61North\_Environmental 2022). Therefore, we used the 25<sup>th</sup> to 75<sup>th</sup> percentiles of the crossing duration for the selected visual track trajectories as the representative crossing time range. Based on that time range, we identified acoustic detections from each PAM station that were within the range and paired them. The first acoustic detection of each encounter was used to calculate the duration it took whales to travel between PAM stations. Based on this information, we calculated the number of “acoustic crossings” (paired PAM detections at both the South and North stations) and single station detections (either the South or North station) per sampled day. For those acoustic crossings concurrent with visual effort, sightings were used to confirm the presence of a single beluga group crossing the port basin.

### **Acoustic detections and pile driving activity**

A rate of single station acoustic encounters was calculated per bin based on how close in time they were from pile driving activity for both impact and vibratory methods. Following Easley-Appleyard and Leonard (in prep.), acoustic detections were binned as follows:

- 1) During a pile driving event.
- 2) 1 hour after a pile driving event.
- 3) 1 to 12 hours after a pile driving event.
- 4) 12 to 24 hours after a pile driving event.
- 5) 24 to 48 hours after a pile driving event.
- 6) More than 48 hours after a pile driving event.

The single station acoustic encounter rate was calculated as the number of detections divided by number of hours sampled for each bin, multiplied by 100. DPM were grouped by type (echolocation or social signals) and by pile driving bin to explore potential changes in vocal behavior based on time from pile driving events.

### **Comparison of visual sightings and acoustic encounters**

The acoustic detection range of beluga calls has been estimated to be 2.2 km for this area of Cook Inlet (Lammers et al. 2012). To be conservative, we added 1.5 km to this range for the comparison between datasets. Two approaches were taken:

- 1) Sighting track locations within the 3.7 km of the moorings were identified and a 30-minute buffer time around the time of the nearest sighting location was used to search for acoustic detections. The buffer time accommodated for underwater whale movements that could not be visually observed, as well as for potential surfacings within the acoustic range that were not added to the track and/or visually missed. This comparison allowed for evaluation of whether any sighting within acoustic detection range was acoustically missed during the monitoring effort.

- 2) The date and times for each acoustic encounter were attempted to be matched with sightings that occurred up to 30 minutes before or after the acoustic encounter start or end time (to accommodate for possible underwater movements or missed surfacings) and within 3.7 km of the mooring locations. This comparison allowed for evaluation of whether any acoustic encounters were visually missed during the monitoring effort.

## RESULTS AND DISCUSSION

### General Acoustic Results

Between 3 June and 6 October 2021, beluga were acoustically detected for a total of 48 days at the North PAM station, and 40 days at the South PAM station. In general, the distribution of positive detection days were very similar between the two PAM stations, with a first peak from 17 May until 1 July, and a second longer period of presence from 8 August until 5 October (the day before mooring recovery; Fig. 3). These results agree with the beluga seasonal presence in Knik Arm documented in previous studies (Castellote et al. 2020, McGuire et al. 2020). A higher number of DPM per day were obtained at the North PAM station, which could reflect a higher concentration of belugas or a difference in the acoustic behavior of whales using this area of the arm.

