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Final report on passive acoustic monitoring for cetaceans in Behm Canal, Alaska

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Executive Summary

The U.S. Navy is interested in understanding marine mammal seasonal occurrence in and around their Southeast Alaska Acoustic Measurement Facility (SEAFAC) located within Behm Canal. In this report, the results from our passive acoustic monitoring efforts to assess the presence and distribution of cetaceans in Behm Canal and neighboring Clarence Strait are described, including the underway sonobuoy deployments conducted during both the spring (8-14 April 2023) and fall (24-29 September 2024) surveys, a brief echolocation detector deployment on the fall survey, and the recorder/echolocation detector cage deployed at the Navy SEAFAC site from 6 February 2023 to 6 February 2024. A total of 38 sonobuoys were successfully deployed with 26.3 hours of recordings monitored. On the spring survey, 15 sonobuoys (14 hours of recordings) were monitored; the only species detected were killer whales (on 4 buoys, all in Clarence Strait). On the fall survey 23 sonobuoys (12.3 hours of recordings) were monitored. Species detected included killer (4 buoys), fin (3 buoys), and humpback (3 buoys) whales; nearly all were in Clarence Strait. Calls from photo identified Alaska Resident killer whales, exhibiting both resting and transiting behavior, were recorded. The echolocation detector was deployed with a surface float for 12 minutes near a group of ten Dall's porpoise, but the data were too noisy to allow for the porpoise to be detected. The instrument cage at SEAFAC was recovered and redeployed by the facilities staff multiple times over the course of the year; a total of 256 days of echolocation data and 270 days of passive acoustic recordings were collected. Humpback whales were detected from April 2023 through January 2024, peaking in June 2023. Killer whales were present year-round, but October/November 2023 had the highest percentage of days per month with detections and July/August 2023 had the lowest. Porpoise (unknown species) were also detected in all months, but detections were highest February through April 2023 and lowest in June and October 2023.

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14. ABSTRACT
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Background

The inland waters of Southeast Alaska (SEAK; Fig. 1) are home to multiple cetacean species listed under the Endangered Species Act (ESA), including humpback whales (*Megaptera novaeangliae* - Mexico Distinct Population Segment) and fin whales (*Balaenoptera physalus*), along with unlisted stocks of killer whales (*Orcinus orca*), minke whales (*Balaenoptera acutorostrata*), harbor porpoise (*Phocoena phocoena*), Dall's porpoise (*Phocoenoides dalli*), and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) (Dahlheim et al. 2009).

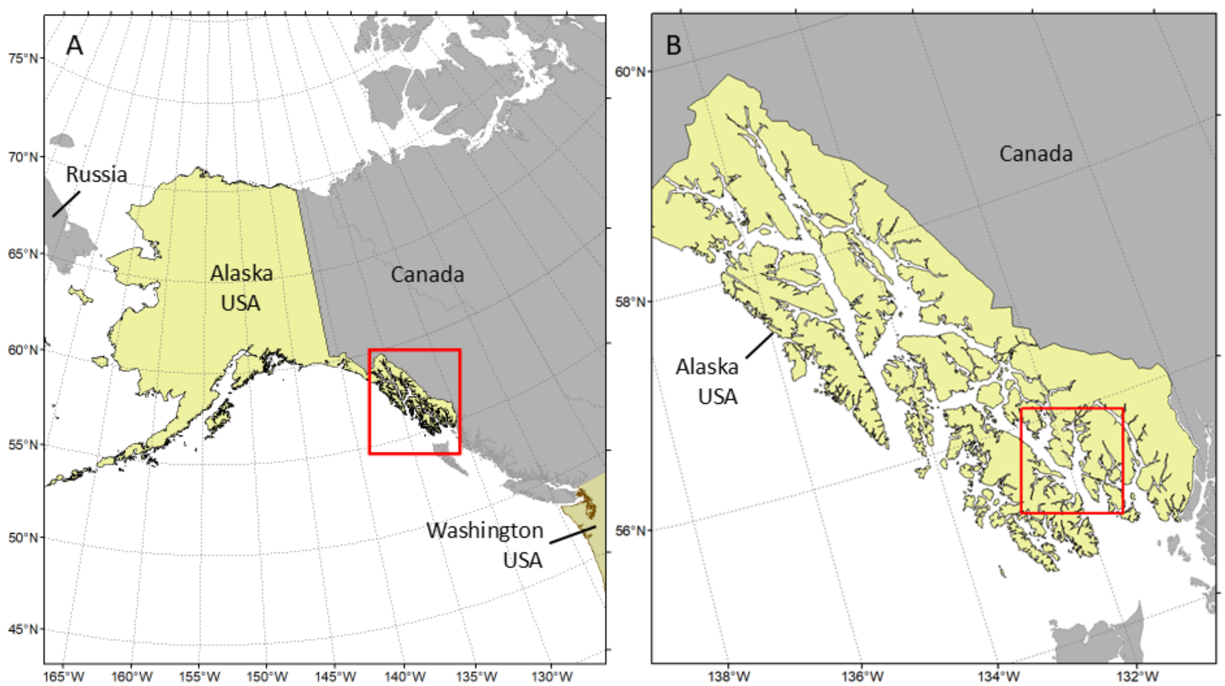

Figure 1. Location of (a) Southeast Alaska (red outline); and (b) zoomed in view showing inner waterways of Southeast Alaska; red outline marks Western Behm Canal and Central Clarence Strait study area.

Data collected during thirty-nine cetacean surveys conducted in this area from 1991 to 2019 have provided information on the distribution of cetaceans (Dahlheim et al. 2009), and the distribution and density of both harbor porpoise (Zerbini et al. 2022, Dahlheim et al. 2015) and Dall's porpoise (Jefferson et al. 2019). However, none of these surveys provided information on winter and early spring cetacean presence and distribution, and many areas within this region remain under-surveyed (see Fig. 2 of Dahlheim et al. 2009).

Behm Canal, near Ketchikan, is one area where spring effort has been sparse and fall effort nonexistent. Filling these data gaps is important for the U.S. Navy, who relies on the Southeast

Alaska Acoustic Measurement Facility (SEAFAC)[1] for acoustic testing of their Pacific Fleet. Western Behm Canal, where SEAFAC is located, is a naturally deep and smooth-sided basin, isolated from the main shipping channels, making it ideal for measuring the quietest of radiated sounds from the fleet. Information on the distribution, density, and timing of cetaceans within Behm Canal and neighboring Clarence Strait is needed by the Navy to support compliance with various environmental statutes and regulations.

Through Interagency and Cooperative Agreements with the U.S. Navy, respectively, the National Marine Fisheries Service Alaska Fisheries Science Center (AFSC) and the University of Washington Cooperative Institute for Climate, Ocean, and Ecosystem Studies (CICOES) partnered to design and conduct two (spring and fall) visual line-transect vessel surveys including underway passive acoustic monitoring, as well as deploy a year-long passive acoustic instrument cage at the SEAFAC site. The visual survey data were analyzed to provide seasonal density and abundance estimates (Zerbini et al. 2025). This report provides information on the year-round seasonal occurrence of cetaceans in Behm Canal and Clarence Strait obtained from the passive acoustic monitoring component of this study.

Methods

The passive acoustic data used to determine cetacean occurrence were collected from sonobuoys deployed during the spring (8-14 April 2023) and fall (23-29 September 2024) Behm Canal vessel surveys, and from a passive acoustic recorder/echolocation detector instrument cage deployed at SEAFAC from 6 February 2023 to 6 February 2024. Data were also collected from an echolocation detector deployed briefly during the fall vessel survey, but were of insufficient quality to be usable.

Vessel Surveys

Survey Design

Because the passive acoustic data were collected opportunistically during the visual line transect vessel surveys, the description of the survey design methods used for both the Spring 2023 and Fall 2024 surveys will be kept brief; see Zerbini et al. (2025) for more details.

The survey area included Western Behm Canal, central Clarence Strait, and their adjacent waters, a region of 1137 km^2 (Fig. 2). This study area was divided into two main strata: Main Bodies of Water ("MBW") which encompassed the main waterways within Behm Canal and

[1] Operated by the Naval Surface Warfare Center Carderock Division under the Naval Sea (NAVSEA) Systems Command

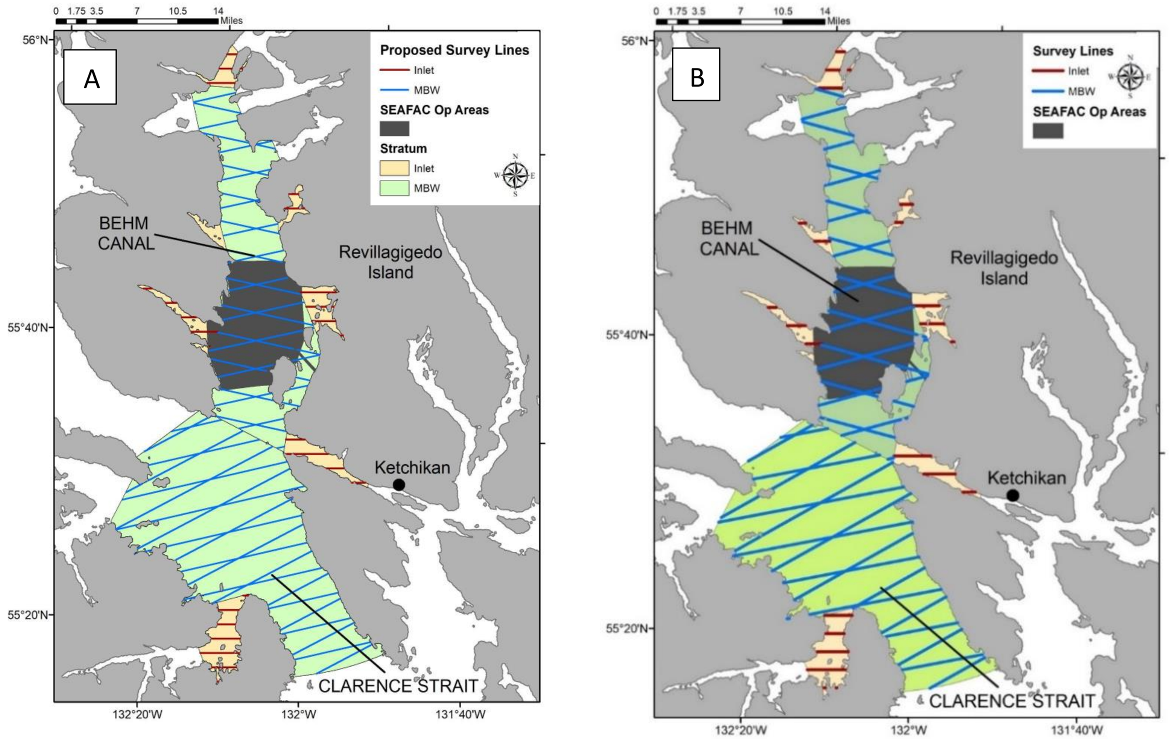

Figure 2. Trackline design (proposed effort) for the vessel survey conducted in Behm Canal and adjacent areas during (a) spring 2023; and (b) fall 2024. Maps are zoomed-in view of the red outline shown in Fig. 1b.

Clarence Strait (1014 km^2 or 89% of the study area), and "Inlets" which included eight small inlets associated with the MBWs (123 km^2 or 11% of the total study area). The track line design - zigzag in MBW areas and parallel within Inlet areas - resulted in equal sampling probability within each stratum. This design was consistent with that used for the summer 2019 survey which occurred from 18 July to 12 August 2019 (Zerbini et al. 2022).

