Saildrone Summer 2016 Bering Sea Mission

Final Report

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Executive Summary

In summer 2016 (late May to early September), the Pacific Marine Environmental Lab (PMEL), and Saildrone Inc. conducted a field survey of Saildrone work in the US Arctic. The project was a collaborative effort between Saildrone Inc., University of Washington (JISAO/PMEL), NOAA Research (PMEL), and NOAA Fisheries (AFSC & MML). In total, 15 engineers and scientists representing six research groups and three non-federal companies worked together to use the Saildrone in a cooperative effort that covered physics/oceanography, novel technologies, engineering expertise, fish, whales, and seals in the southeastern Bering Sea. Two Saildrones were launched from Dutch Harbor, AK, on 24 May 2016, bound for the southeastern Bering Sea. After circling around the oceanographic M2 mooring in the heart of the North Pacific right whale critical habitat, the two Saildrones split up, each one following pre-determined tracklines in an effort to locate vocalizing North Pacific right whales both on the western shelf (west of the 70m isobath) and along the shelf break. The Saildrones then rendezvoused with the NOAA ship *OSCAR DYSON* to conduct comparative field equipment testing on the echo-sounder, before heading north toward the Pribilof Islands to follow tagged northern fur seals and conduct transect line sampling. Finally, the Saildrones went back to the oceanographic M2 mooring around 23 August to again search for the North Pacific right whale, before returning to Dutch Harbor, AK and being recovered on 3 September 2016.

Each Saildrone was equipped with a passive acoustic recorder to document the presence of vocalizing marine mammals. The recorders were set to record continuously, while sampling at 8 kHz, with a usable frequency range of up to 3.5 kHz. This was sufficient to capture the vocalizations of almost all marine mammals in the Bering Sea, excepting porpoise. One recorder failed approximately 5 days prior to the completion of the mission (due to flash card failure), while the other recorder collected data for the entire mission. The two recorders resulted in a combined ~5150 hours of acoustic recordings. Despite ubiquitous water noise throughout the recordings that complicated analyses, results showed successful detections of killer whales and humpbacks, with possible detections of a right whale and fin whale. Although we were unable to complete our objectives, with planned modifications to reduce noise, and an increased sampling rate to include more high-frequency species (e.g., beaked whales), the incorporation of passive acoustics onto the Saildrone has great potential for monitoring large areas for the presence of vocalizing marine mammals.

Introduction

North Pacific right whales, *Eubalaena japonica*, were extensively hunted by sail-based “Yankee” whalers beginning in 1835, and an estimated 26,000-37,000 whales were killed during this period (Scarff 2001). By 1900 they were essentially commercially extinct, although low levels of catches continued for some years. Two populations, eastern and western, are recognized, and both were highly depleted by whaling. By 1960 the frequency of sightings suggested that these populations were beginning to make a slow recovery; however, both became the target of illegal whaling by the USSR in the 1960’s.

An estimated 661 right whales were killed by Soviet whaling fleets in the eastern North Pacific between 1962 and 1968 (Ivashchenko and Clapham 2012), and it appears likely that this represented the bulk of the remnant population. Today, the eastern stock (hereafter “right whales”) is estimated at only about 30 animals (Wade et al. 2011); while this estimate may relate to a sub-population inhabiting the Bering Sea, the extreme paucity of recent sightings elsewhere make it unlikely that the overall population is significantly larger. Despite the fact that this makes it the world’s smallest whale population for which an abundance estimate exists, very little funding has been available to study it, and the resulting major gaps in our knowledge have seriously hindered conservation planning.

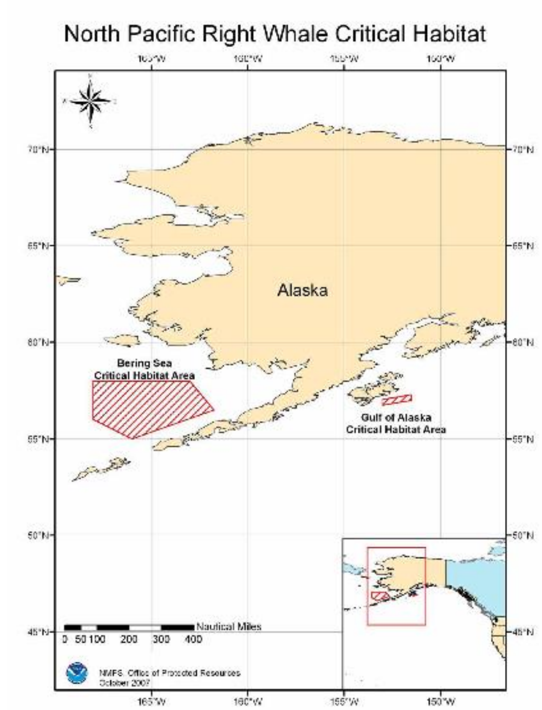

Figure 1. Federally designated Bering Sea and Gulf of Alaska North Pacific right whale critical habitat.

Right whales in the eastern North Pacific once occupied a large range which extended from the Gulf of Alaska to the Bering Sea, and possibly further north. In the Bering Sea, the Alaska Fisheries Science Center’s Marine Mammal Laboratory (AFSC/MML) conducted shipboard and aerial surveys from 2007 to 2010, and found small numbers of right whales to the west of Bristol Bay, in the federally designated right whale critical habitat (RWCH; NMFS 2006; Figure 1). Satellite tagging of several individuals and associated oceanographic studies confirmed the importance of this area as a feeding ground (Baumgartner et al. 2013; Zerbini et al. 2015). However, little is known regarding the distribution of right whales elsewhere in the Bering Sea.

While ship-based surveys have the advantage of covering a large area and the potential for obtaining photo-ID or biopsy samples, they are extremely expensive, and therefore limited to a small time frame (i.e., 1-2 months). They are also daylight and fair weather dependent. Passive acoustics has the advantage in that it is not limited by either weather or daylight, and it is relatively inexpensive in comparison. Furthermore, several studies have shown that passive acoustics can be better at detecting certain species of marine mammals than visual surveys (e.g., Clark and Fristrup 1997; Barlow and Taylor 2005; Peel et al. 2014; Berchok et al. 2015; Crance et al. 2015). Autonomous moored recorders are able to provide data on a long time scale (several months to years), but are limited to a small (10-20 km) detection radius. However, incorporating passive acoustics onto an autonomous mobile platform can provide invaluable marine mammal distribution data over a large spatio-temporal scale at a fraction of the cost of a full scale ship-based survey.

A Saildrone is a sail- and solar-powered surface vehicle (USV) developed by Saildrone Inc. in conjunction with NOAA/PMEL to make remote, season-long meteorological and oceanographic measurements at sea. It can be launched from a dock and sails autonomously between user-controlled waypoints and transmits data ashore via satellite. The platform can operate 2 – 5 times faster than other available autonomous vehicles, creating opportunities for longer, more flexible research deployments that can cover greater distances. Speed is a critical factor for working in rapidly shifting ice environments like the Bering Sea. Reaching 20 ft above the water's surface and 19 ft long, this size allows the Saildrone to carry a payload greater than 200 pounds. The Saildrone's operating electronics rely on solar power. To cope with solar power in limited light environments like the US Arctic, the power storage capacity of the solar cells is very large and overall instrument power consumption is low, allowing for reliable communication and navigation.

Following the successful 2015 Bering Sea oceanographic mission, the Innovative Technology for Arctic Exploration (ITAE) program at the Pacific Marine Environmental Lab (PMEL) teamed up with private sector engineers and fisheries scientists from NOAA Fisheries in a highly collaborative ecosystem study aimed to promote the recovery of protected species in Alaskan waters by combining the physical and chemical measurements with remote biological observations from two Saildrones. In 2016, the Saildrone's sensor suite was expanded to include a new, low-power, scientific fisheries echosounder for fisheries research and a small autonomous acoustic recorder, the Acousonde, mounted on the keel of each Saildrone monitored for the presence of critically endangered North Pacific right whales.

There is an urgent need to better understand the existing range and habitat use of right whales in the Bering Sea as it relates to their historic distribution ranges. The major question being addressed by this work is how far outside the critical habitat does the distribution of right whales extend in the Bering Sea. Passive acoustic data, when integrated with concurrent oceanographic data, can contribute strongly to explaining finer-scale ecological processes and defining those oceanographic conditions that influence marine mammal distribution (e.g., Bluhm and Gradinger 2008; Laidre et al. 2008; Stafford et al. 2013; Berchok et al. 2015).

The specific objectives for this project were:

1. Enhance the current understanding of the distribution and occurrence of right whales in the Bering Sea.
2. Demonstrate the utility of attaching a small, autonomous passive acoustic recorder to a Saildrone for an extended period of time in the eastern Bering Sea to document the presence of vocalizing marine mammals, specifically the North Pacific right whale.
3. Use concurrently collected oceanographic data to correlate marine mammal distribution with oceanographic variables to provide information on physical processes influencing marine mammal distribution.
4. Use concurrently collected active acoustic backscatter and zooplankton data to identify areas of high zooplankton concentrations, and correlate these data to marine mammal presence to identify foraging hot spots and infer habitat use.

Methods

Each Saildrone was equipped with a full suite of oceanographic instrumentation as well as an echosounder to measure fish abundance, and autonomous passive acoustic recorders to detect marine mammal vocalizations. For a diagram showing the orientation of each instrument on the Saildrone, see Appendix 1. To monitor for the presence of marine mammals, a small, autonomous passive acoustic recorder (Acousonde®; Bill Burgess, Greeneridge Sciences, Inc.) was integrated onto the keel of each Saildrone, approximately 1.5 m below the surface (Figure 2, Appendix 1). These recorders sampled at 8 kHz, with a usable frequency range up to 3.5 kHz, which is more than adequate to record the calls of all Bering Sea marine mammals except porpoises (which are outside the sampling abilities of these instruments). The Acousondes were connected to an external battery source that allowed them to record continuously for the full three month survey.

Figure 2. Acousonde integrated onto the keel of the Saildrone.

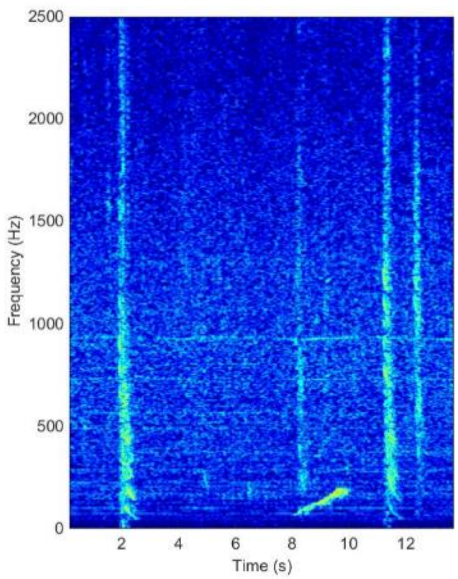

Figure 3. Stereotyped right whale vocalizations, the gunshot (e.g., at 2 s and 11 s) and the upcall (e.g., at 8-10 s).