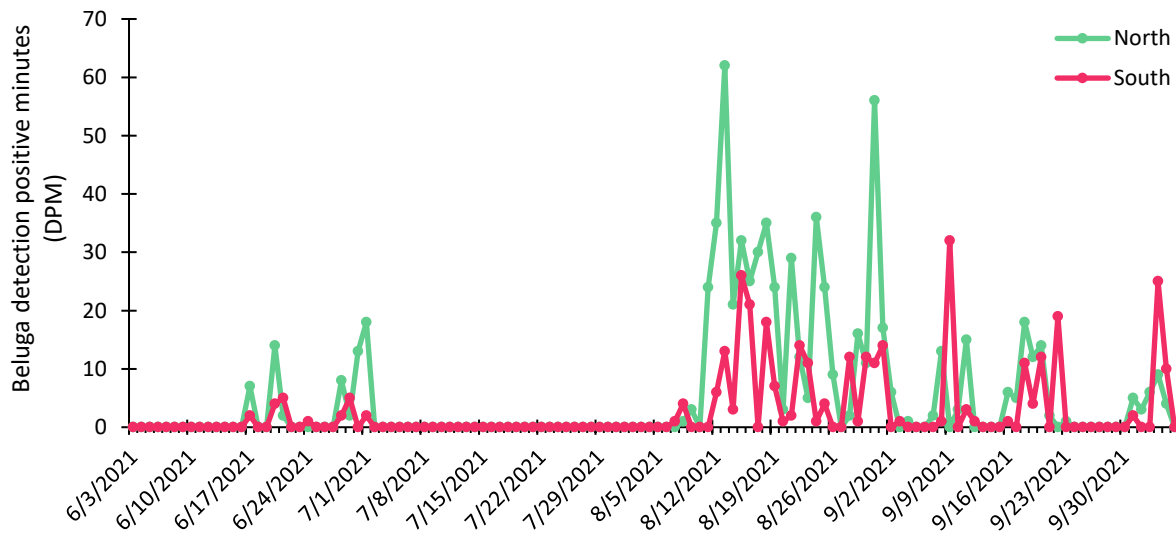


Figure 3. -- Cook Inlet beluga detection positive minutes (DPM) per day at the North and South PAM stations near the Port of Alaska docks, Knik Arm, Cook Inlet, AK.

### Port basin visual crossing durations

From a total of 45 groups of belugas that met the visual criteria, only nine crossed the port basin (Table 1; Fig. 4). For these nine groups, the port basin crossing duration was on average 67 minutes ( $1 \times \text{SD} = 30$ ), median (p50) of 68 minutes, with a 25<sup>th</sup> percentile of 38 minutes and a 75<sup>th</sup> percentile of 96 minutes (Fig. 5).

Table 1. -- Beluga groups from visual sightings included in the crossing duration analysis.

| Encounter ID | Date/time visual encounter (start – end) | Group size | Crossing duration (minutes) | Period to last pile driving |
|--------------|------------------------------------------|------------|-----------------------------|-----------------------------|
| 816          | 4/30/2021 11:10:00 - 12:20               | 4          | 40                          | > 48 h                      |
| 885          | 5/30/2021 6:58:00 - 08:33                | 7          | 35                          | 12-24 h                     |
| 949          | 6/18/2021 10:57:00 - 12:41               | 2          | 21                          | 24-48 h                     |
| 13           | 7/11/2021 9:43:00 - 10:08                | 1          | 70                          | > 48 h                      |
| 1178         | 9/18/2021 13:39 - 15:32                  | 30         | 68                          | > 48 h                      |
| 1198         | 9/20/2021 8:58:00 - 10:52                | 6          | 106                         | > 48 h                      |
| 1204         | 9/20/2021 12:21 - 14:27                  | 14         | 86                          | > 48 h                      |
| 1220         | 9/24/2021 10:56:00 - 12:22               | 5          | 68                          | During sighting             |
| 1235         | 9/25/2021 11:32:00 - 13:26               | 4          | 105                         | During sighting             |