Cruise Information

Both the Spring and Fall surveys were conducted on the M/V Alaskan Song (Fig. 3), a 29 m charter vessel based out of Juneau, AK, from 8-14 April 2023 and 23-29 September 2024, respectively. Both surveys departed from and returned to Ketchikan, AK.

Figure 3. The contracted vessel used for the survey, M/V *Alaskan Song.*

Sonobuoy monitoring

Sonobuoys are free-floating (i.e., drift with the currents), expendable, short-term, passive acoustic devices. They include a hydrophone sensor, surface float with built in VHF antenna and transmitter (Fig. 4a), a weight, and a series of damping plates for decoupling the sensor from surface wave motion (Fig. 4b). There are three different hydrophone sensors within the sonobuoy, one of which is selected prior to deployment: a Directional Frequency Analysis and Recording (DiFAR) hydrophone, located at the bottom of the sonobuoy, which transmits audio data up to 2.5 kHz along with bearing information to the signal, a Calibrated Omni (CO) hydrophone, located ~1 m above the DiFAR sensor, which transmits usable audio data from 5 Hz to 25 kHz (calibrated to +/- 1 dB up to 20 kHz), and a Constant Shallow Omni (CSO) hydrophone that is located at ~14 m below the surface float.

Sonobuoys transform underwater audio signals into electrical signals that are sent in real time via VHF radio waves to receivers on a vessel; no data are stored on the sonobuoy itself. They are programmed to transmit at a specific frequency (160-180 MHz) for a pre-selected duration (0.5 – 8 hrs) and depth (~30-300 m). Their VHF transmission is line-of-sight, and the range depends primarily on the height of the receiving antenna, age of the sonobuoy, sea state, and sonobuoy transmission frequency (typical ranges are ~ 15-30 km). At the end of their programmed lifespan, the sonobuoy scuttles by sending an electrical short to a resistor in the float which deflates the float (Fig. 4c) and floods the electronics housing, causing the sonobuoy to sink to the bottom.

The sonobuoys were stripped of as much plastic and unnecessary components as possible prior to shipping to Ketchikan. However, because the parachute portion of the buoy is removed during this process, the depth setting pins can slide out of the mechanism causing the sonobuoys to deploy to their full 300 m. Because of the shallow depths throughout most of the survey area, the sonobuoys were also modified (i.e., tying the depth mechanism components together) in Seattle to shorten the deployment depth to approximately 30 m (Fig. 5).

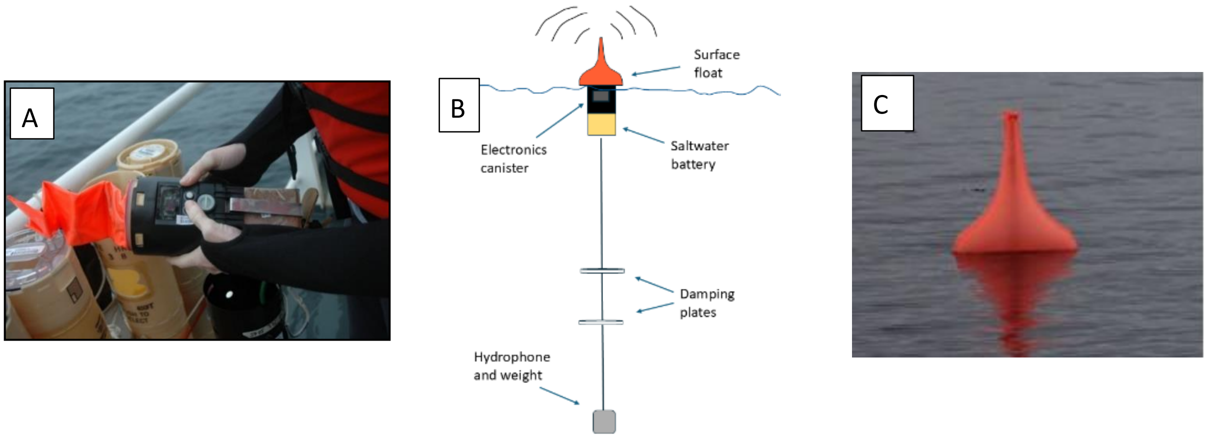

Figure 4. Sonobuoy components (a) prior to deployment, showing float, electronics, and saltwater battery; (b) schematic of a deployed sonobuoy; and (c) deployed sonobuoy showing inflated surface float

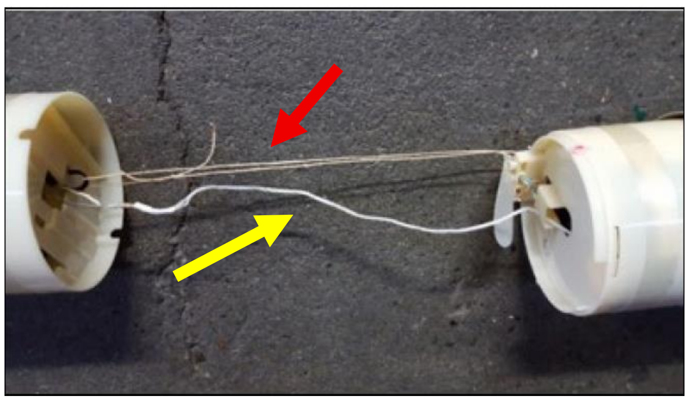

Figure 5. Modification made to sonobuoy to limit deployment depth of sensor to 30m. The tie (red arrow) connects two wire canisters, preventing unspooling of the wire (yellow arrow).

The sonobuoy receiving system was comprised of a receiving antenna, pre-amplifier, sonobuoy receiver, external soundcard, and a laptop computer. The omnidirectional, Morad VHF 156HD VHF marine antenna (tuned to the range 160-180 MHz) was installed on the aft rail of the flying bridge of the M/V *Alaskan Song* at a height of approximately 6 m above sea level (Fig. 6a). A coaxial cable was run from the antenna's preamplifier down to monitoring station on the bridge (Fig. 6b), where it was connected to a G39WSBe WinRadio sonobuoy receiver, then input to a MOTU Ultralite mk3 external soundcard. The soundcard digitized the signal at a sampling rate of 48 kHz, and was connected to a laptop computer where the recordings were monitored in real-time. Having the sonobuoy monitoring station in the bridge allowed the acoustic technician to interact with the captain and visual observation team, and to make simultaneous visual and acoustic observations when possible. A custom MATLAB[2]-based tracking and plotting program

[2] The MathWorks Inc., Natick, Massachusetts: https://www.mathworks.com

(Fig. 6c) was used to plot the sonobuoy deployments and vessel's position (updated every minute via GPS feed into the laptop). All audio data were recorded in ten-minute increments to an external hard drive using ISHMAEL software (Mellinger 2001). For more details regarding sonobuoy data collection protocols, see Crance et al. (2017).

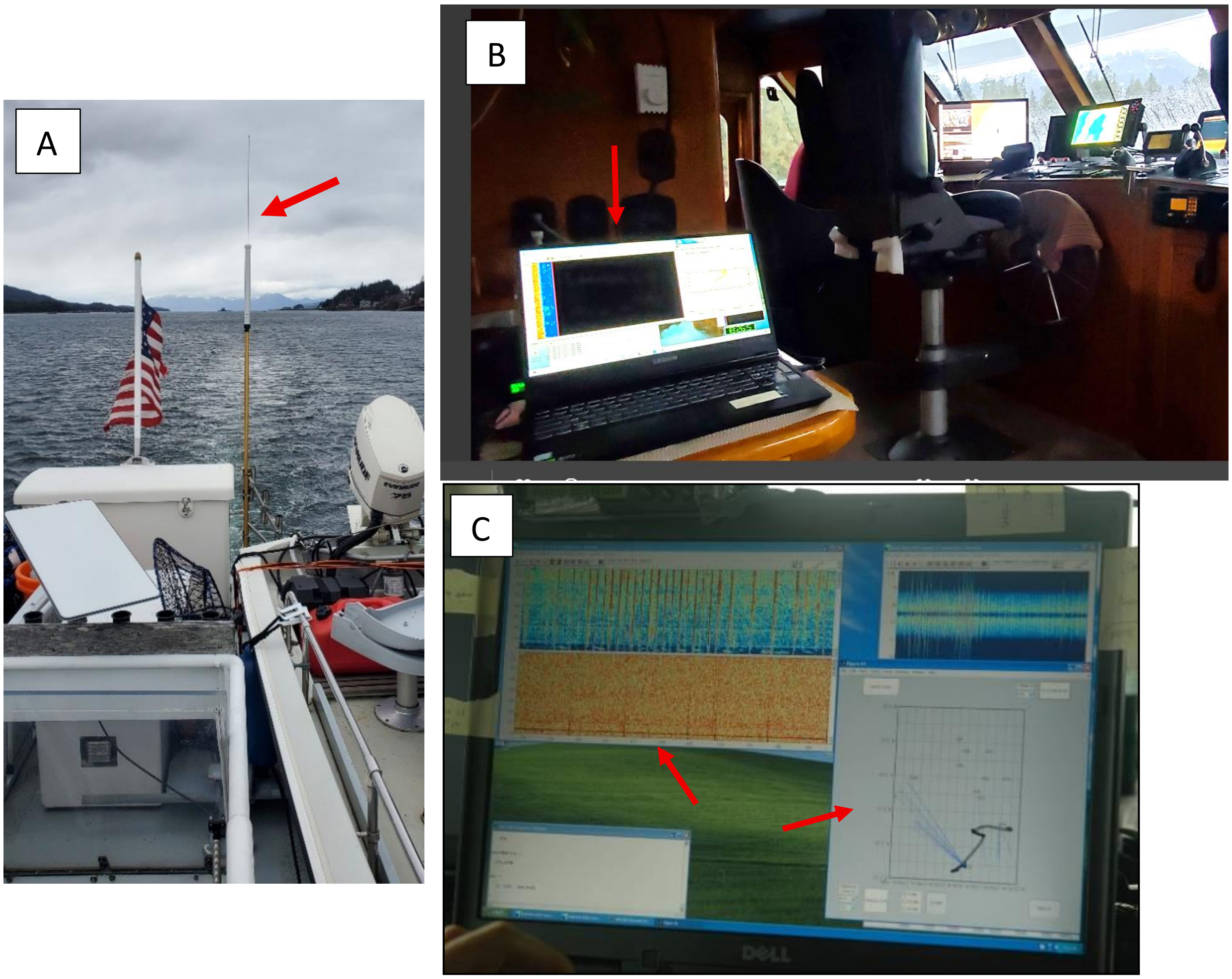

Figure 6. Sonobuoy monitoring system including (a) receiving antenna on aft railing of the flying bridge; (b) monitoring station on bridge (external soundcard and sonobuoy receivers are partially hidden behind laptop); and (c) sonobuoy monitoring screen including scrolling spectrogram (top left) and tracking map (bottom right).

Sonobuoys were deployed by hand over the side rail of the vessel while underway. To acoustically monitor for marine mammals, sonobuoys were deployed every few hours, when possible, throughout the survey area during daylight hours, to obtain an evenly sampled cross-survey census of marine mammal vocalizations.

At the request of the SEAFAC site director, no sonobuoys were deployed within their Ops area (i.e., the dark gray area shown in Figure 2). Furthermore, if a sonobuoy was deployed close to the Ops area, the acoustician communicated the deployment plans to SEAFAC personnel to ensure they approved of the plan and had personnel keeping an eye on the sonobuoy and the Ops area. Due to the narrow survey area, all sonobuoy deployments were limited to those areas where there was no risk of buoys washing up on shore; in addition, the sonobuoys were programmed to scuttle after no more than two hours.