Two main call types are used to identify right whales: up-calls, with variable frequency and sweep rate characteristics on average from 80 – 160 Hz and ~1 s in length, and the gunshot, a broadband (20 Hz – 20 kHz), impulsive calls of < 1 s duration (Figure 3; Clark 1982; McDonald and Moore 2002; Parks and Tyack 2005; Munger et al. 2008; Matthews et al. 2014). Although right whales were the target species for this study, the Acousondes will record and detect any vocalizing marine mammal. Humpback whales (*Megaptera novaeangliae*) also make a large variety of similar FM sounds in the range of 30 Hz to 10 kHz+, usually with some degree of amplitude modulation (Thompson et al. 1986; McSweeney et al. 1989). They typically repeat the same call multiple times in a row, with less than five seconds between calls. Humpbacks were distinguished from right whales by the timing and frequency of call production. Humpbacks vocalize more frequently, with inter-call intervals averaging 2-5 s, while right whales vocalize infrequently, with inter-call intervals averaging 5-15 s (Mellinger et al. 2004). Killer whales (*Orcinus orca*) were identified by the pulsive and stereotypic nature of their calls, as well as the high frequency components (Deecke et al. 2005). Fin whale (*Balaenoptera physalus*) calls are distinguished easily from all other species as they are stereotyped, short (≤ 1 s) downsweeps with most of the call frequency bandwidth below 50 Hz (Watkins et al. 1987; Edds 1988).

Typically, analyses of passive acoustic data involve one of two methods. First, autodetectors may be used if the species of interest produce unique, stereotyped, easily attributable calls, and if the ambient noise levels are sufficiently quiet to allow for call detection. Although some institutions use autodetectors, they are ineffective for this region given the high degree of similarity among calls of multiple species. The second method is to manually analyze the data by visually scanning through spectrograms of the sound files. While more time consuming, this method allows analysts the use of contextual clues (e.g., call timing, patterning, etc.), and ensures correct attribution of calls to species. Preliminary scans of the data show that sounds of water hitting the hull/keel were pervasive throughout our recordings (Figure 4). Due to the ubiquitous broadband impulsive water sounds, we were unable to visually scan the recordings for marine mammal vocalizations. While this noise was not unexpected, it complicated analyses, as we were required to listen to the sound files for calls types, rather than visually scan. This significantly increased the analysis time, and prevented us from listening to all the files. As a result, specific times were chosen on which to focus the analyses. All analyses were conducted using Raven Pro (Bioacoustics Research Program 2011), and preliminary results are shown below.

Figure 4. Spectrogram of recordings collected from Acousonde on SD-126 showing broadband impulsive noise from water hitting the platform. Clip from 23 August 2016 at 07:50 UTC.

Passive Acoustic Results

Two Saildrones were launched from Dutch Harbor, AK on 23 May 2016, heading for the southeastern Bering Sea for a 3 month mission. Both Saildrones performed remarkably well, averaging ~1.5 kts, and sailing for 103 days (Figure 5). Together, they sampled well over 5600 km, surveying the North Pacific right whale critical habitat (~10 days total), the western shelf (~37 days, SD-126), and the shelf break (~34 days, SD-128) (Figure 5). This resulted in a combined total of over 5150 hours of acoustic recordings.

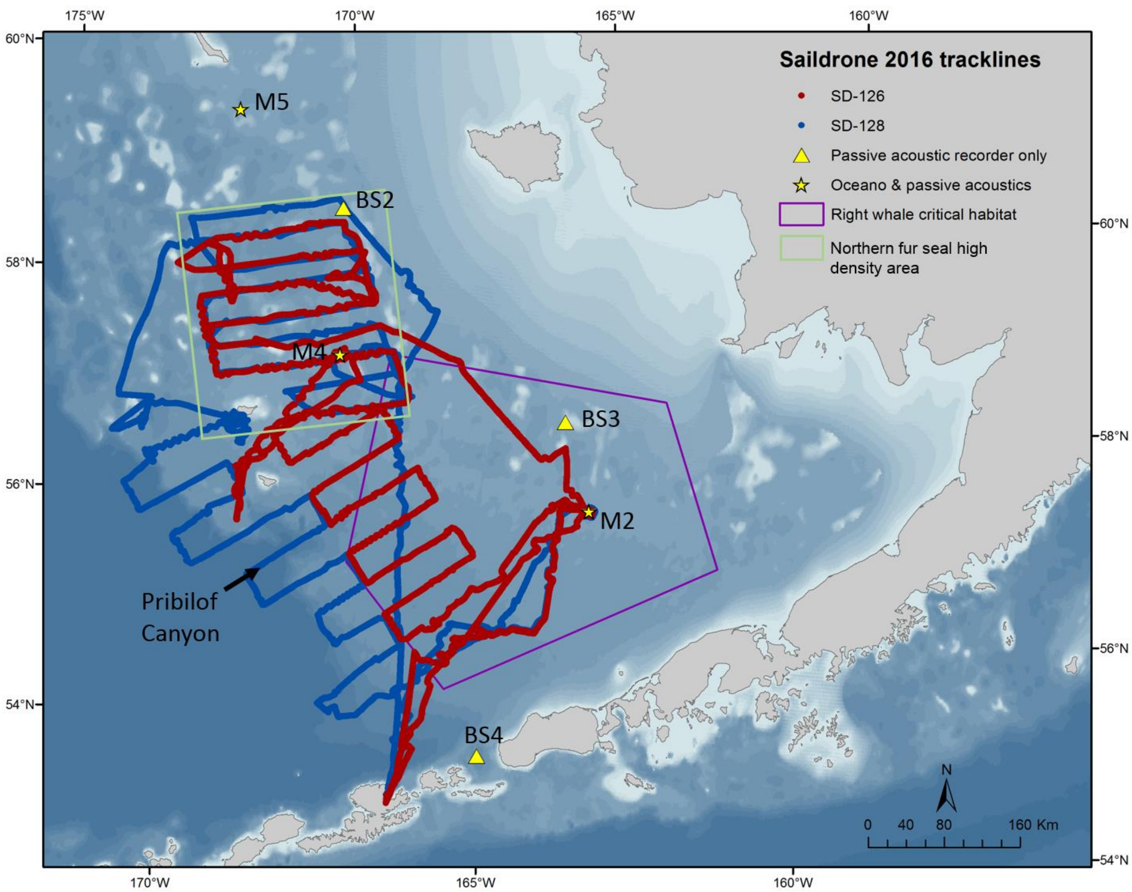

Figure 5. Tracklines taken by Saildrones SD-126 (red line) and SD-128 (blue line) during the 3-month mission. Triangles represent passive acoustic recorder moorings. Stars represent combined oceanographic and passive acoustic moorings. Purple pentagon represents federally designated right whale critical habitat. Light green box represents northern fur seal high density area (determined by satellite tag data).

Because files had to be analyzed by listening to them rather than visually scanning, analyses were focused on four specific time frames. The first two included those times when the Saildrones were circling MML's long-term passive acoustic recorders on the M2 and M4 moorings; these recorders have been deployed in the Bering Sea since 2007 and 2009, respectively (Figure 5, yellow stars and triangles). This allowed for a groundtruthing of the detections on the long-term recorders with the detections on the

Acousondes. But more importantly, it allowed for easy detection of a call. If a vocalizing right whale was in the area (from the M2 or M4 recordings), then a time-synchronized comparison of the Acousonde data with the M2/M4 data should pinpoint the call's location, within a few seconds. The third time frame analyzed was when SD-128 was transiting up Pribilof Canyon. Right whales in the Gulf of Alaska are frequently found in Barnabas Trough, a canyon off Albatross Bank near their critical habitat. As such, one goal was to determine whether right whales in the Bering Sea are entering the southeastern portion from the west by coming up Pribilof Canyon. Finally, analyses included a brief time frame during the launch of the Saildrones. Recordings during the first several hours of the launch were collected when the bay was calm with zero wave interaction. These recordings represent the baseline data, and allow for a determination of how well passive acoustics could work on a Saildrone in ideal conditions. A map showing the location of all detections relative to the Saildrone tracklines is presented in Figure 6.

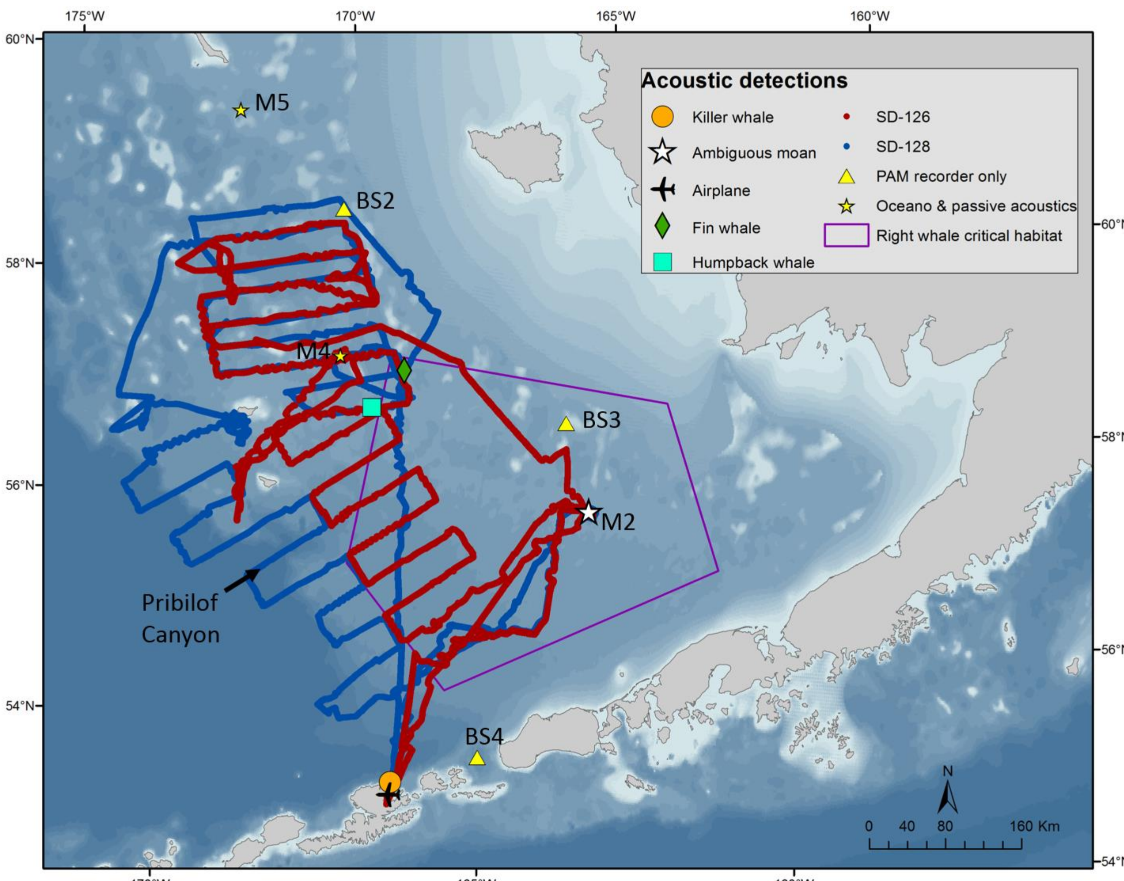

Figure 6. Map showing the location of each detection relative to the Saildrone tracklines. Note: the location of the time-synchronized comparison between M2 and SD-126 is the same location as the ambiguous moan (white star).

Focus Area 1: Launch baseline data analysis

The Saildrones were launched on 23 May 2016 at 19:45 UTC. Conditions in the bay were calm, with minimal wind or wave action. Recordings from this time were clean and quiet, allowing for the detection of ships and even airplanes (Figure 7). These data show the quality of recordings in ideal conditions.