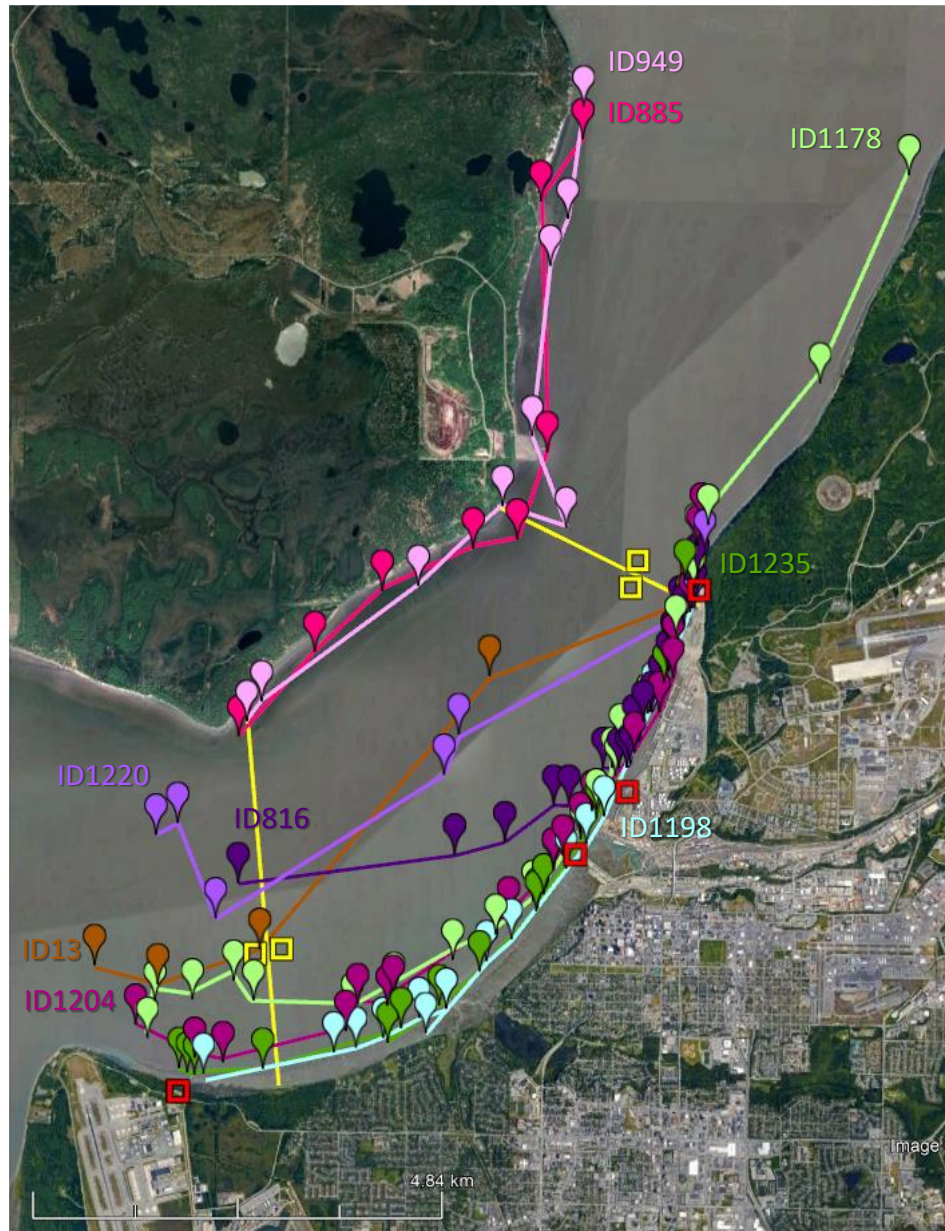


Figure 4. -- Theodolite-based visual tracks of the nine beluga groups from sightings included in the crossing duration analysis. The map also includes the location of the PAM moorings (yellow squares), the basin crossing borders (yellow lines), and the sighting unique IDs for the nine visual encounters (color coded by encounter).