Vessel-based F-POD deployment

In addition to sonobuoys, a small echolocation detector (F-POD, see Long-term monitoring section below) drifting buoy was built to deploy opportunistically during the surveys near groups of Dall's and harbor porpoises for short periods (10-15 minutes). These two species produce echolocation clicks that, while very similar, have a slight difference in centroid frequency that can be used to differentiate between them (Kyhn et al. 2013). It is unknown how well this difference can be detected by the F-POD. These proposed *in situ* recordings will test whether the centroid frequency method of distinguishing between species is possible using the F-POD, and allow for this differentiation on the F-POD deployed at the SEAFAC site as well as those deployed on other long-term moorings. The F-POD was hung with ~ 5 m of rope from a small basketball-sized hard plastic mooring float. The design included a weight hung from the F-POD to keep it vertical and away from the sea surface, but that unfortunately was not communicated to the science crew. The F-POD was programmed to run continuously.

Long-term monitoring at SEAFAC

To monitor cetacean presence during all four seasons, a passive acoustic instrument cage was deployed off the power barge at the SEAFAC static site in collaboration with the SEAFAC personnel. The instrument cage was deployed eight times between 6 February 2023 and 6 February 2024.

Two instruments were mounted in the instrument cage (Fig. 7a): a SoundTrap ST600 STD (Ocean Instruments, Inc., Auckland, New Zealand) passive acoustic recorder (Fig. 7b), and an F-POD D10 (F-POD D10; Chelonia Ltd., Cornwall, United Kingdom) echolocation detector and classifier (Fig. 7c). The ST600 was programmed to collect data continuously at a sampling rate of 96 kHz. This produced a possible frequency range of up to 48 kHz for the recordings, which was sufficient to capture the signals of most vocalizing marine mammal species in the area, excepting porpoises and some beaked whales. The F-POD was programmed to run continuously at the fixed sampling rate of 1000 kHz. This allowed for capture of all echolocation clicks up to 220 kHz, which includes all odontocete species in the area. Because both instruments were running continuously at high sampling rates, battery life and memory card storage space was limited; therefore, it was necessary to swap them out with new units every four months.

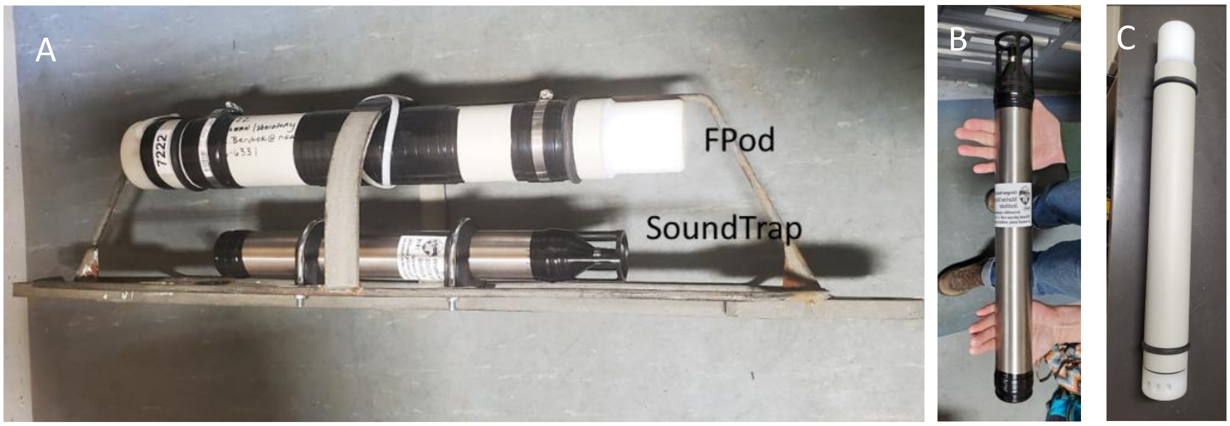

Figure 7. Instrument package deployed at the SEAFAC site. (a) Both instruments installed in cage, ready for deployment; (b) The SoundTrap recorded all marine mammal vocalizations up to 48 kHz; and (c) the F-POD detected echolocation clicks up to 220 kHz.

Because of the classified nature of the measurements conducted by SEAFAC, the AFSC-standard bottom-mounted mooring design was not approved. Instead, it was determined that the best solution would be to deploy the instrument cage off a line secured to a cleat on the power barge at the static site. This allowed SEAFAC staff to recover the instruments prior to any sensitive activities, and to replace the instruments with fresh units.

Trial deployment and recovery

Berchok and Crance from AFSC travelled to the SEAFAC site 9-10 January 2023 to program and secure the two instruments into the cage, to work with SEAFAC staff to rig the cage for deployment, and to train SEAFAC staff on deployments, recoveries, and instrument replacement.

The final rigging design is shown in Figure 8a. The cage was suspended to a depth of ~12 m with a deployment line and 15 lb. weight. Two rubber strips were tied into the deployment line just below the water line to serve as a "snubber", isolating the vertical movement of the instrument cage from the movement of the barge and surface waves.

A trial deployment and recovery operation was run by SEAFAC personnel (under the guidance of AFSC staff) on the power barge on 10 January 2023. For deployment, the mooring was hand-lowered over the side of the barge (Fig. 8b) and secured to a cleat (Fig. 8c) near the crane on the inboard side (facing the suspension barge). Retrieval was also done by hand, although there was an option to recover via the crane if desired.

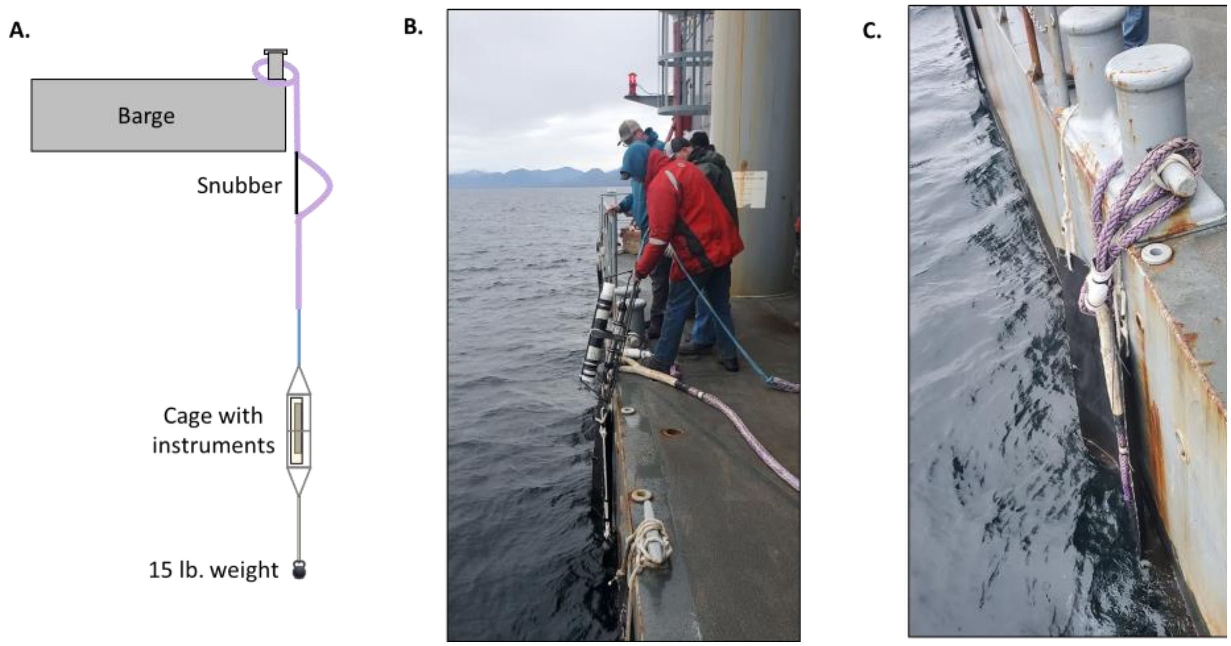

Figure 8. Mooring design and deployment. (a) Schematic of the mooring design; (b) Mooring being hand deployed; and (c) Deployed mooring secured to the cleat.

Long-term deployments and recoveries

Because of the classified nature of the measurements conducted during SEAFAC trials, the instruments were retrieved by SEAFAC personnel whenever these trials were occurring, and re-deployed after the trials concluded. When not in the water, the entire system, including the cage, were placed inside the barge on a foam pad to prevent vibrations or other noise triggering the echolocation detector and filling up its memory card prematurely.

In addition to these SEAFAC-directed recovery/redeployment events, a set of newly refurbished, tested, and programmed SoundTrap ST600 and F-POD units were shipped to SEAFAC every ~ 3-5 months. SEAFAC personnel removed the older units from the cage, and reinstalled the newer units in their place. The older instruments were then sent back to AFSC for processing and analyses of the data, as well as cleaning, testing, and programming the units for redeployment during the next instrument replacement period.

<u>Analyses</u>

Sonobuoys

All sonobuoys were monitored in real time using an Ishmael scrolling spectrogram (Fig. 6c) while listening with headphones. The analyst noted any species or sound sources detected, and any sounds heard of particular interest, and any visual observations of importance conveyed to them by the visual team. For any signals needing further review, the same scrolling spectrogram program was used with the audio files saved to the external drive. A summary list of all species detected on each sonobuoy was then compiled for the entire survey.

Vessel-based F-PODs

The F-POD deployed during the survey was analyzed using the same methods as described below for the long-term passive acoustic monitoring at the SEAFAC site.

SoundTraps

Most of the data from the SEAFAC site were manually analyzed. Autodetectors have historically performed poorly due to several factors including many species producing the same signals and/or calling simultaneously, masking from anthropogenic and environmental sources, and the noise produced by the motion of the barge in the waves. In addition, because it is important not to miss any calls from rare species and/or species that call infrequently (e.g., gray, North Pacific right whales), we cannot lower our autodetection thresholds. This results in a high number of false detections for each species analyzed. Because our analysts review the data for multiple species in one pass, it is faster to process the full mooring manually than to review all false detections for each individual species.

The manual processing of data from the SoundTrap recorder was conducted by AFSC and UW/CICOES following well-established methods using SoundChecker software for comparability and consistency with our database (Wright et al. 2018). All data (i.e., 100% of sound files) were examined by expert analysts specializing in Alaskan species, for the presence of all mid-frequency (i.e., bowhead, right, gray, and humpback whales; walrus; unidentified pinniped; vessel noise and seismic airguns; double-knock calls) and high-frequency (i.e., killer, sperm, and beluga whales; ribbon and bearded seals) marine mammal species.

In summary, raw data were converted into 10-minute wave files. Spectrogram image files were pre-generated from these 10-minute wave files, and displayed as either five rows of 45 s spectrograms (mid-frequency; Fig. 9) or two rows of 45 s spectrograms (high-frequency; Fig. 10) of data at a time. This resolution is ideal for quick visual identification of species and sound sources within these bands, but these image files were also indexed to the wave files for playback and zoom functionality when further verification was needed by the analyst. For all species or signals including in the frequency band, the analyst marked its presence in each image file with a yes, no, or maybe. Data results were aggregated into ten-minute time bins (corresponding to the ten-minute wave files), for comparison among species from the different frequency bands.

In addition, recordings were normalized by effort, creating the metric *Daily Calling Activity* (CA_{daily}), defined as the percentage of ten-minute time intervals with the presence ('yes' results only) of that species or sound source per day. It is important to note that CA_{daily} does not indicate number of call detections or number of vocalizing animals. We also calculated the Percentage of Days (PoD) per month with detections.