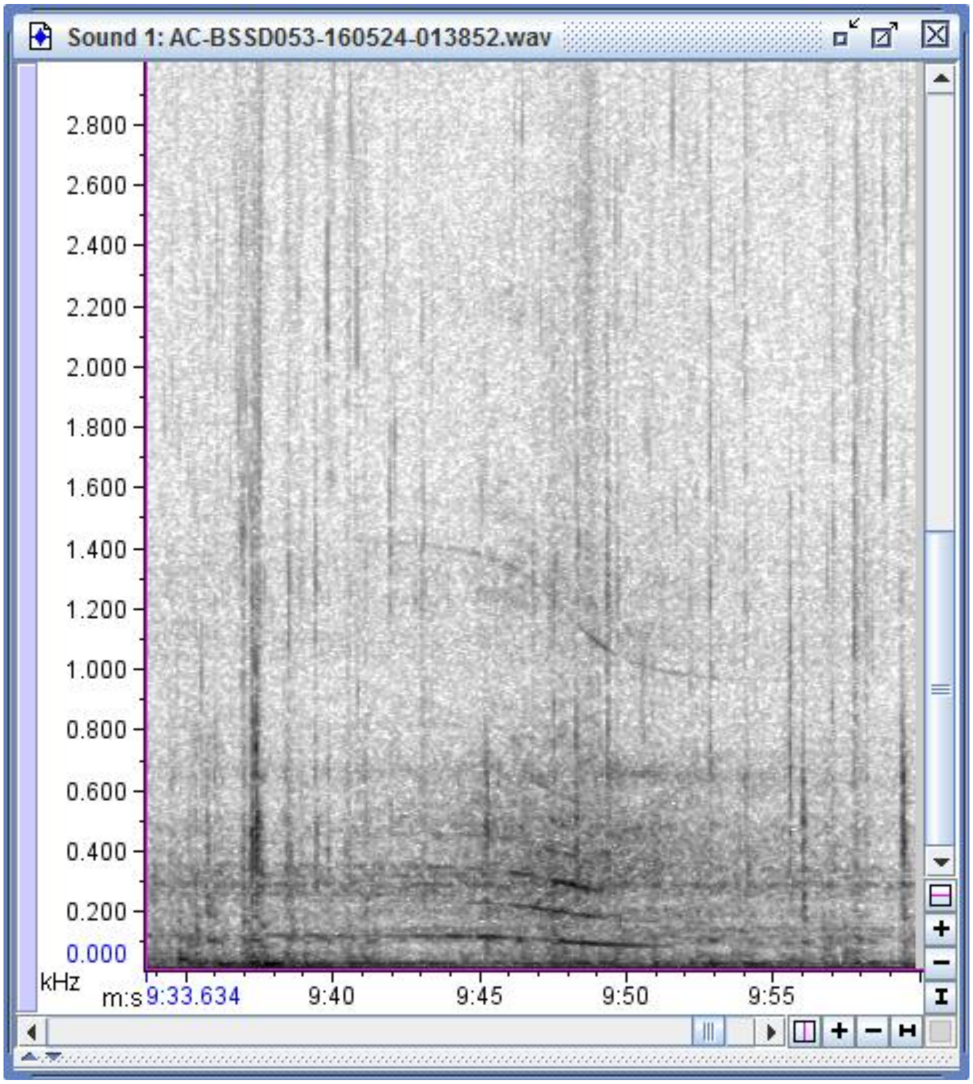

Figure 7. Spectrogram of SD-128 showing detection of an airplane signal on the Acousonde. Clip from 24 May 2016 at 01:47 UTC.

Shortly after deployment, SD-128 detected killer whale vocalizations just outside the harbor. On 24 May 2016 from 13:36 to 14:36 UTC, over 80 detections of killer whale vocalizations occurred (Figures 6, 8). This number only included those vocalizations that were readily visible on the spectrogram; it is possible that additional vocalizations were recorded but unable to be detected. Wind conditions were mild (~6.6 kts), which may have increased the detectability of the vocalizations. It is also possible that the higher frequency nature of the killer whale calls made them easier to detect, as the fundamental frequency of the calls is above the majority of the platform noise. These results show that marine mammals with higher frequency vocalizations may be an ideal candidate for passive acoustic monitoring via Saildrones.

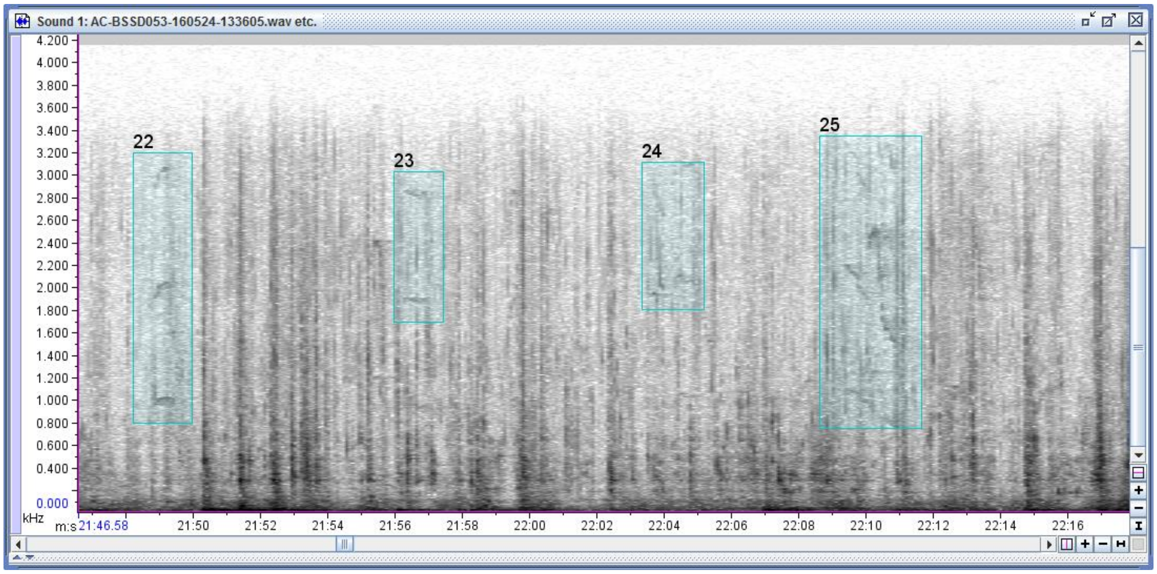

Figure 8. Spectrogram of recordings from SD-128 showing visible killer whale calls, outlined in light blue boxes. Clip from 24 May 2016 at 13:56 UTC.

Focus Area 2: M2 data analysis

Shortly after their launch, both Saildrones sailed toward M2, as a means to calibrate the oceanographic instrumentation with those on the M2 mooring. They circled around M2 for three days, from 4 to 7 June. SD-126 also sailed around M2 near the end of the deployment, on 23 August 2016. Because right whales are not frequently detected in the critical habitat until mid-July, we used SD-126's second rendezvous with M2 as the comparison test with the Acousonde data. Right whales were detected at ~07:30 UTC on M2 (Figures 9-10). At this time, SD-126 was approximately 1.8 km away from M2 (Figure 6, white star). When analyzing data from the same time frame on the Acousonde, the upcalls that are clearly visible at M2 are nearly indistinguishable in the Acousonde data (Figures 9-10). It is important to note, however, that the distance of the whale to the recorder at M2 is unknown. It is possible that the whale is on the other side of the mooring relative to the Saildrone, and as such is too far away to be acoustically detected on the Saildrone.

However, despite not detecting clear right whale upcalls, a moan was clearly visible at 07:29:47 UTC at ~225 Hz (Figure 11). Because both right whales and humpback whales make moans within this frequency, and there were no additional calls or contextual clues, definitive attribution of this moan to species was not possible.

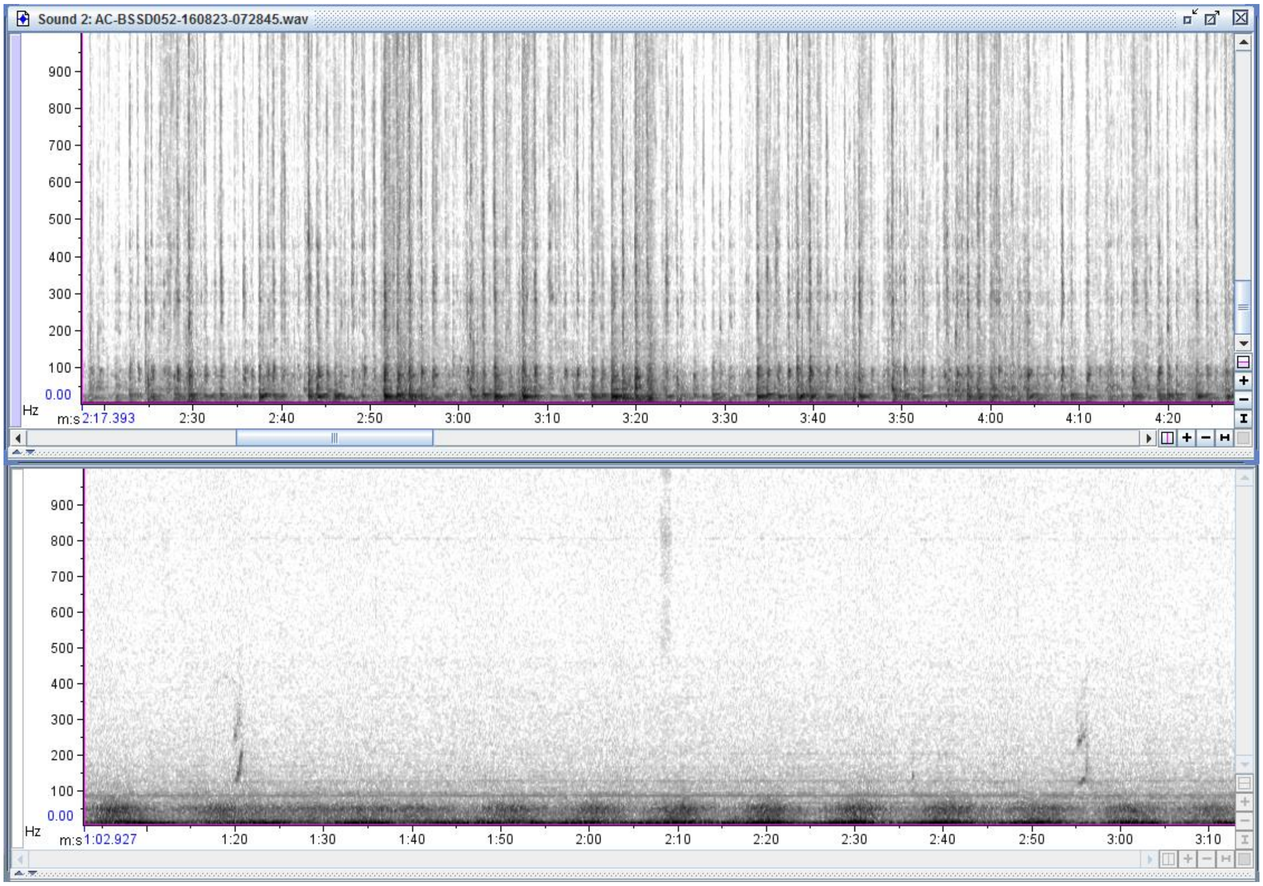

Figure 9. Time-synchronized spectrograms of recordings from SD-126 (top) and M2 (bottom). Right whale upcalls visible in bottom M2 spectrogram at 1:20 s and 2:56 s, but are extremely difficult to distinguish in the Acousonde data due to platform noise. Clips from 23 August 2016 at 07:30 UTC.