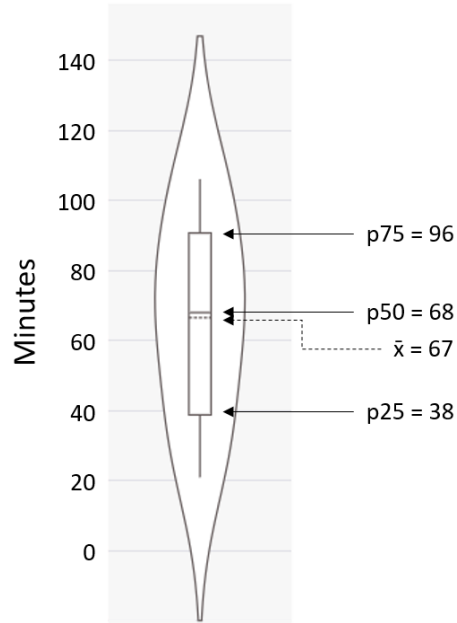


Figure 5. -- Violin plot with percentile distribution (box plot) and mean (dashed line) for the visual-based port basin crossing durations, in minutes, from the nine beluga groups that met the visual criteria.

#### Acoustic detections and pile driving activity

Based on a port basin visual crossing duration range of 38 to 96 minutes (p25 to p75 for the nine visual sighting groups), only five acoustic encounters qualified as acoustic crossings (Table 2). All five acoustic crossings occurred > 48 hours from a pile driving event. The rest of the acoustic detections were grouped in 340 single station events. No acoustic encounters were detected during any pile driving event or within 1 hour of an event. For impact pile driving, the single station encounter rate increased gradually with time after a driving event. For vibratory pile driving, the increase with time was less marked (Fig. 6).

Table 2. -- Date, times, and direction of travel of acoustic crossings.

| Date    | South PAM station time | North PAM station time | Crossing duration (h:mm) | Direction of travel | Time to pile driving event |
|---------|------------------------|------------------------|--------------------------|---------------------|----------------------------|
| 8/23/21 | 6:43                   | 7:56                   | 1:13                     | Northwards          | > 48 h                     |
| 8/31/21 | 4:28                   | 3:12                   | 1:16                     | Southwards          | > 48 h                     |
| 8/31/21 | 22:00                  | 23:08                  | 1:08                     | Northwards          | > 48 h                     |
| 9/16/21 | 19:58                  | 21:24                  | 1:26                     | Northwards          | > 48 h                     |
| 9/19/21 | 11:14                  | 12:08                  | 0:54                     | Northwards          | > 48 h                     |

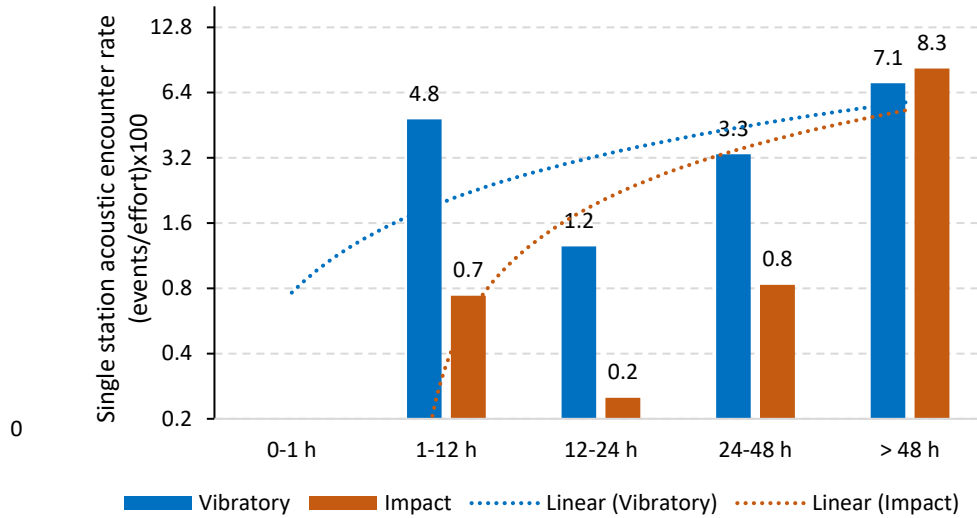


Figure 6. -- Distribution of single station acoustic encounter rates across the different bins based on the time to pile driving events, and linear regression fit for each of the two series.