Our in-house, machine-learning software, INSTINCT (Woodrich and Berchok 2020), was used to process these data for the presence of low frequency species (i.e., fin and sei whales). INSTINCT is a modularized data pipeline software that contains methods to train and apply cutting-edge EfficientNet deep learning models for detection/classification of signals in large-scale acoustic datasets. An expert analyst performed a review of all signals flagged as detections. For ease of comparison among species, the verified INSTINCT results were aggregated into the same ten-minute time bins used by the SoundChecker analysis using in-house MATLAB code.

Static site F-PODs

F-PODs were analyzed using custom F-POD software (designed by Chelonia, Ltd.) to identify echolocation detections (Fig. 11). F-POD data were run through the software click classifiers to identify porpoise clicks. As mentioned above, the echolocation clicks from harbor and Dall's porpoise are very similar in frequency and cannot currently be distinguished with the F-POD classifier; as such, both species are grouped together and noted only as 'porpoise'. For comparison with the other species run through the manual SoundChecker analysis, porpoise detections were aggregated into ten-minute time bins, using in-house MATLAB code.

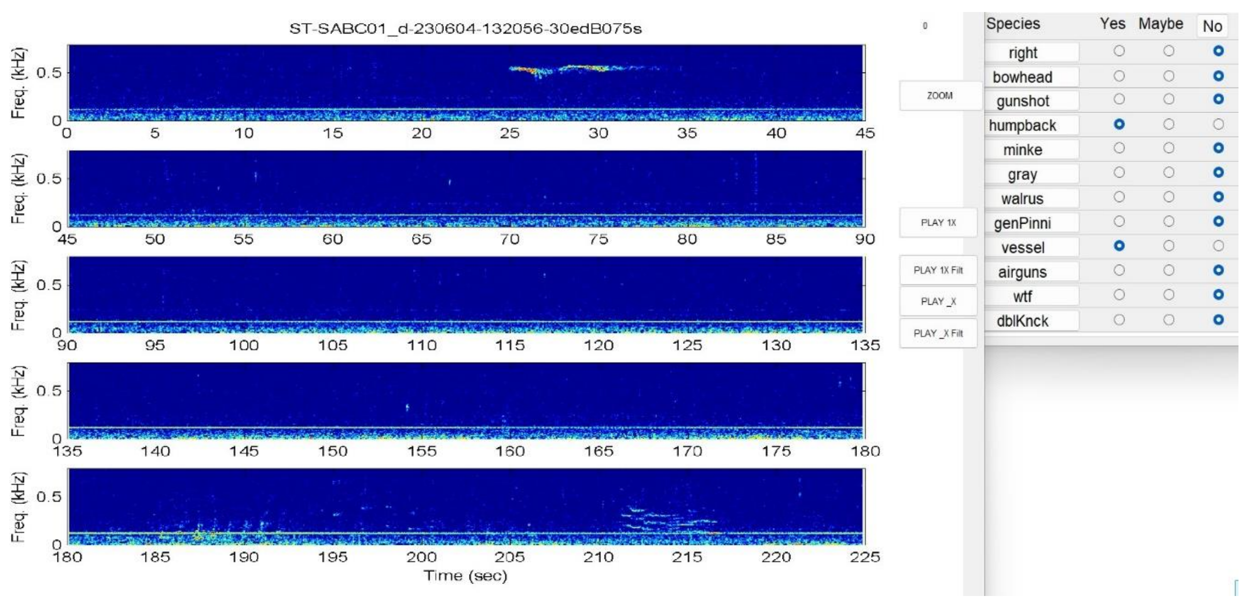

Figure 9. Screenshot of SoundChecker analysis software for the mid-frequency analysis showing humpback whale detections (e.g., at 25-35, 185-191, and 212-217 s). Data from 4 June 2023 at 13:21 UTC. Panel to right shows species included in mid-frequency analysis. Vessel in this case includes noise from the power barge.

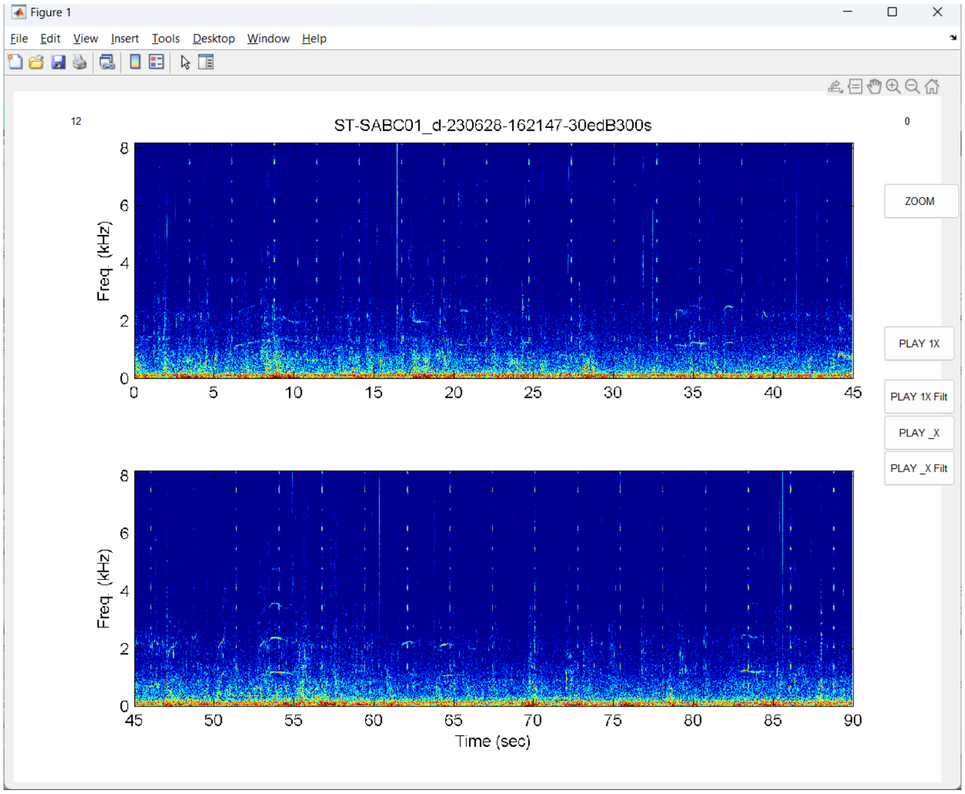

Figure 10. Screenshot of SoundChecker analysis software for high frequency analysis showing killer whale detections (e.g., at 7, 35, and 54 s). Vertical dotted bars are ADCP pings from the power barge (e.g., at 27 and 62 s). Data from 28 June 2023 at 16:21 UTC.

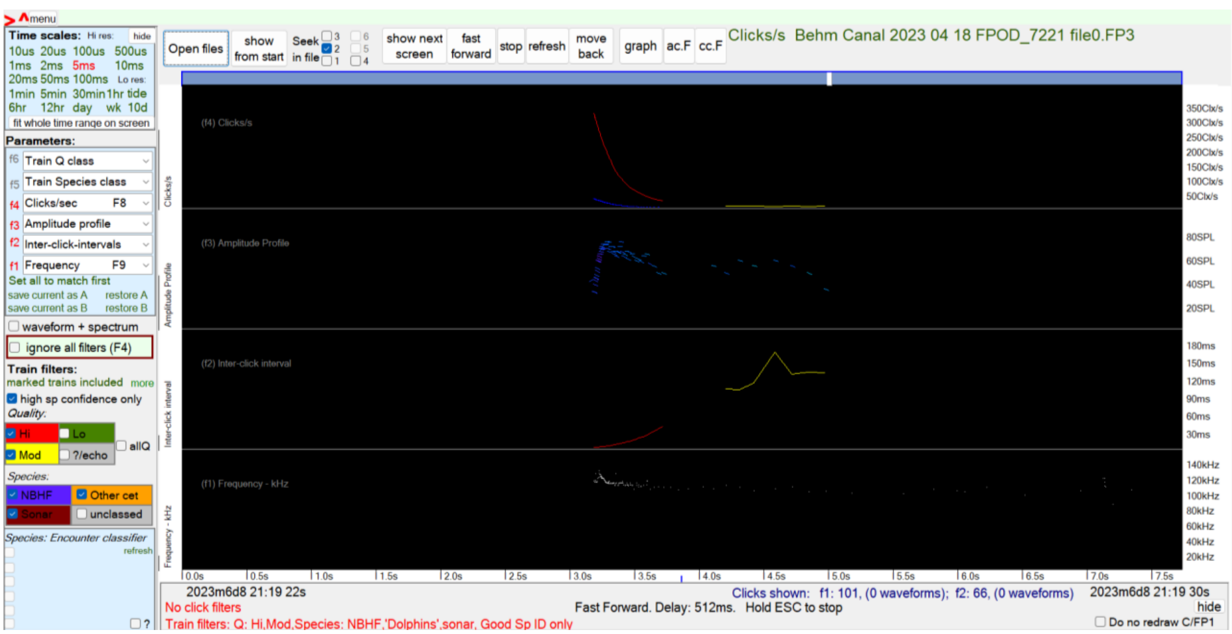

Figure 11. Screenshot of F-POD software analysis showing a porpoise click train. Top row: number of clicks per second. Second row: Amplitude of the clicks (SPL). Third row: Inter-click interval (ms). Bottom row: Frequency of clicks (kHz). Data from 8 June 2023 at 21:19 UTC.

Results

<u>Sonobuoys</u>

A total of 44 sonobuoys (18 and 26, respectively) were deployed on the Spring 2023 and Fall 2024 surveys (Fig. 12). Of these, 38 (15 Spring, 23 Fall) successfully transmitted data for an overall success rate of 86% (83% Spring, 88% Fall). The floats never appeared at the surface for the six units that failed.

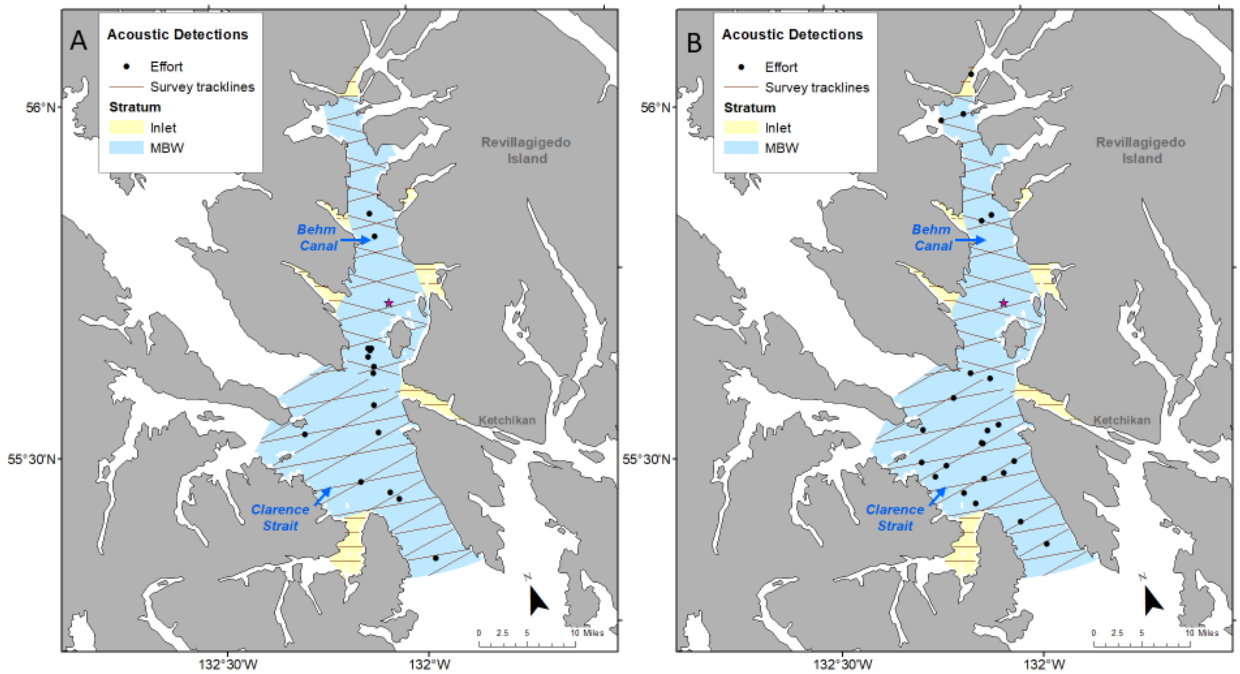

Figure 12. Sonobuoy effort during the Behm Canal vessel surveys in (a) Spring 2023; and (b) Fall 2024. Black dots mark locations of successful sonobuoy deployments. Brown lines = survey track lines. Light blue and light yellow shading = MBW and Inlet areas, respectively. Magenta star = SEAFAC static site.