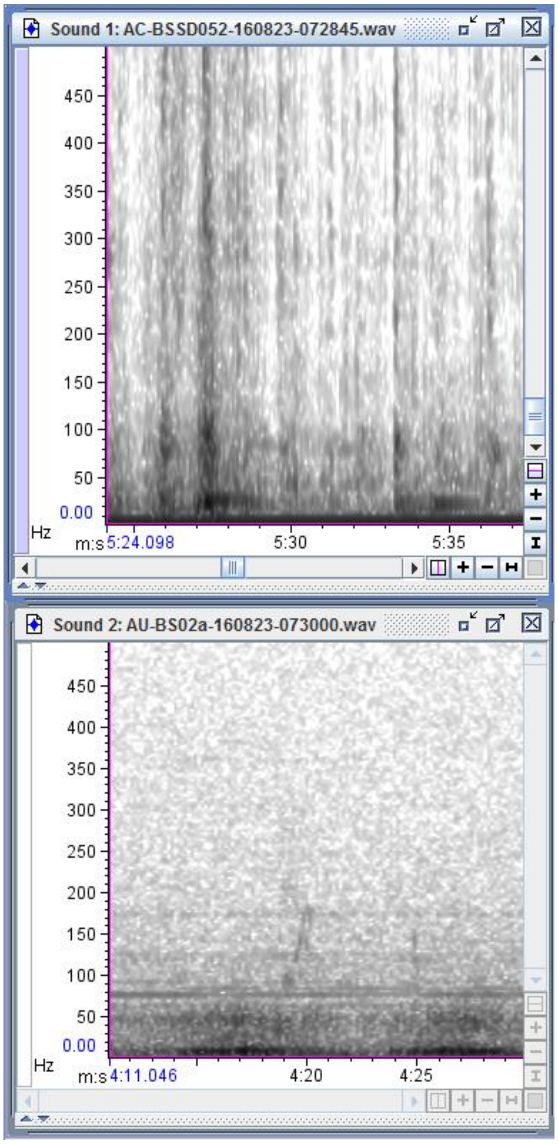

Figure 10. Zoomed-in time-synchronized spectrograms of recordings from SD-126 (top) and M2 (bottom). Right whale upcall visible in bottom M2 spectrogram at 4:19 s, but is extremely difficult to distinguish in the Acousonde data. Clips from 23 August 2016 at 07:34 UTC.

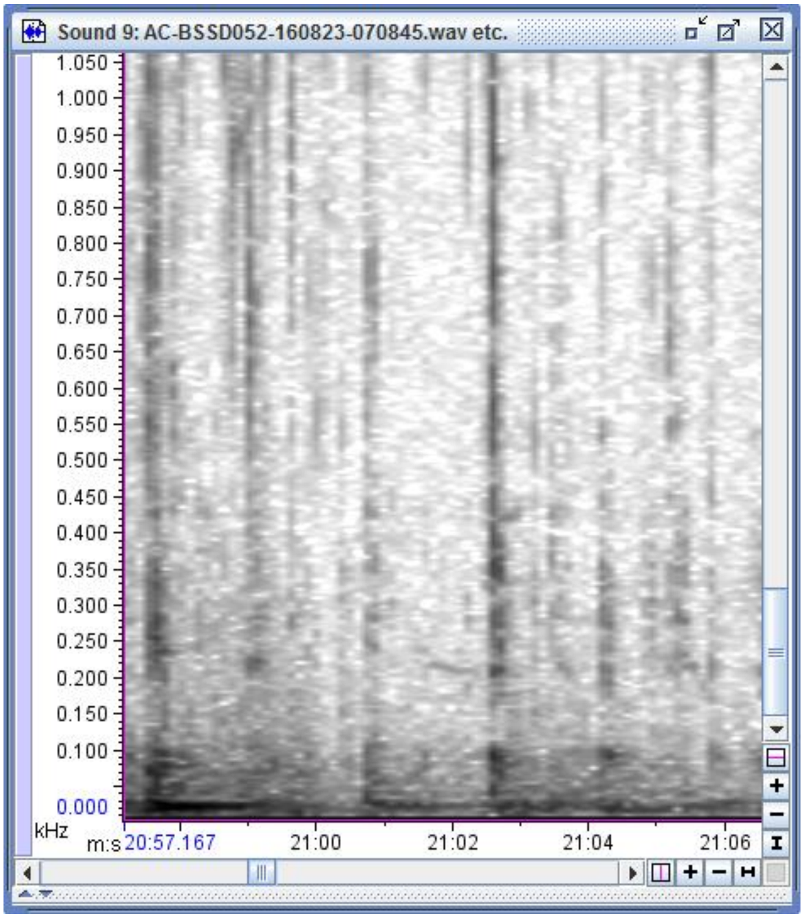

Figure 11. Spectrogram of low frequency moan at 225 Hz, visible at 21:02 s. Clip from SD-126, 23 August 2016 at 07:29:47 UTC.

Focus Area 3: M4 data analysis

The second are of focus was SD-128's transit around M4, on 4 August 2016 from 00:50 – 13:00 UTC. Right whale upcalls were detected at 02:07 at M4; unfortunately SD-128 was over 30 km away at the time, so those upcalls were not detected on the Acousonde. When SD-128 was within 2-4 km of M4 (12:00 – 13:30 UTC), there were no definitive upcalls detected on M4, so time-synchronized comparisons were not possible. Wind speeds were higher than average at 16-19 kts, which may have resulted in even more masking than usual. Wind was clearly audible on the acoustic recorder, at approximately 09:34 UTC on 4 August 2016 (Figure 12). This further complicated analyses, as wind often looked spectrographically similar to marine mammal vocalizations.

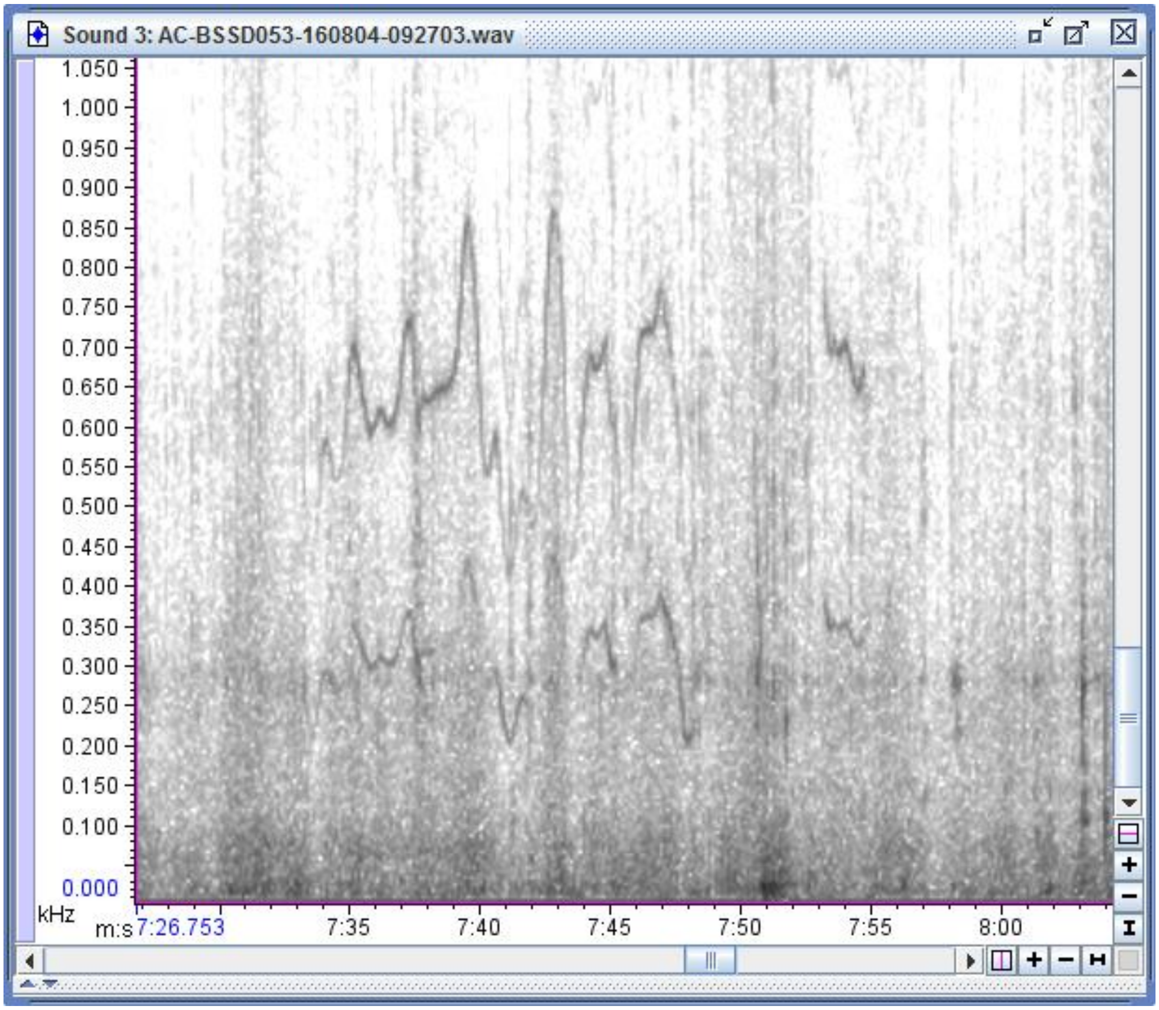

Figure 12. Spectrogram of recordings from SD-128, in which wind sounds are clearly visible, seen here as two matching lines from 7:33 s to 7:55 s. Clip from 4 August 2016, 09:34 UTC.

Focus Area 4: Pribilof Canyon data analysis

SD-128 was in Pribilof Canyon (Figure 5) from 12:00 UTC on 22 June to 06:00 UTC on 23 June. There were no audible or visual detections of marine mammals during this time frame. The overnight hours saw a slight reduction in water noise. Although the wind speed is very high (~23 kts) and winds are clearly audible, there is less broadband, impulsive noise (Figure 13). This suggests that the Saildrone was traveling with the waves, which is referred to as "storm mode", as opposed to against or broadside. These results suggest that regularly operating in "storm mode" when in the RWCH may help reduce platform noise and increase the detectability of vocalizing right whales.

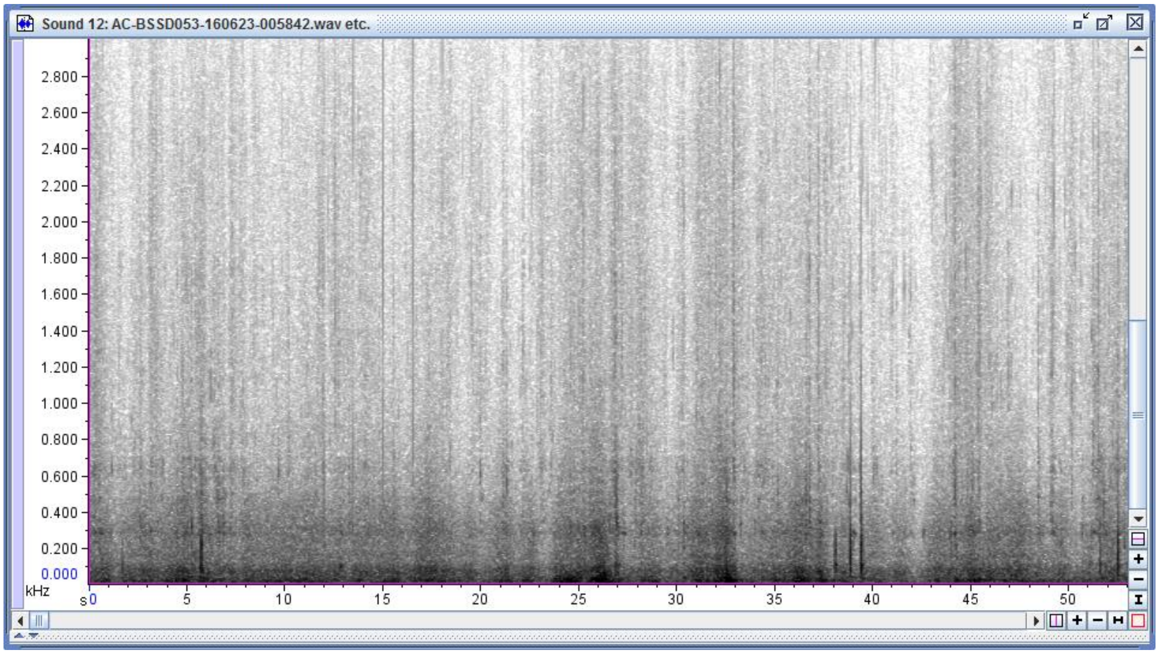

Figure 13. Spectrogram of recordings collected from SD-128 while transiting through Pribilof Canyon. Spectrogram shows a reduction in the impulsive, broadband water slap sounds. Clip from 23 June 2016 at 00:58 UTC.