The lack of acoustic detections in the 0-1 h bin, for both crossing groups or single station encounters suggests belugas avoid using this area of Knik Arm while pile driving is ongoing or soon after it ended, independently of the type of driving method. The higher single station encounter rates in the > 48 h bin, for both impact and vibratory pile driving, suggest beluga have a preference for using this area at least 48 h after pile driving events have concluded. However, when comparing results in the intermediate bins of 1-12 h to 24-48 h between pile driving types, single station encounter rates are higher for vibratory than impact pile driving, suggesting beluga have less aversion for vibratory pile driving. Figure 6 shows a gradual increase in presence with time after pile driving ends, reflecting a residual displacement effect after the disturbance has ended, lasting more than 24 h but for no more than 48 h (assuming the encounter rate for the > 48 h bin can be considered its baseline).

However, it is important to consider these results in the context of the limitations of this study. The acoustic crossings were based on independent detections at each PAM station and we assumed it was the same beluga group detected twice, based on the duration of the visual crossings. It is therefore possible that the paired acoustic detections from each PAM station considered as acoustic crossings could have been generated by different beluga groups. However, single PAM station detections were only observed during pile driving or up to one hour after the event, which is supportive of a preference to cross the port basin in the absence of pile driving activities. It is also possible that belugas were acoustically missed in one of the two stations while crossing, biasing our acoustic results with single PAM station detections that in reality were true crossings. However, we weren't able to find a possible explanation for this bias to occur only during pile driving or up to one hour after the event.

Another important consideration is beluga whale vocal behavior. A decrease or cessation of acoustic activity in the presence of natural predators or human disturbance has been observed in both captive and free-ranging belugas, and it is interpreted as a survival strategy to avoid detection by predators (Schevill 1964, Morgan 1979, L  sage et al. 1999, Karlsen et al. 2002, Van Parijs et al. 2003,

Castellote and Fossa 2006, Castellote et al. 2012, Castellote et al. 2022). A previous acoustic study at the Port of Alaska described “silent behavior” during construction noise, and the only acoustic detections were echolocation signals (Kendall et al. 2013). However, the proportion of echolocation and social signal acoustic detections in our data did not differ between pile driving bins (Fig. 7) and our results do not support a bias in acoustic detection by changes in the whale’s behavior during pile driving activities.