Spring 2023 survey

For the Spring 2023 survey (Table 1), no sonobuoys were deployed on the first two days at SEAFAC's request, but were deployed on each of the remaining five days. All were 2008 Sparton 53F sonobuoys. For the fifteen successful units, six were programmed to scuttle after two hours, seven after one hour, and two after a half-hour; total listening time was 13.2 hours. Two of the units were deployed in DiFAR mode, the rest were deployed in Calibrated Omni mode. The only species detected was killer whales, heard on four sonobuoys (27% of all successfully deployed buoys) that were deployed in Clarence Strait on 12-13 April 2023 (Fig. 13a). All detections of the killer whales were in same general area as, but slightly south of, the visual sightings (Fig. 13b, dark orange circles). No marine mammals were acoustically detected within

Behm Canal. Reception range, from the sonobuoy to the vessel, was much less than expected (i.e., between 2-7 km), and resulted in a shortened monitoring time as the vessel moved away from the deployment site at the 10 kt survey speed.

Table 1. Sonobuoy deployment details and results from the Spring 2023 vessel survey. Gray rows indicate sonobuoys that did not successfully deploy. Sono year is manufacture date, CO = Calibrated Omni and DF = DiFAR sensor. Detections on each sonobuoy are marked with 0 (none), 1 (yes), and 2 (uncertain) for each species.

SB#	Deployment Date/Time (Local Time)	Latitude (°N)	Longitude (°W)	Water depth (m)	Sono Year	Scuttle time (hrs)	Sensor Chosen	Humpback Whale	Fin Whale	Killer Whale
1	10-Apr-2023 07:08	55.510	-131.892	1000	2008	2.0	CO	0	0	0
2	10-Apr-2023 08:23	55.666	-131.777	7000	2008	1.0	CO	0	0	0
3	10-Apr-2023 12:45	55.835	-131.754	400	2008	1.0	CO	0	0	0
4	10-Apr-2023 13:12	55.759	-131.751	660	2008	1.0	CO	0	0	0
5	10-Apr-2023 13:51	55.701	-131.771	500	2008	1.0	CO	0	0	0
6	10-Apr-2023 18:53	55.509	-131.884	440	2008	1.0	CO	0	0	0
7	11-Apr-2023 07:19	55.506	-131.888	400	2008	1.0	CO	0	0	0
8	11-Apr-2023 12:10	55.473	-131.899	320	2008	4.0	CO	0	0	0
9	11-Apr-2023 14:59	55.420	-132.123	84	2008	1.0	CO	0	0	0
10	12-Apr-2023 08:50	55.195	-131.926	400	2008	0.5	DF	0	0	0
11	12-Apr-2023 09:16	55.180	-131.903	440	2008	0.5	DF	0	0	1
12	12-Apr-2023 11:25	55.282	-131.943	380	2008	2.0	CO	0	0	1
13	12-Apr-2023 15:13	55.324	-132.024	460	2008	2.0	CO	0	0	1
14	13-Apr-2023 08:01	55.295	-131.959	366	2008	2.0	CO	0	0	1
15	13-Apr-2023 11:44	55.386	-131.937	420	2008	0.5	DF	0	0	0
16	13-Apr-2023 13:25	55.427	-131.926	200	2008	2.0	CO	0	0	0
17	13-Apr-2023 19:32	55.482	-131.892	300	2008	1.0	CO	0	0	0
18	14-Apr-2023 10:22	55.498	-131.899	360	2008	1.0	CO	0	0	0

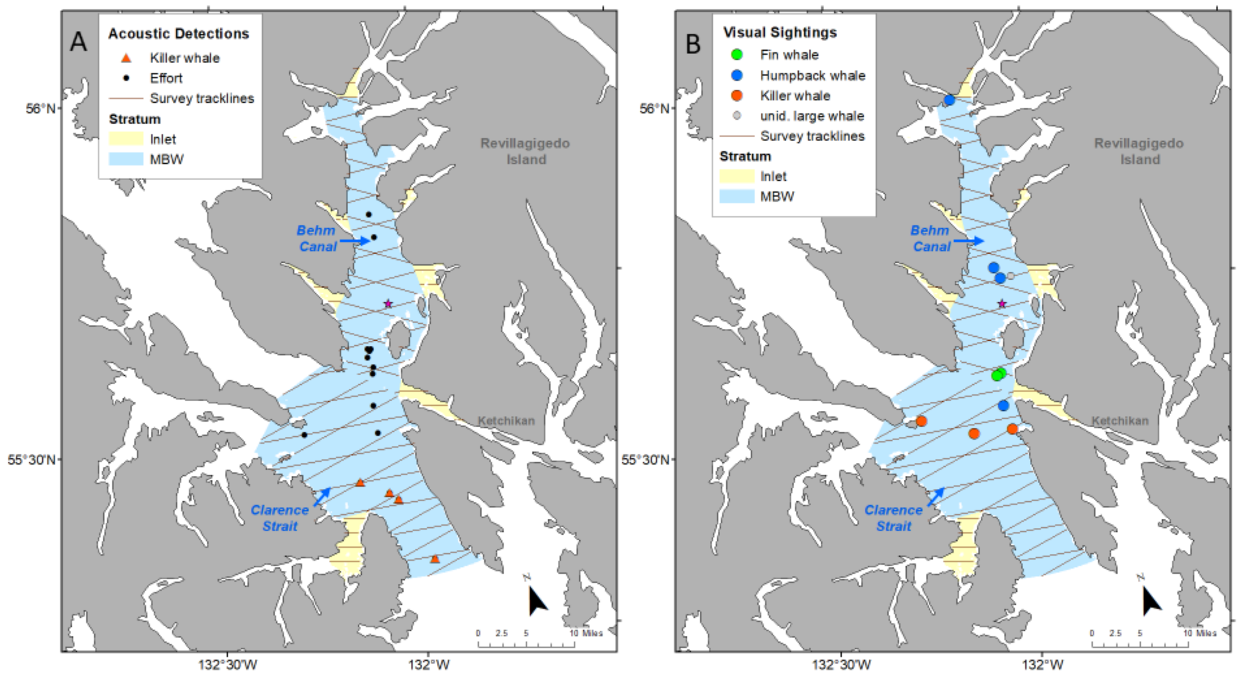

Figure 13. Detections and sightings during the Spring 2023 Behm Canal vessel survey. (a) The only species acoustically detected were killer whales, shown in dark orange. Black dots mark sonobuoys with no detections; and (b) Visual sightings (circles) of fin (green), humpback (blue), killer (dark orange), and unidentified large whales (gray). Other items included are survey track lines (brown lines), MBW and Inlet areas (light blue and light yellow shading), and SEAFAC static site (magenta star).

Fall 2024 survey

Sonobuoys were deployed on all seven days of the Fall 2024 survey (Table 2), most were 2008 Sparton 53F sonobuoys; however, two, which both failed, were manufactured in 2014. Of the 23 successful units, twelve were programmed to scuttle after two hours, eight after one hour, and three after a half-hour; total listening time was 12.3 hours. Only one sonobuoy was deployed in DiFAR mode, the rest were deployed in Calibrated Omni mode.

Killer whales were detected on two sonobuoys (9% of successfully deployed buoys, Fig. 14a), humpback whales were detected on one sonobuoy (4%, Fig. 14b), and fin whales were detected on three sonobuoys (13%, Fig. 14c). Nearly all detections were heard in Clarence Strait, with only one (humpback whale on 23 September 2024) heard within Behm Canal. Locations of acoustic detections and visual sightings were fairly similar for fin and killer whales, while humpback whales showed an inverse trend (Fig. 14d). A significant highlight from the fall survey is that sonobuoys were able to be deployed near photo-identified Alaska resident killer whales (Fig. 15) on two different days, when the whales were exhibiting different behaviors (resting vs. transiting).

Table 2. Sonobuoy deployment details and results from the Fall 2024 vessel survey. Gray rows indicate sonobuoys that did not successfully deploy. Sono year is manufacture date of unit, CO = Calibrated Omni and DF = DiFAR sensor. Detections on each sonobuoy are marked with 0 (none), 1 (yes), and 2 (uncertain) for each species.

SB#	Deployment Date/Time	Latitude (°N)	Longitude (°W)	Water depth (m)	Sono Year	Scuttle time (hrs)	Sensor chosen	Humpback whale	Fin whale	Killer whale
1	23-Sep-2024 13:27	55.696	-131.754	500	2008	2.0	CO	1	0	0
2	23-Sep-2024 14:37	55.852	-131.736	300	2008	2.0	CO	0	0	0
3	23-Sep-2024 15:37	55.905	-131.682	400	2008	2.0	CO	0	0	0
4	24-Sep-2024 10:01	55.854	-131.797	200	2008	2.0	CO	0	0	0
5	24-Sep-2024 12:47	55.692	-131.784	500	2008	2.0	CO	0	0	0
6	25-Sep-2024 12:33	55.465	-131.899	250	2008	0.5	DF	0	0	0
7	25-Sep-2024 14:28	55.395	-131.917	330	2008	2.0	CO	0	0	0
8	25-Sep-2024 15:05	55.325	-132.000	600	2008	2.0	CO	0	1	2
9	25-Sep-2024 19:26	55.315	-132.063	210	2008	2.0	CO	0	1	2
10	26-Sep-2024 08:24	55.362	-132.084	100	2008	2.0	CO	0	0	0
11	26-Sep-2024 10:24	55.392	-131.951	500	2008	2.0	CO	2	0	0
12	26-Sep-2024 11:08	55.336	-131.911	300	2008	1.0	CO	0	0	0
13	26-Sep-2024 13:25	55.455	-132.033	400	2014	2.0	CO	0	0	0
14	26-Sep-2024 13:32	55.455	-132.008	400	2008	1.0	CO	2	0	0
15	26-Sep-2024 15:03	55.481	-131.943	175	2008	1.0	CO	0	0	0
16	27-Sep-2024 13:07	55.426	-132.093	130	2008	1.0	CO	0	0	0
17	27-Sep-2024 13:11	55.424	-132.111	150	2008	1.0	CO	0	0	0
18	27-Sep-2024 17:29	55.375	-131.973	600	2008	1.0	CO	0	0	1
19	27-Sep-2024 18:38	55.377	-131.977	250	2008	1.0	CO	0	2	0
20	27-Sep-2024 19:39	55.294	-132.043	300	2008	1.0	CO	2	0	0
21	28-Sep-2024 09:10	55.246	-131.946	333	2008	2.0	CO	0	0	1
22	28-Sep-2024 12:52	55.320	-131.944	430	2014	2.0	CO	0	0	0
23	28-Sep-2024 12:55	55.323	-131.947	430	2008	2.0	CO	0	0	2
24	29-Sep-2024 12:04	55.203	-131.901	400	2008	0.5	CO	0	0	0
25	29-Sep-2024 15:43	55.379	-132.142	100	2008	0.5	CO	0	1	0
26	29-Sep-2024 16:33	55.351	-132.119	50	2008	1.0	CO	0	0	0