Additional detections

In addition to the detections mentioned above, a humpback whale was detected on SD-126 on 19 July 2016 at 13:03 UTC (Figure 14). At this time, SD-126 was approximately 65 km southeast of M4 (Figure 6). This detection shows that lower frequency vocalizations can be detected on the Saildrone under ideal conditions, and if the whale is close enough to the Saildrone. Further supporting this, a possible fin whale detection occurred on SD-128 on 23 August 2016, east-southeast of M4 (Figures 6, 15). Although visually sharing similar characteristics to a fin whale downsweep, the signal also occurs at the same time as two impulsive sounds. Additionally, fin whales tend to be very vocal; it is unusual to detect only one fin whale call. While it is possible that there is a vocalizing fin whale in the area, additional calls would need to be detected to be confident in attributing this signal to a fin whale.

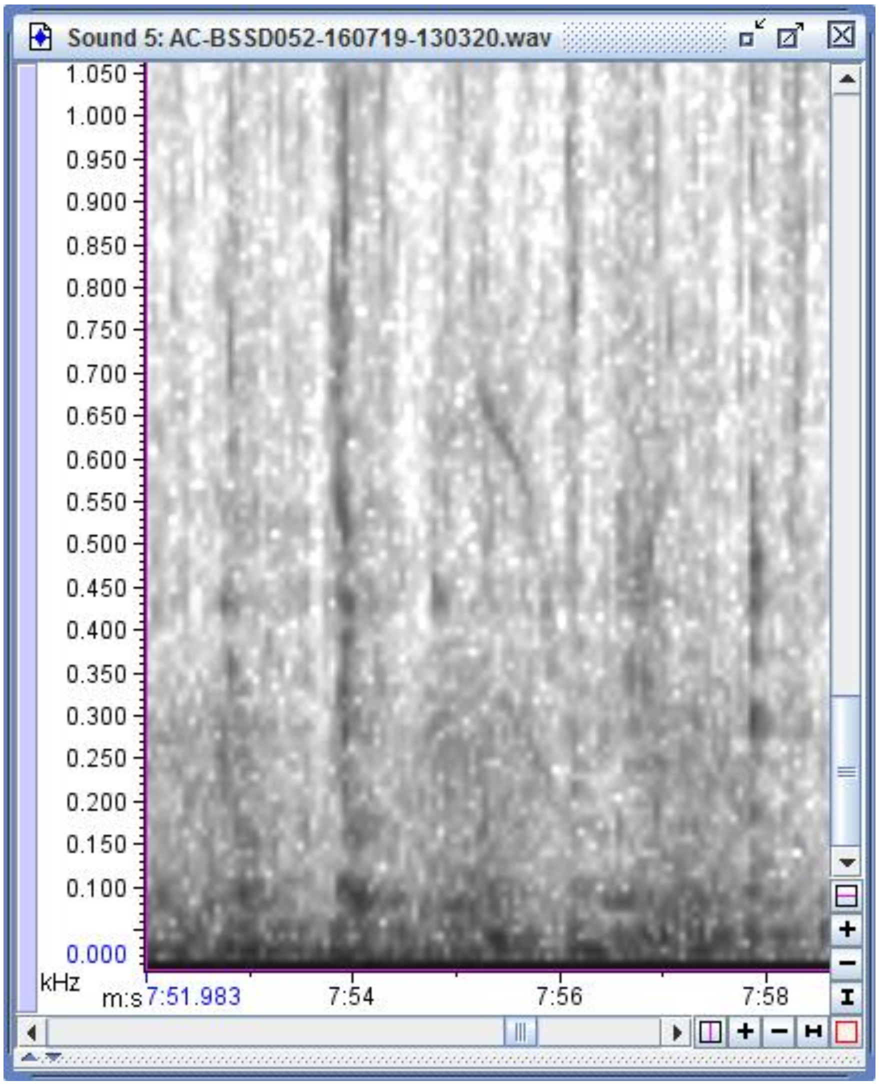

Figure 14. Spectrogram of recordings from SD-126 showing the detection of a humpback whale tonal call, visible at 7: 55 s. Clip from 19 July 2016 at 13:10 UTC.

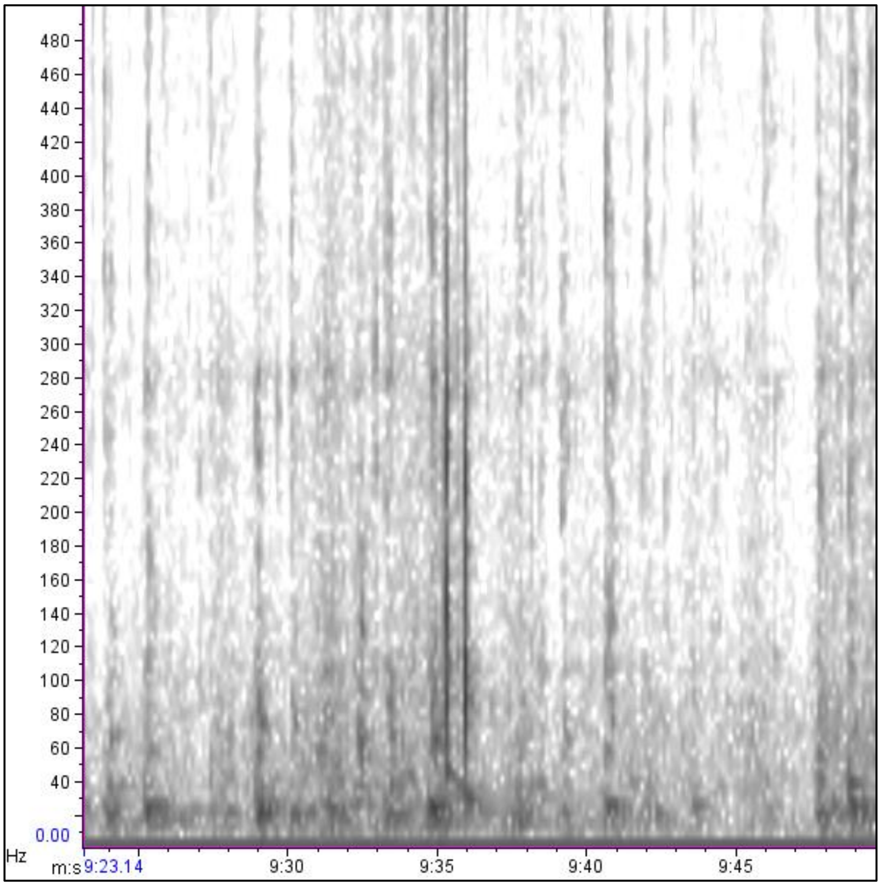

Figure 15. Spectrogram of recordings from SD-128 showing possible detection of a fin whale downsweep from 50 to 30 Hz, seen at 9:35 s. Clip from 23 August 2016 at 01:31 UTC.

Discussion

Unfortunately, ubiquitous impulsive, broadband noise from water hitting the platform masked most lower frequency signals, and prevented a complete analysis of the data. As a result, we were unable to address our objectives, and did not gain any additional information on the distribution of right whales and other marine mammals in the Bering Sea. However, despite these challenges, we were able to detect many killer whale vocalizations, as well as a humpback whale, an unattributed large whale moan, and a possible fin whale downsweep. These results suggest that, with a reduction in noise and increasing the sampling rate to include higher frequency species, the Saildrone could be a useful tool for monitoring marine mammals.

Future steps

Although time restrictions prohibited the analysis of additional data, plans are in place to analyze data from those times when the Saildrones were transiting within the critical habitat, not only those times they were circling M2 and M4. These results show that large whale vocalizations can be detected on a Saildrone if the whale is close enough to the platform, and if sea states are relatively calm.

Additionally, the Saildrones have undergone major structural modifications, including increasing the hull length and removing the outrigger. These modifications, in particular the removal of the outrigger, should reduce the amount of water noise in the recordings. They are also investigating the possibility of lining the inside of the hull with insulating material to reduce the reverberation effects of the hollow hull. Saildrone, Inc. is currently testing these new designs off San Francisco, with an Acousonde attached to record data during the test mission. A comparison of data between the new hull design and the 2016 Bering Sea mission will determine whether these new hull designs have reduced the platform noise sufficiently to warrant redeploying the Acousondes on the Saildrones during the 2017 summer field mission in the Bering Sea.

Discussions are also underway about integrating Acousondes into oculus wave gliders that are being developed by ITAE and PMEL. These oculus gliders are another autonomous mobile platform, but rather than being wind-driven and remaining at the surface, they are wave-driven and sample throughout the entire water column. This would solve the problem of the current design, which is vulnerable to noise from water slapping the platform and severe pressure changes near the surface. Instead, the oculus gliders would be able to dive throughout the water column, providing quiet recordings that would greatly increase the detectability of marine mammals.

Summary of results from other components

The oceanographic instrumentation on the Saildrone performed remarkably well, and measurements were collected throughout almost the entire mission. The rendezvous with the NOAA ship *OSCAR DYSON* (Figure 16) resulted in a successful comparative testing of the echosounders on the Saildrones, and almost all of the pre-determined tracklines were completed in the tagged northern fur seal (*Callorhinus ursinus*) high density area (Figure 5). Preliminary results are shown below.

Figure 16. Saildrone and the NOAA ship *OSCAR DYSON*

Oceanographic data

Figure 17 shows a chart of the sea surface temperature for both Saildrones with SD-126 denoted by black and SD-128 by cyan centerlines. Warmer temperatures were seen northeast of the Pribilofs; max temperatures hit 14° C on 19 July 2016 at SD-126. The coldest temperatures were seen south near the Aleutian Islands, with minimum temperatures at 6.5° C on 26 May 2016 at SD-128.