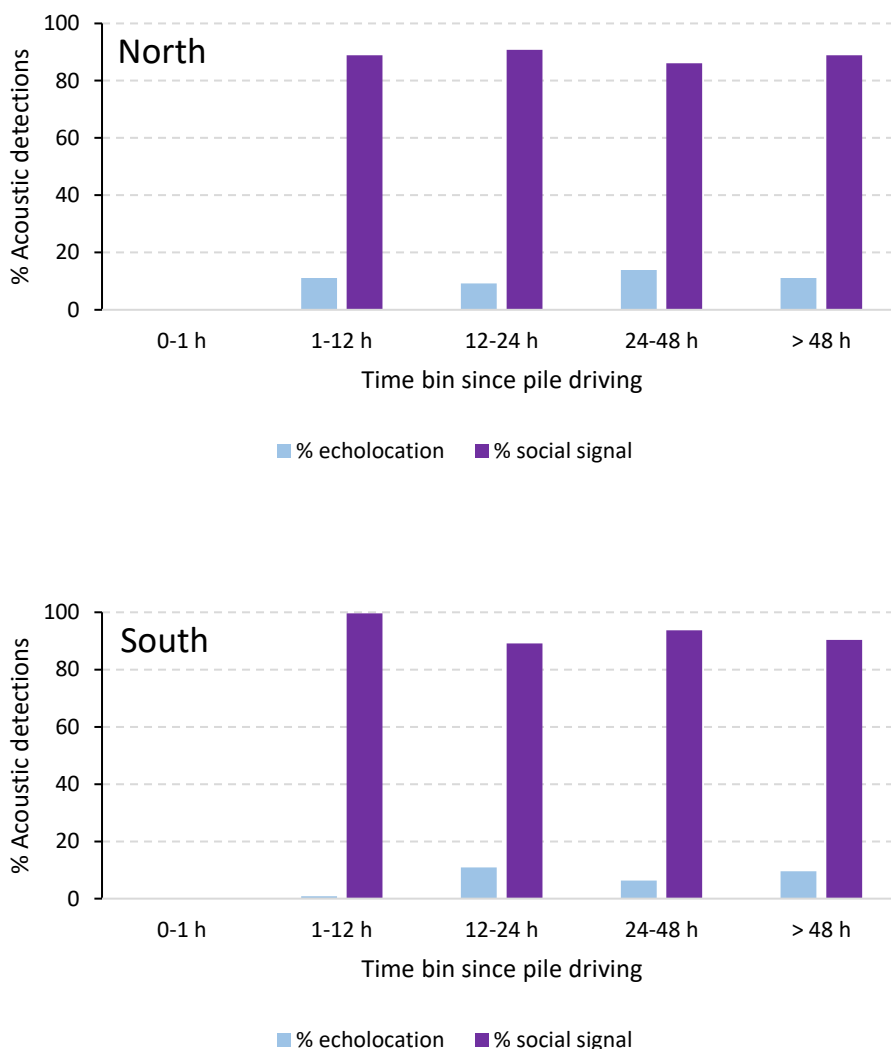


Figure 7. -- Proportion of echolocation and social signal DPM per pile driving bin for each PAM station.

### Comparison of visual sightings and acoustic encounters

A total of 15 sighting groups met the criteria of being spatially and temporally separate enough from other visually sighted groups, and their trajectories were within the 3.7 km of any of the PAM moorings. Five additional sightings overlapped temporally with other visual sightings but were outside the 3.7 km distance to the acoustic moorings, therefore, they were also included in the analysis. Only 7

of the 20 groups were acoustically detected at the closest mooring. These had a median group size of 10 whales, and all but two groups had more than 9 whales (Fig. 9).

Of the 20 sighting groups included in this analysis, 13 sightings were never detected acoustically when within the 3.7 km range from any of the PAM moorings (Fig. 8). The undetected groups had a median group size of three whales, and all but three groups had less than five whales (Fig. 9).