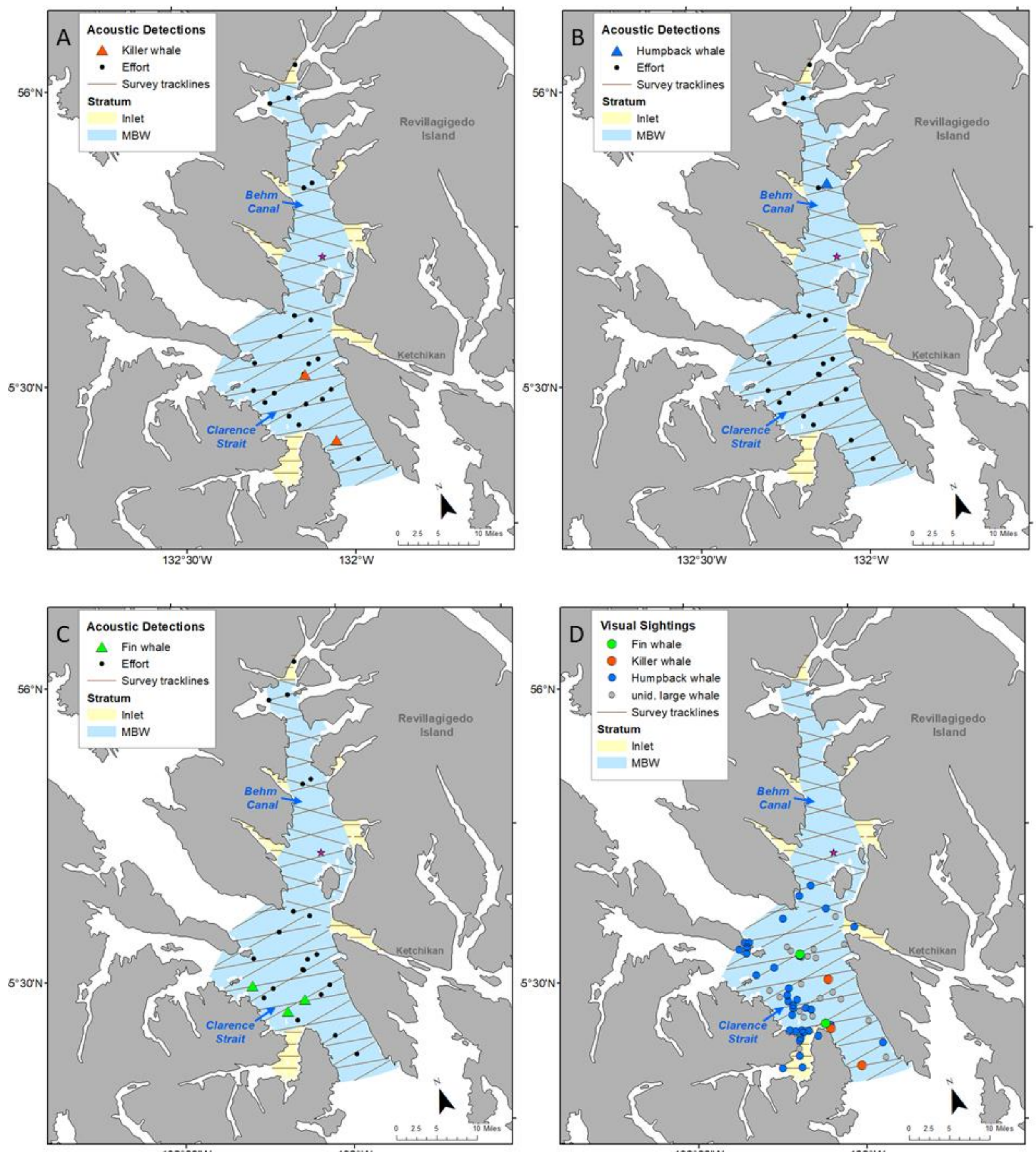

Figure 14. Detections and sightings during the Fall 2024 Behm Canal vessel survey. Acoustic detections of (a) killer whales; (b) humpback whales; and (c) fin whales. Black dots mark sonobuoys with no detections. Visual sightings (d, circles) of fin (green), humpback (blue), killer (dark orange), and unidentified large whales (gray). Other items included are survey track lines (brown lines), MBW and Inlet areas (light blue and light yellow shading), and SEAFAC static site (magenta star).

Although the majority of the sonobuoys deployed during the fall survey successfully transmitted, the reception range from the sonobuoy float to the vessel was again extremely limited, with most buoys detectable within only 4 km and exhibiting a clear signal only within 2 km. In addition, many did not consistently scuttle at their programmed time, and had to be manually scuttled.

Figure 15. Alaska resident killer whale, photo and ID by Janice Waite (AFSC) taken on Fall 2024 vessel survey under National Marine Fisheries Service Permit No. 25563-02.

Vessel-based F-PODs

The F-POD was deployed within 100 m of a group of approximately 10 Dall's porpoises on 28 September 2024, and recorded for approximately ten minutes from 03:36 UTC to 03:48 UTC. Due to the presence of an extreme amount of noise in the file, it was not possible to analyze these data for the presence of porpoise signals.

Long-term monitoring at SEAFAC

The instrument cage was deployed eight times, for a total of 6341 hours between 6 February 2023 and 6 February 2024. All deployment and retrieval dates and times were determined by a combination of the log maintained by the SEAFAC staff, the temperature records from the F-POD and SoundTrap, the tilt-sensor data from the F-POD, and visually and aurally reviewing the spectrograms. These dates and times are listed in Table 3.

There were a few cases where the instruments, primarily the F-PODs, either stopped recording prior to recovery, were masked by self-noise for proper analysis to be conducted, or experienced a glitch resulting in a data gap. Table 4 shows the number of days the instrument cage was deployed for each month of the study (273 days total), and the number of days the SoundTraps (270 days total) and F-PODs (256 days total) had data available for analysis. The SoundTrap recorders were used for all species except porpoises, which were analyzed from the F-PODs. There were only three marine mammal species detected at the SEAFAC site: killer whales, humpback whales, and the porpoises (unknown species). Only these species are included in Figures 16-18 and Table 5.

Table 3. Deployment and retrieval dates for the instrument cage deployed at the SEAFAC power barge, and the serial numbers of the SoundTraps and F-PODs included in the cage.

Deployment	Deployment Date/Time (UTC)	Recovery Date/Time (UTC)	ST600 S/N	F-POD S/N
BC01-a	2/6/2023 22:52:19	2/27/2023 19:31:57	7171	7222
BC01-b	3/13/2023 17:13:49	3/30/2023 16:40:06	7171	7222
BC01-c	4/10/2023 17:51:05	4/24/2023 16:14:58	7171	7222
BC01-d	5/15/2023 18:13:56	7/8/2023 00:09:49	7622	7221
BC01-e	7/14/2023 16:25:58	9/8/2023 20:24:18	7622	7221
BC01-f	9/9/2023 00:00:04	10/25/2023 16:59:50	7621	7222
BC01-g	11/27/2023 19:01:53	12/7/2023 17:26:17	7621	7222
BC01-h	12/21/2023 18:06:46	2/6/2024 03:35:00	7621	7222

Porpoises

Porpoises showed almost ubiquitous presence, with CA_{daily} near 100%, in the late winter/early spring of 2023 (i.e., February, March, and April), but were present in lower CA_{daily} levels from May 2023 to February 2024 (Fig. 16, top). The Percent of Days (PoD) per month with detections of porpoises was ~75-100% February through April 2023, ~50-75% November 2023 through January 2024, and < ~25% May through October 2023 (Fig. 17, top; Table 5). The lower PoD in 1-6 February 2024 is consistent with calling in February of 2023 not ramping up until closer to mid-month. The median CA_{daily} differed among the four seasons (Fig. 18, orange), but was significantly different (95% confidence, see Fig. 18) for the spring (Mar-May) compared with the summer (Jun-Aug), fall (Sep-Nov), and winter (Dec-Feb). The median CA_{daily} for winter was also significantly different from summer. The median CA_{daily} for porpoises also was significantly different from that for humpback and killer whales in the spring and winter months.

Table 4. Number of days instrument cage was deployed and the number of days of data available for the SoundTrap and F-POD instruments deployed at the SEAFAC power barge. Bold indicates data are missing from that month.

Year	Month	# days deployed	# days effort ST600	# days effort F-POD
2023	Feb	22	22	22
2023	Mar	18	18	18
2023	Apr	15	15	***13***
2023	May	17	17	17
2023	Jun	30	30	***29***
2023	Jul	26	26	***25***
2023	Aug	31	31	31
2023	Sep	30	30	***28***
2023	Oct	25	25	***23***
2023	Nov	4	4	4
2023	Dec	18	18	18
2024	Jan	31	31	***22***
2024	Feb	6	***3***	6
Total		273	270	256

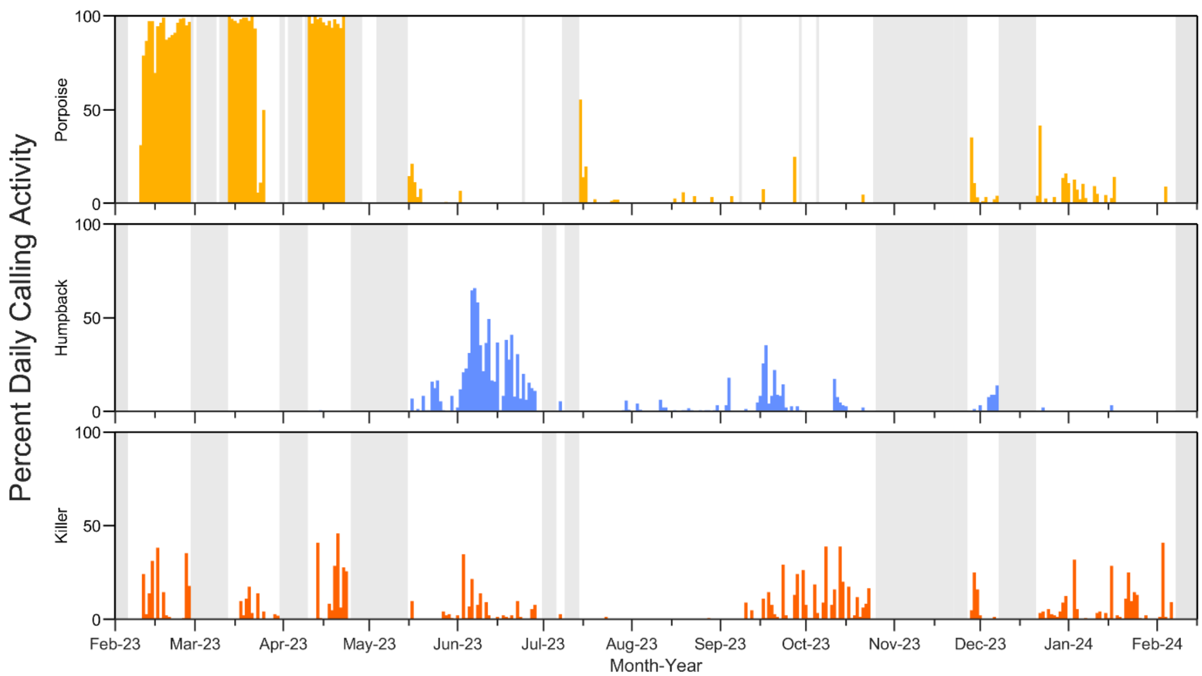

Figure 16. Percent Daily Calling Activity (CA_{daily}) for the three marine mammal species (from top: unknown porpoise, humpback whales, and killer whales) detected at the SEAFAC static site from February 2023 to February 2024. Black lines indicate the CA_{daily} (percent of ten-minute bins of recordings per day with detections of that species). Gray shading indicates periods where no data are available.