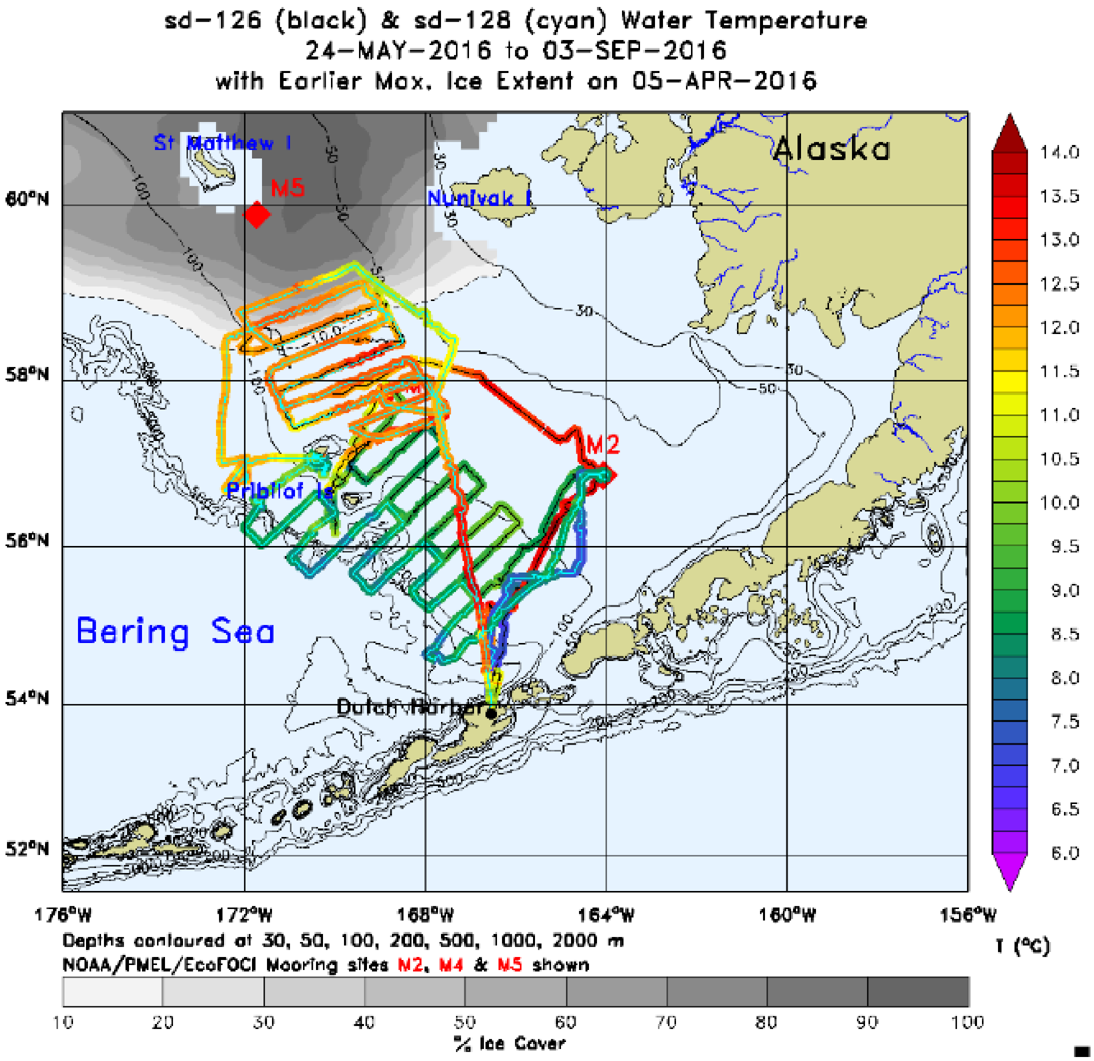

Figure 17. Sea surface temperatures (° C) measured by Saildrones SD-126 (black centerline) and SD-128 (cyan centerline). Figure by Ned Cokelet, PMEL.

Figure 18 shows the sea surface salinity. The lowest salinity (~31.1 psu) was encountered northeast of St. Paul Island around 30 July 2016 on SD-126, close to the location of southernmost ice extent. The greatest salinity (~32.9 psu) was around 26 July 2016 on SD-128, in the basin seaward of the 2000-m isobath where sea-ice melt has no effect. The large salinity gradient west of the Pribilof Islands marks the Outer Front between the basin and the continental shelf.

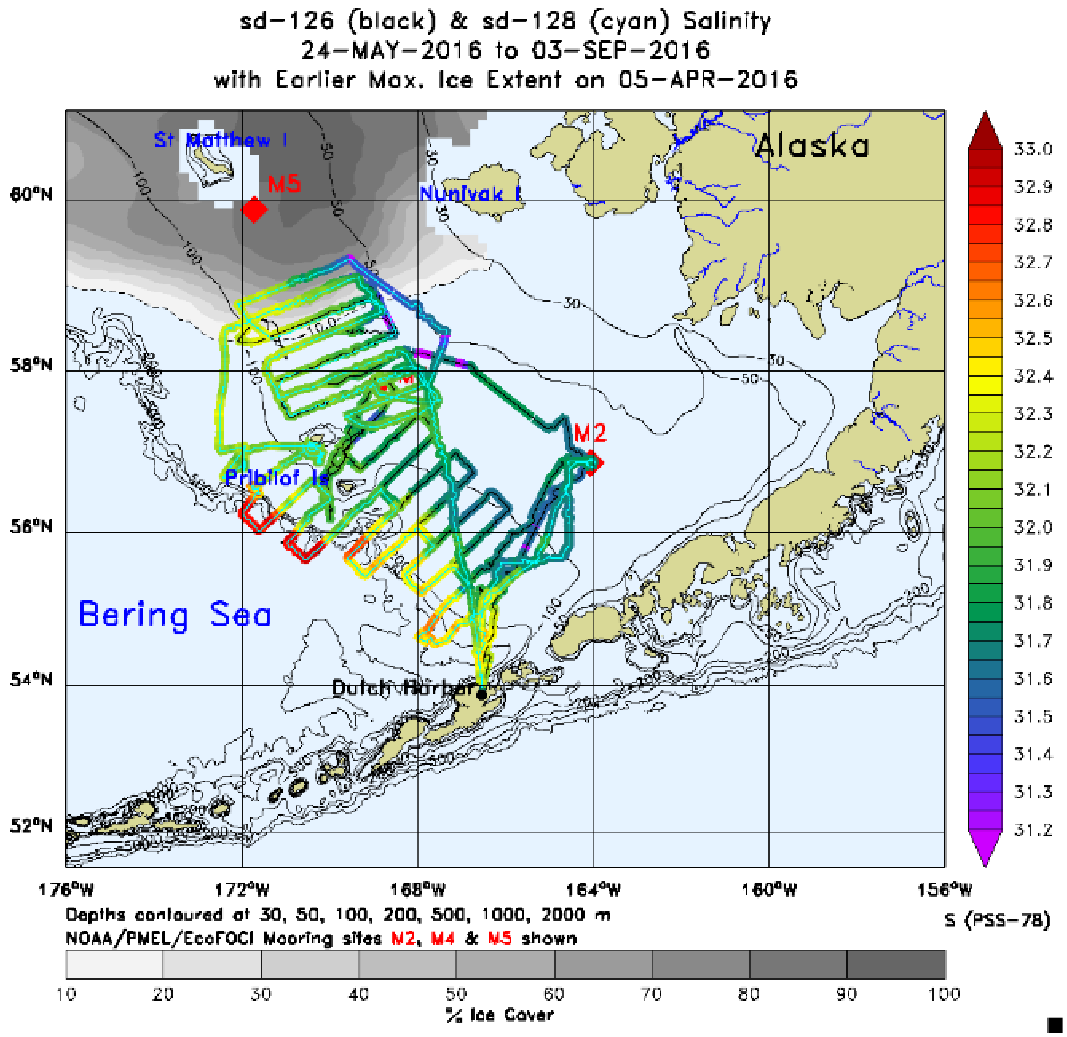

Figure 18. Sea surface salinity (psu) measured by Saildrones SD-126 (black centerline) and SD-128 (cyan centerline). Cyan line with no color represents times when instruments were turned off to save power. Figure by Ned Cokelet, PMEL.

Chlorophyll-a concentrations (μg/l) are shown in Figure 19, which correlates with the presence of phytoplankton. Saildrone SD-128 (cyan centerline, Figure 19) transited through a bloom of higher chlorophyll-a along the southeastern shelf break. This region is called the Green Belt where blooms occur as nutrient-rich water from the basin meets nutrient-poor, but ecologically rich, water from the Bering Sea shelf and available phytoplankton can flourish.

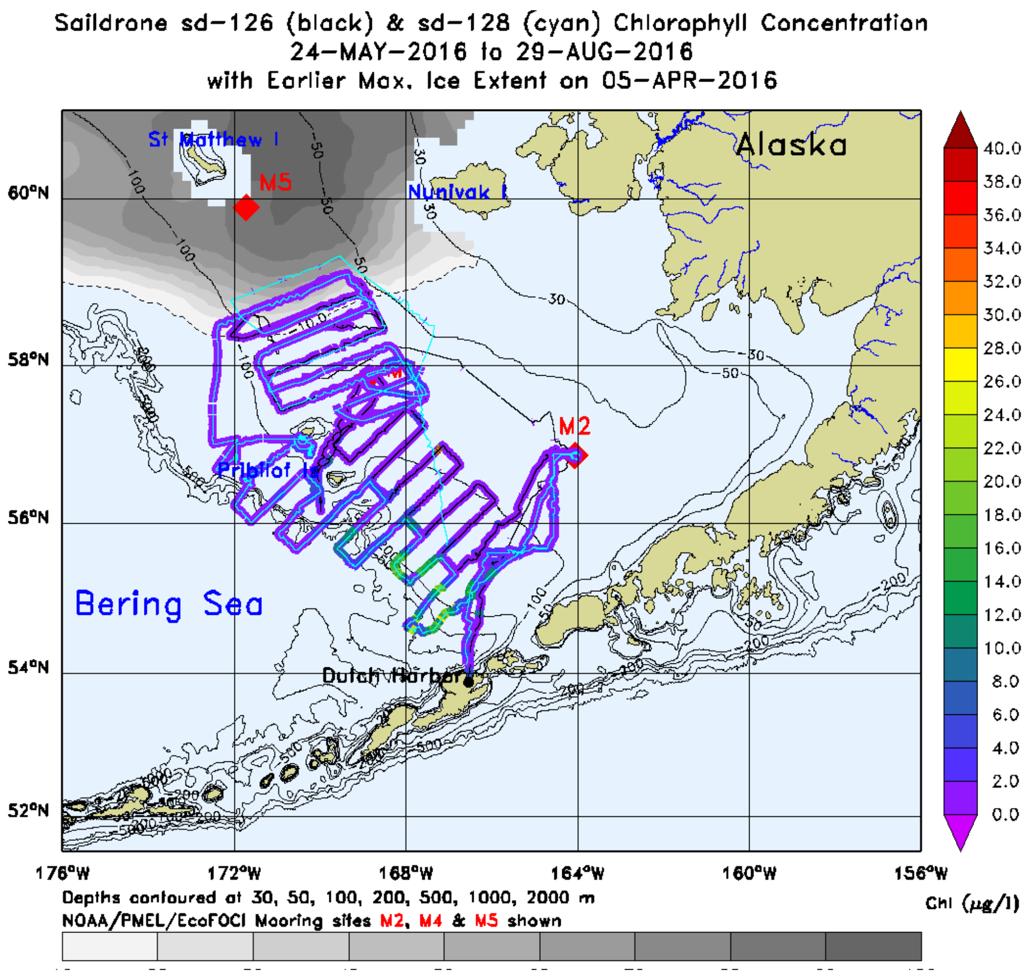

Figure 19. Sea surface chlorophyll-a (μg/l) measured by Saildrones SD-126 (black centerline) and SD-128 (cyan centerline). Figure by Ned Cokelet, PMEL.

Echosounder results

Preliminary results from the echosounder data are shown in Figures 20 and 21. Figure 20 shows data collected on 7 June 2016 at 00:31 UTC from SD-128. These results show fish in the midwater column, and a krill layer near the bottom. Later that month, on 23 June 2016 at 09:00 UTC, SD-128 encountered schools of Pollock on the outer shelf (Figure 21).