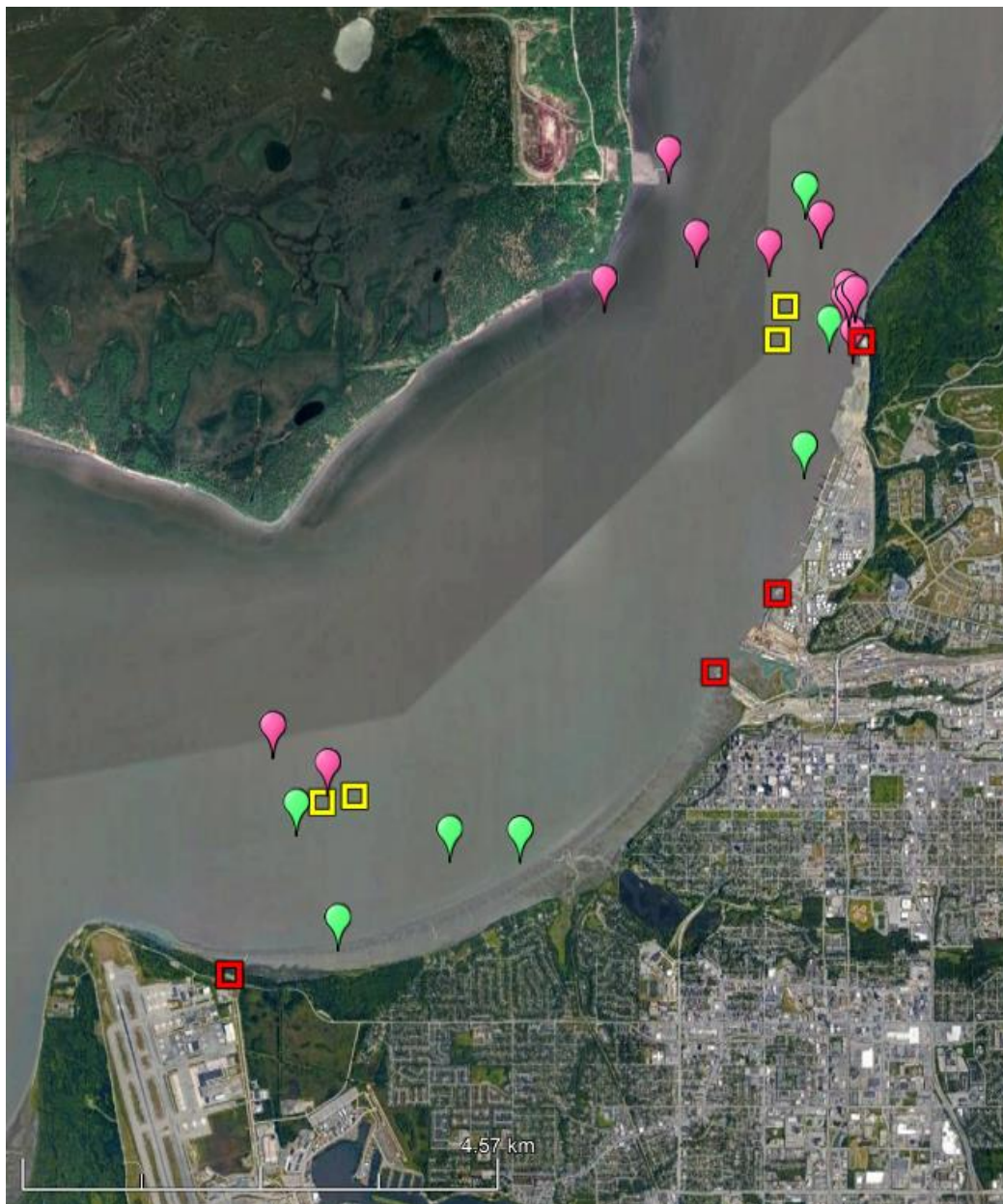


Figure 8. -- PAM locations (yellow squares) and closest sightings for each of the 20 visually isolated groups used in the comparison with acoustic encounters, color coded for acoustically detected (green) or non-detected (pink) cases.

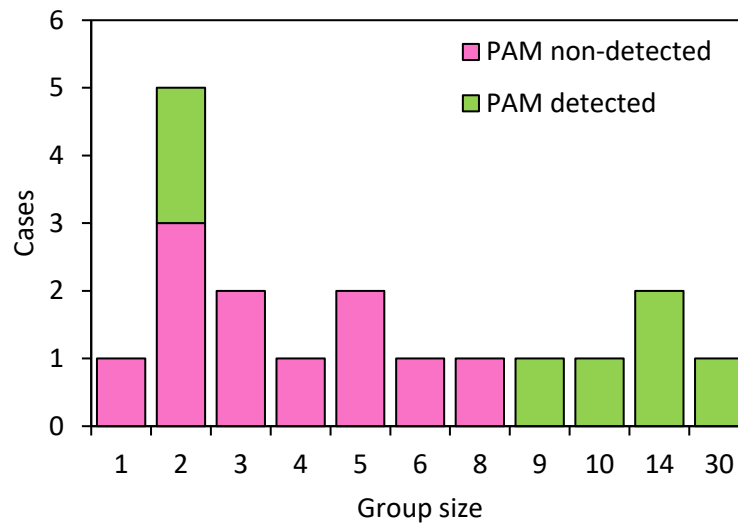


Figure 9. -- Distribution of group sizes of beluga sightings that matched the criteria of no splitting or merging, and no overlap in time or space with other groups within 3.7 km of any of the four acoustic moorings. Sightings are color coded for acoustically detected (green) or non-detected (pink) cases.