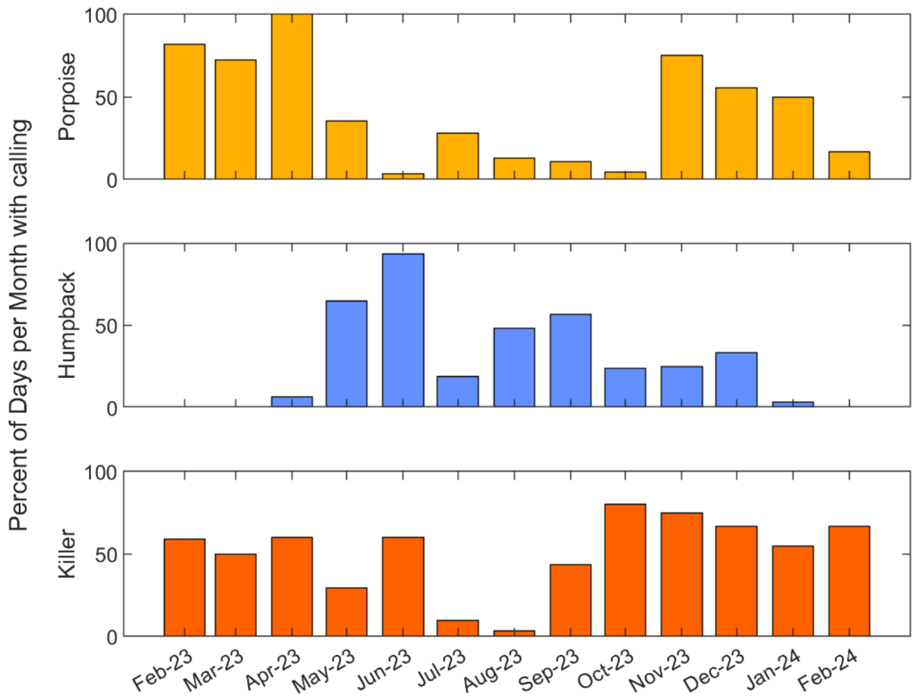

Figure 17. Percent of days (PoD) per month with data that have detections (from top) porpoise, humpback whales, and killer whales at the SEAFAC static site from February 2023 to February 2024. See Table 3 for the number of days per month

Humpback whales

Humpback whales showed a bimodal seasonal presence from April through January (Fig. 16, middle), with CA_{daily} peaking in June 2023. They were detected at low CA_{daily} levels from July 2023 through January 2024, with a second peak occurring in September 2023; none were detected in the late winter/early spring of 2023 (i.e., February-April). Their monthly PoD followed an inverted trend from that of the porpoises, with the highest PoD levels occurring in the late spring to early fall (May-September 2023). Again, June 2023 had the highest PoD at >90%, and PoD was 0 in February of both years and March (Fig. 17, middle; Table 5). There were slight differences in the median CA_{daily} among the four seasons, but none were significant (Fig. 18). Other than the previously mentioned differences with porpoises, humpback whales showed a higher median CA_{daily} from killer whales in the summer and winter months, and a lower median CA_{daily} in the fall, but none of these differences were significant.

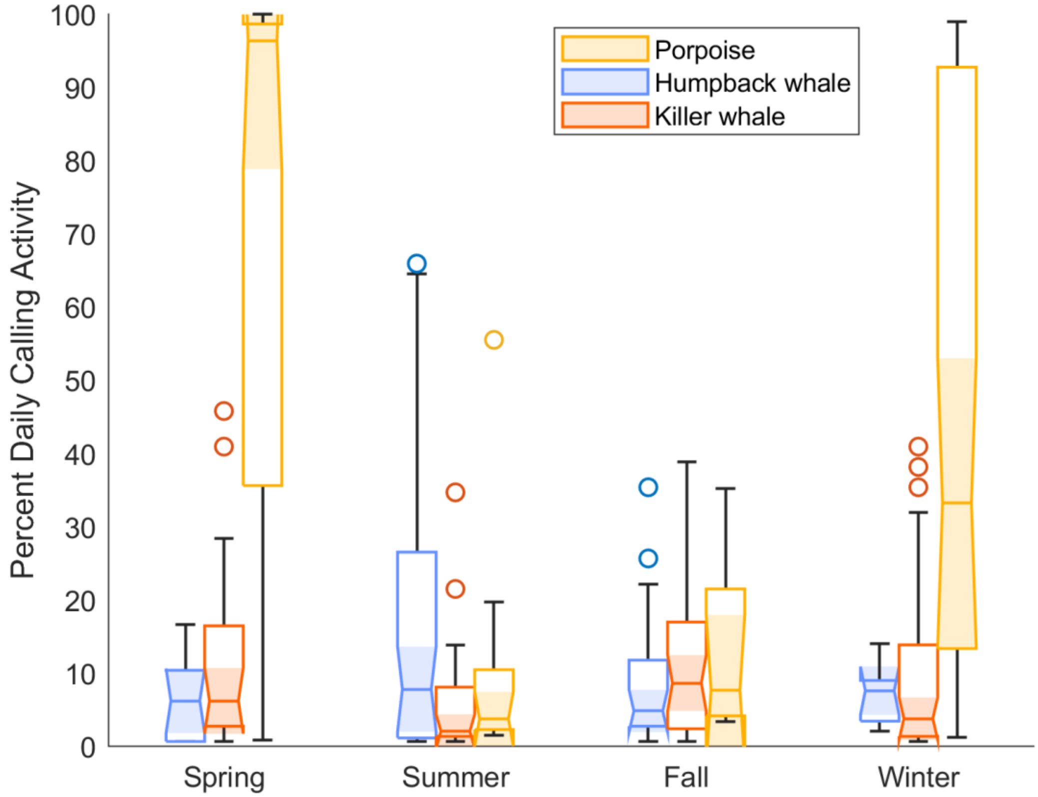

Figure 18. Comparison of Percent Daily Calling Activity (CA_{daily}) among seasons for porpoise (yellow), humpback whales (blue), and killer whales (orange) at the SEAFAC static site. Spring (Mar-May), Summer (Jun-Aug), Fall (Sep-Nov), Winter (Dec-Feb). Only CA_{daily} > 0 are included in plot. Circles indicate outliers, colored lines within boxes are median values. Shaded areas represent a 95% confidence interval (CI) around the median; folded regions indicate high uncertainty in true median. Shaded areas that do not overlap have different medians at the 0.05 significance level (based on normal distribution).

Killer whales

Killer whales were detected throughout all deployments (i.e., February 2023 through February 2024). Their CA_{daily} was not as high as the spring porpoises or the June humpbacks, but were generally at a higher, more consistent level throughout the year (Fig. 16, bottom). This is more evident in Figure 17 and Table 5, which show the PoD levels between 50-75% for all months except May, July, and August of 2023 where levels were at 25% or less. The median CA_{daily} for killer whales was highest in the spring and fall, but not significantly (Fig. 18). See the humpback whale and porpoise sections above for comparisons of median CA_{daily} among the species.

Table 5. Number of days, and percentage of days, per month with detections of killer whales, humpback whales, and porpoise at the SEAFAC static site. Percentages are based on the available number of days of recordings for the SoundTrap (Killer and Humpback whales) and F-POD (Porpoise) instruments (see Table 4).

Year	Month	# days with detections			% days with detections		
		Killer Whale	Humpback whale	Porpoise	Killer Whale	Humpback whale	Porpoise
2023	Feb	13	0	18	59.1	0	81.8
2023	Mar	9	0	13	50.0	0	72.2
2023	Apr	9	1	13	60.0	6.7	100
2023	May	5	11	6	29.4	64.7	35.3
2023	Jun	18	28	1	60.0	93.3	3.4
2023	Jul	2	4	7	9.5	19.0	28.0
2023	Aug	1	15	4	3.2	48.4	12.9
2023	Sep	13	17	3	43.3	56.7	10.7
2023	Oct	20	6	1	80.0	24.0	4.3
2023	Nov	3	1	3	75.0	25.0	75.0
2023	Dec	12	6	10	66.7	33.3	55.6
2024	Jan	17	1	11	54.8	3.2	50.0
2024	Feb	4	0	1	66.7	0	16.7
Total		126	90	91	46.7	33.3	35.5

Discussion

The passive acoustic monitoring results produced by this study support and extend those reported from both its visual survey component (Zerbini et al. 2025) as well as past visual surveys through the SEAK region (Dahlheim et al. 2009, 2015; Zerbini et al. 2022). Humpback whales, killer whales, and porpoise were detected in the long-term recordings at SEAFAC across all four seasons (i.e., spring (Mar-May), summer (Jun-Aug), fall (Sep-Nov), and winter (Dec-Feb)). Not only does this broaden the overall seasonal presence of these species in Behm Canal to now include winter, it provides evidence of their occurrence throughout a greater proportion of the spring, summer, and fall, where vessel surveys have been limited to fairly brief periods of time (i.e., one to two weeks).

Although small gaps exist in these long-term recordings throughout the year, several trends were seen for the three species detected. First, it is important to note that neither Daily Calling Activity (CA_{daily}) nor Percent of Days (PoD) per month with calls represent the number of individuals present in an area; one lone individual or a group of 100 could produce the same results. Furthermore, these data cannot capture individuals that are present but not vocalizing.

However, CA_{daily} and PoD do capture differences in persistence of each species around the SEAFAC site, with the former indicating how long the species persists around the site in a particular day, and the latter showing how many days even the slightest occurrence is being detected.

Porpoises had a near-ubiquitous CA_{daily} and PoD starting in mid-February (winter) through nearly the end of April (spring). The Spring 2023 vessel survey ran for a week starting in mid-April, so it occurred during this high peak in both CA_{daily} and PoD porpoise occurrence (Fig. 19a). Although porpoises were detected in all months of the year, their CA_{daily} was substantially lower outside the Feb-Apr period, with the second largest peak occurring in mid-July, which was half the CA_{daily} of the main period. This supports the much lower porpoise results obtained from the Fall 2024 visual survey that occurred for a week at the end of September (Fig. 19b). Comparing to the stratum-specific seasonal density estimates obtained from the visual sightings made on the Summer 2019, Spring 2023, and Fall 2024 vessel surveys (i.e., Fig. 7, MBW_2 stratum, of Zerbini et al. 2025), the trends seen in the long-term passive acoustic data suggest the majority of detections were likely from Dall's porpoise. The distribution of sightings during the spring and fall surveys (Fig. 19) also show a spatial difference between the two species, with harbor porpoise occurring closer to shore and the Dall's porpoise out in deeper water (such as around the SEAFAC static site). Lastly, not only was porpoise CA_{daily} high in the spring and winter seasons compared to summer and fall, its median spring and winter CA_{daily} greatly exceeded that seen in any season for the humpback and killer whales. One caveat of the porpoise results from the long-term deployments is that there was a lot of noise produced by the barge and rigging that made it difficult to confidently verify many of the porpoise detections. These were left as 'maybe' detections and left out of the results; as such, the porpoise results reported here are likely an underrepresentation of porpoise presence in Behm Canal.