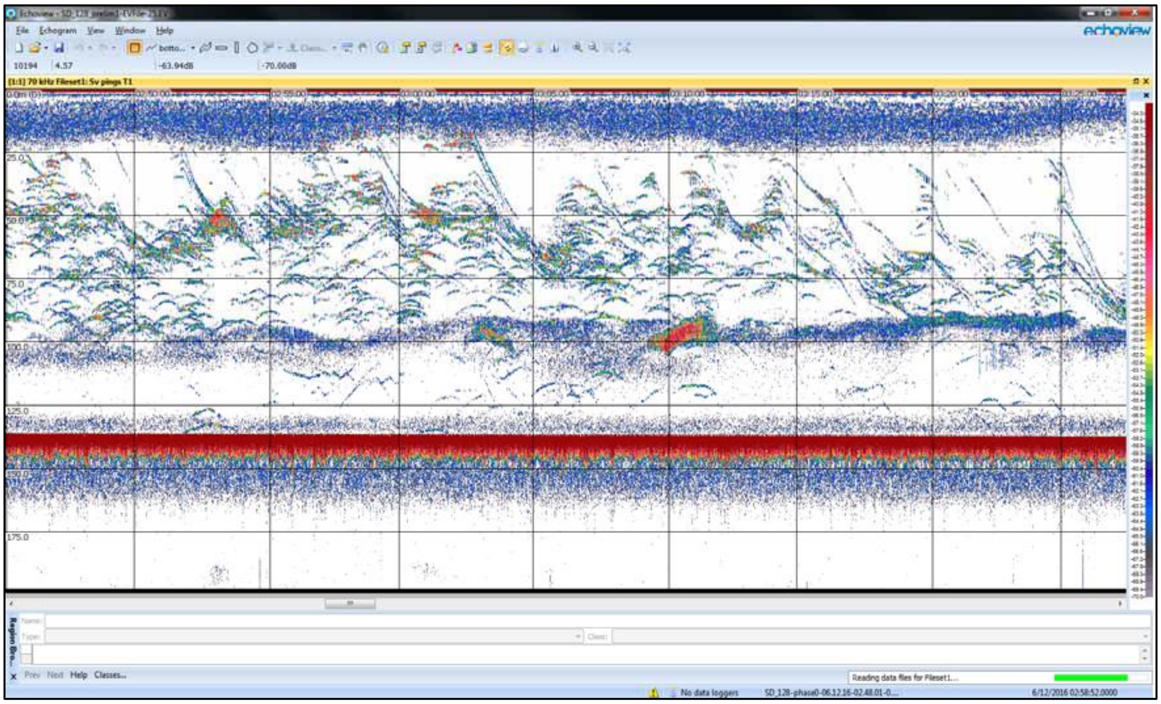

Figure 20. Sample of echosounder data on SD-128 showing fish in midwater column and a krill layer near the bottom. Data collected on 7 June 2016 at 00:31 UTC, in ~8 kts of wind. Wide red band is the sea floor. Figure by Alex DeRobertis, AFSC.

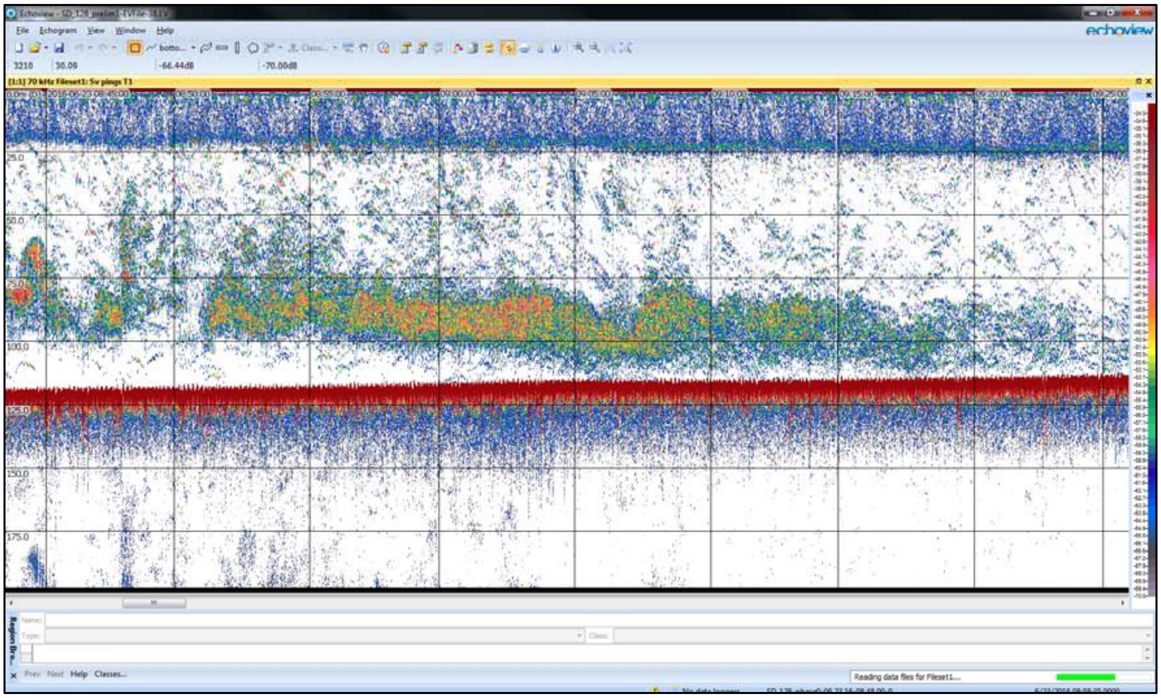

Figure 21. Sample of echosounder data on SD-128 showing schools of Pollock on outer shelf. Data collected on 23 June 2016 at 09:00 UTC, in ~16 kts of wind. Wide red band is the sea floor. Figure by Alex DeRobertis, AFSC.

During their rendezvous with the NOAA ship *OSCAR DYSON*, a comparison between the Saildrone echosounder data and those data from the vessel show that fish are responding to the presence of the vessel by diving to deeper depths than the Saildrone. Figure 22 shows this reaction, evident by the almost 13 m difference in average fish depth between the Saildrone (blue line) and the NOAA ship *OSCAR DYSON* (red line). Even though the NOAA ship *OSCAR DYSON* is an acoustically quiet vessel, fish still react to its presence more than the wind-powered Saildrone. These findings have the potential to affect fisheries management, as they reveals a bias in their data that was previously unknown before this mission.

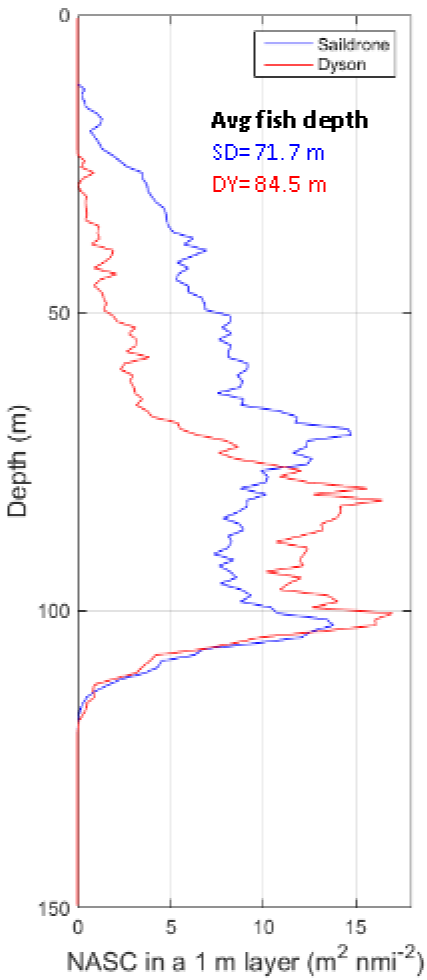

Figure 22. Comparison of Saildrone echosounder data (blue line) with the echosounder from the NOAA ship *OSCAR DYSON* (red line). Data show that fish react to the vessel noise by diving an average of 13 m deeper. Figure by Alex De Robertis, AFSC.

Fur seal tagging

The Saildrones also examined how variations in the availability of pollock influenced fur-seal behavior and foraging success at sea. Echosounders mapped walleye pollock distribution and abundance within the fur-seal range while the behavior of 29 satellite-tagged, adult female fur seals was simultaneously tracked. The Saildrones spent a combined 65 days within the fur seal core use areas. The satellite tag data for the 29 tagged animals resulted in a total of 34,000+ hours at sea, and 284,000+ dives logged. Figure 23 shows the locations of the tagged animals relative to the Saildrone tracklines.

Not only did the Saildrones follow the predetermined grid lines, but it also followed the tracks of tagged animals. The lag time between when the fur seal was at a location to the time the Saildrone was at that same location was at most four days, but often less than 36 hours. Figures 24 and 25 show the results of a comparison between the dive data of two tagged fur seals and the corresponding echosounder data. In Figure 24, the echosounder data (top row) show a congregation of age zero walleye pollock at the 10-20 m depth. The bottom panel shows the dive data for a tagged female fur seal, where dive depths averaged 20 m, the same depth as the concentration of pollock. In Figure 25, the top panel shows a concentration of pollock at 60-70 m; the corresponding dive data (bottom panel) show the tagged seal consistently diving to the same depths as the pollock concentration.

These results show that they were able to spatially and temporally link foraging behavior patterns of tagged female northern fur seals to echosounder (prey) data. Future steps include attaching accelerometers and cameras to the tags to identify prey captures, which will be a direct measure of foraging success. These findings will help guide conservation efforts for this population which has been steadily declining since 1998.

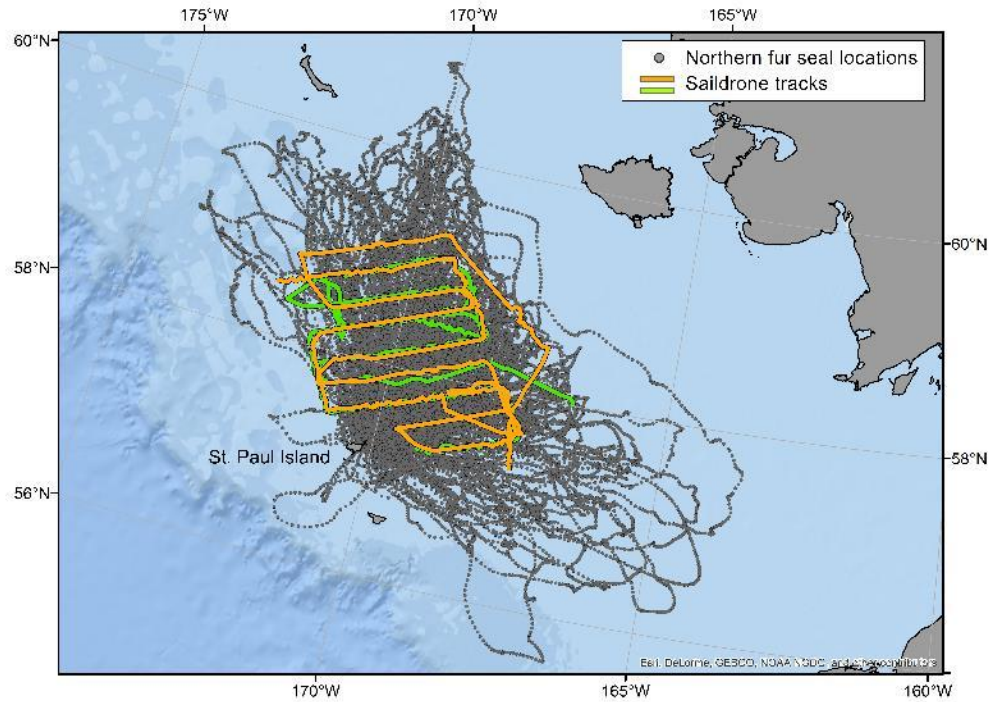

Figure 23. Map showing results from 29 satellite tagged female adult northern fur seal foraging trips (gray lines) and the tracklines taken by the Saildrones (yellow and green lines) surveying for walleye pollock.