These results suggest that when beluga cross the port basin in small groups, they can be acoustically missed, in particular when groups are smaller than nine animals (but note two instances of pairs of belugas acoustically detected). It is logical to think that there is a positive relationship between group size and calling rate, as more calls may be emitted if more whales are present. This relationship has not yet been explored in belugas, but it is known for other odontocete species (i.e., Luís et al. 2015, Papale et al. 2020, Banfield et al. 2024).

A total of 31 acoustic encounters across 21 days occurred during visual effort. Of these, 17 encounters on nine days had no corresponding visual sightings (Fig. 10). The incidence of visually undetected beluga groups was almost two times higher at the North PAM station than the South PAM station, which is surprising as the north area of Knik Arm is narrower than the south area, and moorings were closer to the north observer's station (~800 m in arm width vs. ~1,900 m at the South PAM station). It is possible that the location of the moorings allowed the detection of whales near shore in an area that the observers could not visually observe due to the physical constraints of the visual field (land topography) by Cairn Point for the North PAM station and Point Woronzof for the South station (Fig. 2). However, this would imply that these whales never surfaced within the field of view of the observers, and remained near shore south of Point Woronzof or north of Cairn Point, which is unlikely. Inspection of the acoustic detections for these visually missed belugas suggest these were small groups based on the small amount or absence of overlapping calls and whistles. This suggests that when belugas cross the basin in small groups, they tend to be both visually and acoustically cryptic, making this a difficult challenge for marine mammal monitoring and mitigation efforts.

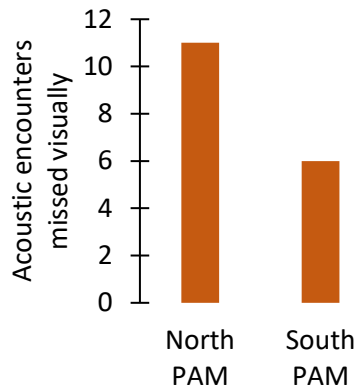


Figure 10. --Total number of beluga acoustic encounters at the North and South PAM stations that were visually missed.

## CONCLUSIONS

The POA implemented a comprehensive visual-based marine mammal monitoring and mitigation program to reduce potential impacts from POA construction activities in 2021. Our analysis indicates that there were multiple small groups of belugas that were either visually or acoustically missed during monitoring efforts. Exploring the addition of commercially available real-time passive acoustic monitoring (moorings with a surface expression to transmit detections in real-time) to future POA monitoring and mitigation programs could potentially further reduce the risk of unintentional behavioral harassment to belugas and other marine mammal species from POA construction project activities. However, our results suggest that even with both visual monitoring and PAM, there is a risk that belugas will transit through the area undetected. Undetected belugas could be exposed to sound exceeding the harassment threshold. Therefore, even mitigation plans with extensive monitoring coverage such as this one with 4 observer stations and 4 PAM stations do not guarantee complete protection and cannot entirely eliminate the risk of involuntary harassment takes.

Additionally, maintaining monitoring effort beyond construction daylight hours, or during days when pile driving is not planned within the construction operational season, is beneficial to better characterize the potential displacement effects to beluga from construction activities at the POA. Habitat north of the POA in Knik Arm is known to be critical foraging grounds for belugas from mid-August to late October (Castellote et al. 2020, McGuire et al. 2020), and loss of access to this habitat could significantly impact this population. While our sample size was small, our results indicate that belugas exhibited spatial displacement for up to 48 hours after a pile driving event. We recommend exploring the correlation between the spatial displacement from pile driving activities at the port basin and the presence of Cook Inlet beluga further up Knik Arm, especially in foraging grounds such as Eagle Bay and Eagle River.

## **ACKNOWLEDGMENTS**

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