Humpback whales at the SEAFAC site followed an opposite seasonal trend from that of the porpoises, rising to their highest CA_{daily} and PoD levels in the summer, with no detections in February or March. The peaks in June (CA_{daily} exceeding 50%) and September (CA_{daily} ~ 25%) suggest a migratory basis for their seasonality in Behm. Humpback whales undergo extensive annual migrations from warm water, southern breeding grounds to colder, northern feeding grounds (Baker et al. 1986). However, detections in December suggest some individuals either delay their southbound migration, or potentially remain in SEAK year-round (Straley et al. 2018). The majority of humpback sightings during the Spring 2023 survey were in Behm Canal (Fig. 13b), whereas those during the Fall 2024 survey were primarily concentrated in or near Clarence Strait (Fig. 14d), although no sightings were made close to the SEAFAC site. The density estimates for humpback whales reported by Zerbini et al. (2025) were low in general, but were higher for the fall than spring and summer.

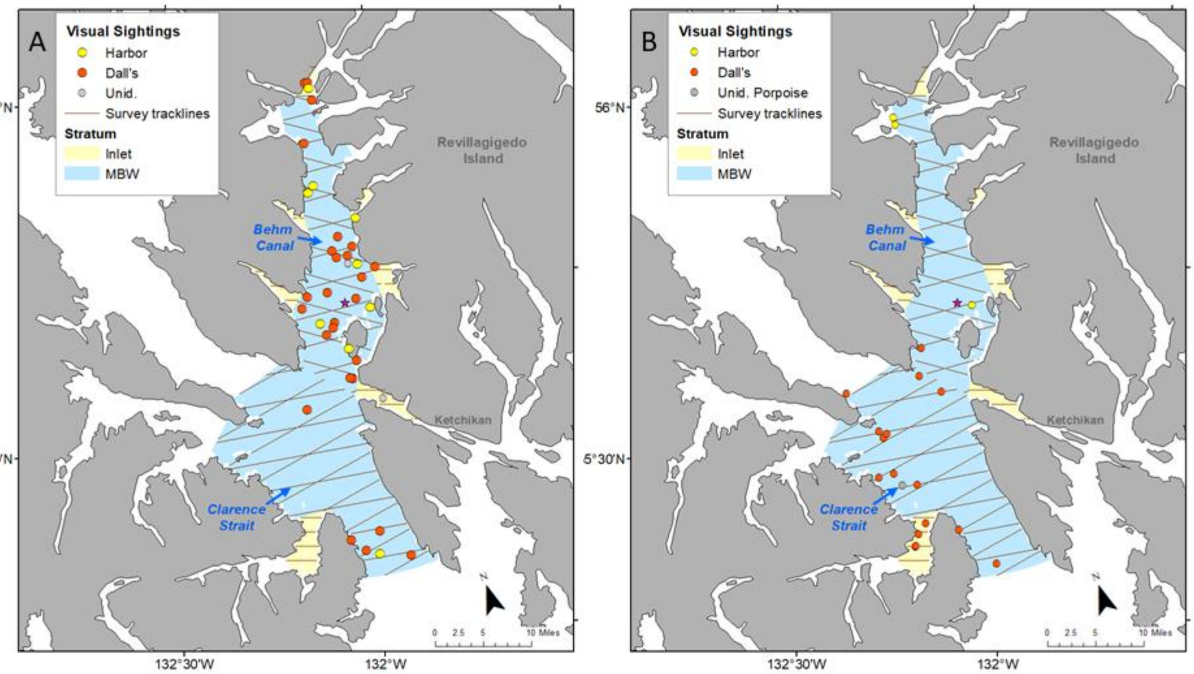

Figure 19. Harbor and Dall's porpoise sightings during the (a) Spring 2023; and (b) Fall 2024 Behm Canal vessel survey. Harbor porpoise are shown with yellow circles, Dall's porpoise with red circles, and unidentified porpoise with gray circles. Other items included are survey track lines (brown lines), MBW and Inlet areas (light blue and light yellow shading), and SEAFAC static site (magenta star).

There was consistent, year-round presence of killer whales in Behm Canal, suggesting regular use of Behm Canal waters. This agrees with the findings of Zerbini et al. (2025) for spring, summer, and fall, and confirms their presence in all twelve months of the year. It is important to note, however, that we did not identify the killer whale calls to ecotype, only to species. Therefore, specific ecotype seasonal distribution within Behm Canal currently remains unknown, but will be investigated in the next year as call catalogs are finalized for the Navy funded Western Gulf of Alaska work (Cooperative Agreement N62742-25-2-0002). Dalheim et al. (2009) showed year-round use of SEAK waters by both resident and transient killer whales, with occasional summer use by offshore killer whales. For the area included in the current study, Dahlheim et al. (2009) reported no sightings of any killer whales in Behm Canal. Although their results were based on limited survey data from this area, they reported sightings in Clarence Strait of resident killer whales in the spring and fall, offshores in the summer, and transients in all three seasons.

There were no detections of fin whales on the long-term recordings. This fits with the visual survey results that found very low density estimates for fin whales in the spring and fall, and no sightings in the summer. Furthermore, the fin whale sightings were made either in Clarence Strait (Fall 2024, Fig. 14d) or close to Clarence Strait at the southern end of Western Behm Canal (Spring 2023, Fig. 13b).

Lastly, there was ubiquitous low frequency tonal noise detected year-round on the long-term recordings. This is most likely due to electrical noise interference from the power barge itself, due to the instrument cage being suspended so close to its edge. We had expected an increase in vessel noise in the summer to reflect the increase in pleasure craft and whale watch vessels, but this was not reflected in the acoustic data collected. To eliminate the possibility of misinterpretation, these results are not included in this report.

Although the main contribution to the Behm Canal study came from the long-term passive acoustic results, the sonobuoy monitoring that occurred on the spring and fall surveys provided data that support the overall findings. The advantage of concurrent passive acoustic monitoring on vessel surveys is that it provides a complementary data stream; some species can exhibit behaviors that make them harder to visually sight, while others fall silent when a vessel is in the area (e.g., Clark and Fristrup 1997, Lesage et al. 1999). Despite having a dismal sonobuoy reception range on both the Spring 2023 and Fall 2024 vessel surveys, fin and killer whales were acoustically detected in roughly the same areas as the visual sightings of these species, which were limited to Clarence Strait. Humpback whales were sighted much more often than they were detected; although they were not heard in Clarence Strait, they were detected on sonobuoys and visually sighted in Behm Canal. Given that humpback whales are highly vocal, it is surprising that there were not more detections. However, all sightings except one were of single individuals, which may account for the lack of detections during the spring and fall surveys. Videsen et al. (2021) found a low call rate for solitary feeding humpbacks in Greenland. They also reported that source levels of these calls were 30 dB lower than humpback song, reducing the space over which the sounds can be detected, and hypothesized that this combination of infrequent, quieter calls may reduce competition for food or attacks from killer whales.

Several species were sighted but not acoustically detected (i.e., porpoises, sea otters (*Enhydra lutris*) harbor seals (*Phoca vitulina*), and Stellar sea lions (*Eumetopias jubatus*)); however, these results were not surprising. Porpoises vocalize outside of the range detectable by sonobuoys; sea otters do not typically produce vocalizations underwater; and no sonobuoys were deployed near the last two species, due to the narrow and shallow inlet and the risk of the sonobuoy drifting ashore.

Future work

Although the CAdaily and PoD for killer whales were fairly consistent throughout the year, there may be hidden seasonality revealed once the detections are identified to ecotype. As mentioned above, our work compiling killer whale call catalogues in the Western Gulf of Alaska are well underway. Results from that work can be applied to data collected for this study, and the focal follow data collected on the Fall 2024 survey can also contribute to the cataloguing effort.

In addition, there is no killer whale echolocation classifier included in the F-POD software, and as such is likely either missing or misclassifying killer whale echolocation. However, the simultaneous SoundTrap/F-POD data collection allows for an investigation into how killer whale echolocation detections appear in the F-POD data, and whether there are differences among the ecotypes that are apparent enough to be used for classification. For example, killer whale ecotypes are known to produce clicks at different rates (Barrett-Lennard et al. 1996). It will also be interesting to see if there is a difference in seasonal occurrence of echolocation clicks versus regular whistles and pulsed calls.

Once this information is available, analyses comparing seasonal trends to prey species can be undertaken. One example would be to compare transient killer whale occurrence with that of the porpoises. In an informal conversation with Berchok, A. Zerbini suggested that it would seem likely that higher proportion of transient killer whales would be occurring in the spring, when porpoises are at their maximum CA_{daily} (Fig. 16, top row). Would there be a difference in trend based on whether it was Dall's or harbor porpoise?

As previously stated, Dall's and harbor porpoise detections cannot currently be easily or reliably distinguished from one another on the F-PODs. Future will focus on collecting F-POD data in the presence of each species separately. The results obtained from this study suggest that a preliminary investigation into Dall's echolocation may be possible since they seem to be the species more likely to have been near the long-term instruments at the SEAFAC static site.

We also plan to deploy an improved version of the drifting F-POD buoy on the upcoming Navy-funded killer whale survey in the Western Gulf of Alaska (i.e., PacMAPPS 2026, also part of Cooperative Agreement N62742-25-2-0002). The data from the unit deployed during the Fall 2024 survey was corrupted because the F-POD floated up to the surface and was slapped around by surface waves which, as impulsive sounds, swamped the detector. The redesign will include an instrument cage, like the one deployed at the static site, that will serve to weigh the F-POD down away from the surface, and a spar buoy instead of a spherical float, which will help isolate the F-POD from any surface wave motion, quieting the incoming signals considerably and therefore allowing for clean detections of the porpoises.

The high success rate of the sonobuoys is fairly standard, a float that does not appear at the surface could indicate a weak battery, damaged float, or that the unit became jammed in its deployment canister. The biggest disappointment in the performance of the sonobuoys was the extremely reduced reception range. This was likely a combination of the age of the buoys (16 years), the fact that the antenna was not installed very high on the vessel, and a very high amount of VHF radio traffic in the area. The additional problem of the sonobuoys failing to scuttle was more likely due to low battery power, a result of both the age of the buoys as well as the fact that the buoys were prepped over a year prior. While the buoys were stored inside protected hangars, the tubes containing the units were no longer waterproof. It is possible that the saltwater batteries became damp and their power was drained. Coming prepared with newer sealed units with fresher batteries is critical for this area, especially considering the lower-than-normal antenna height and increased VHF radio traffic in the 156 and 174 MHz range. Our antennas are tuned to 168 MHz to allow reception in the middle of the sonobuoy transmit frequency range; the further away from 168 MHz the transmission frequency is, the weaker the received data at the monitoring station. Although it is difficult to place the receiving antenna any higher on the vessel of this size, it is worth the effort to add a Yagi directional antenna to greatly increase the signal strength and therefore the reception range. A switch can be installed at the monitoring station in the bridge to seamlessly switch from the omni antenna (required when the sonobuoy is not directly astern), and the Yagi antenna (when the sonobuoy is directly behind the vessel).

Lastly, the deployment of the long-term instrument package at the SEAFAC static site proved highly beneficial to putting the visual survey results into a full-year perspective. However, there were time-consuming and logistical challenges of working directly at SEAFAC, where the instruments needed to be taken in and out of the water repeatedly, and the noise and motion from the barge and its instruments made the data less ideal for analysis. This could be avoided by deploying autonomous subsurface moorings at sites outside the area of interest that would still provide valuable long-term data without the national security risk.

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