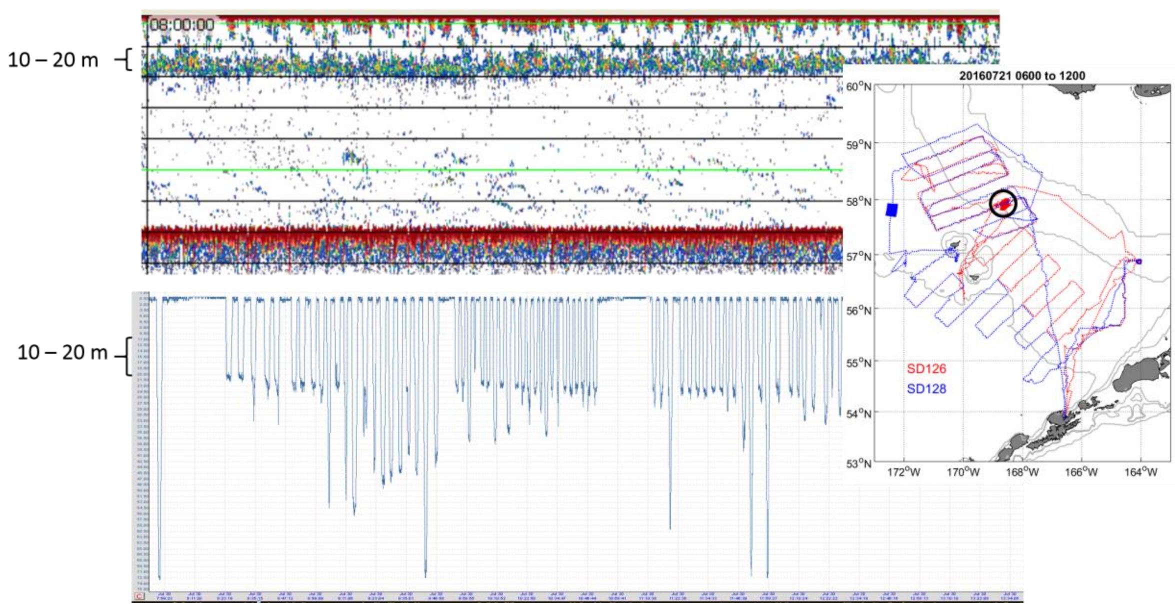

Figure 24. Comparison of echosounder data (top panel) with dive data from a tagged female northern fur seal (bottom panel). Top panel reveals a concentration of age zero pollock at 10-20 m. The bottom panel shows the fur seal repeatedly diving to depths of 20 m. Inset map shows location of the tag data relative to the study area and Saildrone track lines. Figure by Carey Kuhn, MML.

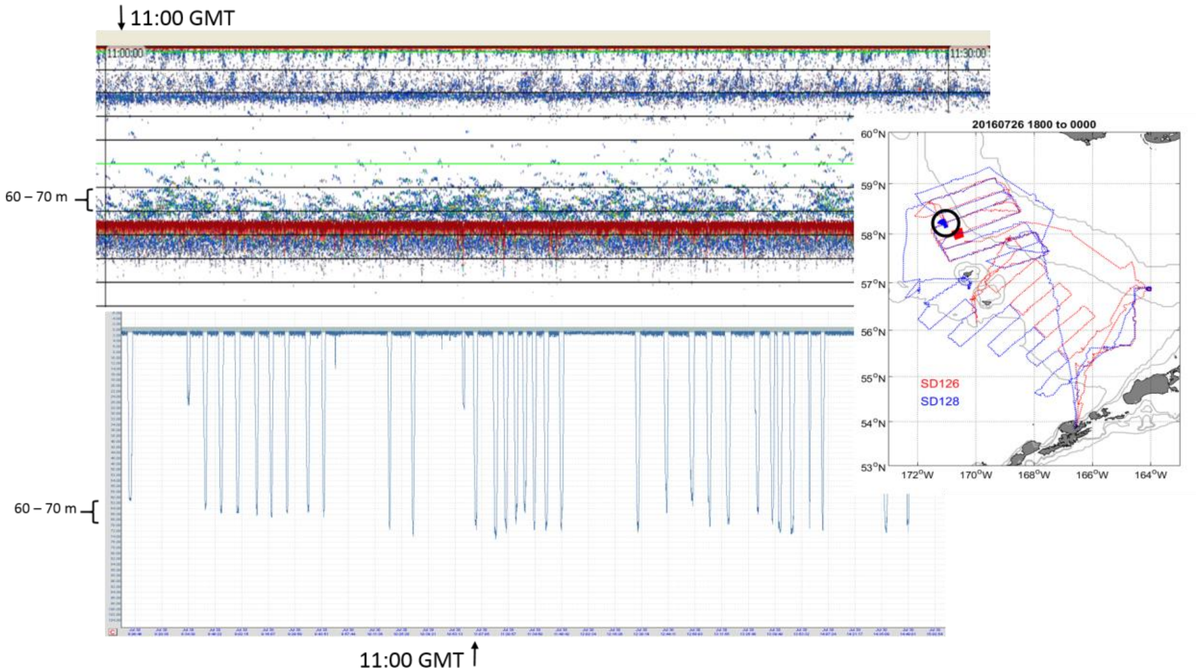

Figure 25. Comparison of echosounder data (top panel) with dive data from a tagged female northern fur seal (bottom panel). Top panel reveals a concentration of age zero pollock at 60-70 m. The bottom panel shows the fur seal repeatedly diving to depths of 60-70 m. Inset map shows location of the tag data relative to the study area and Saildrone track lines. Figure by Carey Kuhn, MML.

Presentations, meetings, or outreach

1 November 2016 – Scientists from PMEL, ITAE, Saildrone, Inc., and MML meet for a "Saildrone Data" workshop, in which discussions on processing the data, implications for the results, and the future of Saildrone research technology took place.

10 November 2016 – "Using ground-breaking technology to search for the cause of the northern fur seal decline in Alaska". Presentation by Carey Kuhn (MML/AFC) at the Discover Science Weekend. Seattle Aquarium, Seattle, WA.

25 January 2017 – "Saildrone 2016: Simultaneously measuring the environment, fishes, and marine mammals in the Bering Sea." Poster presentation by Ned Cokelet at the Alaska Marine Science Symposium. 23-27 January, Anchorage, AK.

14-16 February 2017 – The Saildrone project is presented on a poster at the Oceanology International Conference. 14-16 February, San Diego, CA.

27 February – 3 March 2017 – Saildrone, Inc., and ITAE/PMEL are testing the newly redesigned Saildrone off San Francisco, CA. After two days in San Francisco Bay, the Saildrone will sail south toward Santa Barbara, and rendezvous with the NOAA ship *SHIMADA* and some moored instruments for data comparisons. This test mission also has an Acousonde integrated onto the keel to collect passive acoustic data. This will allow for a comparison between the redesigned hull noise and the 2016 mission noise.

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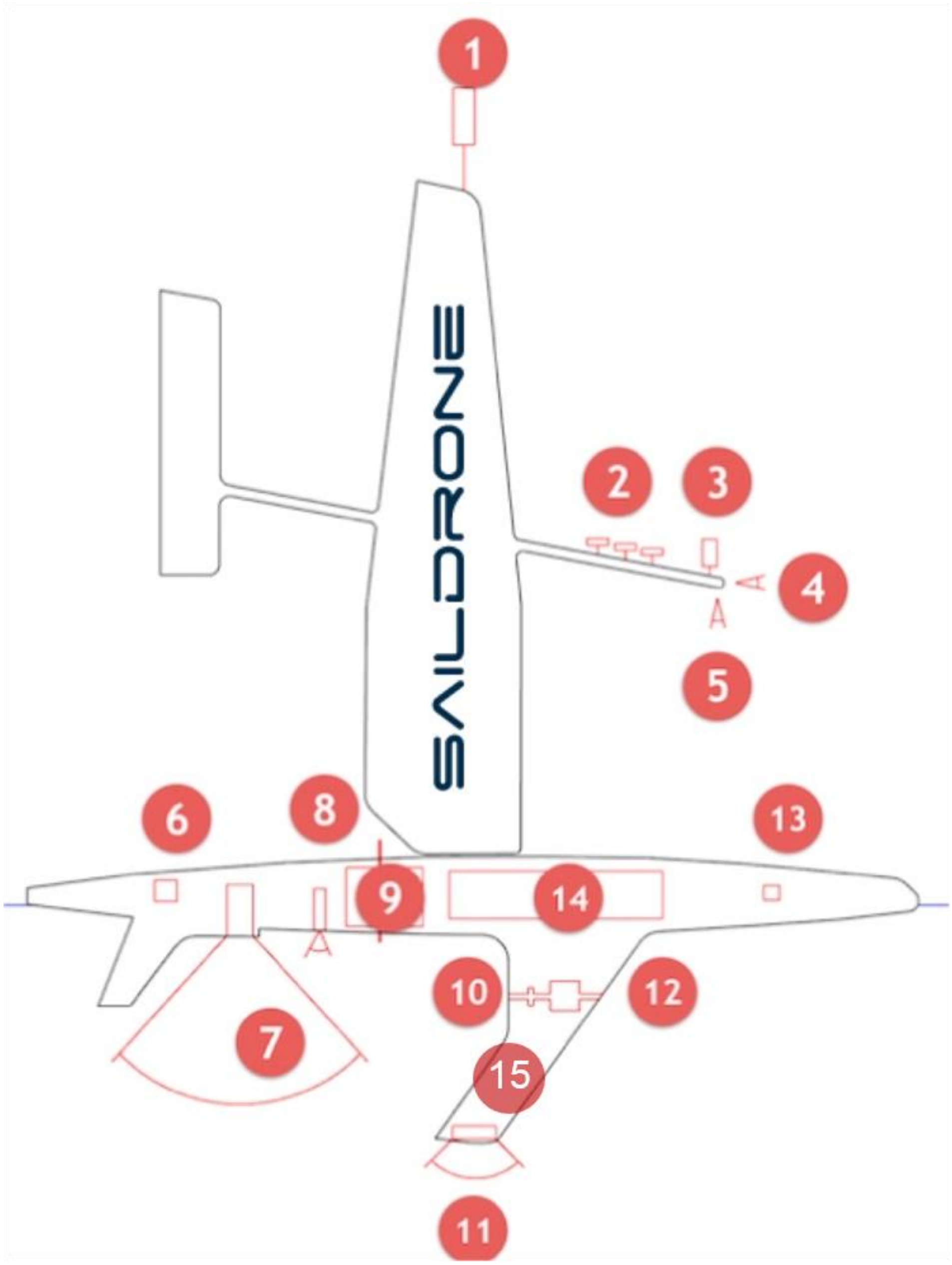
Appendix 1. Diagram showing a complete list of instrumentation and their orientation on the Saildrone.



1	**Anemometer @ 4.5m** Windmaster 3D ultrasonic 20Hz	6	**Barometric Pressure** Viasala PTB210	11	**Wide Band Acoustic Transducer** SIMRAD EK60
2	**Long & Shortwave Radiometers** Sunshine Pyranometer	7	**ADCP 150kHz** Phased Array	12	**Thermosalinograph @0.5m** Teledyne
3	**AT/RH @ 2.2m** Rotronic HC2 - S3 w/ rad shield	8	**Fluorometer @2m** Wetlabs (Chl., CDOM, Fluor.,backscatter)	13	**Magnettometer** Barrington MAG 648
4	**Wide angle camera - 4** forward, aft, left, right	9	**pCO2** PMEL MAPCO2	14	**Guest Payload** 250lb capacity
5	**IR Pyrometer** KT15 II for SST	10	**Dissolved Oxygen @0.5m** Teledyne	15	**Passive acoustic recorder** Acousonde