



Notes


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Acoustic documentation of temperate odontocetes in the Bering and Chukchi Seas

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Warming in the Arctic region is three times the rate of the global average with summer sea ice declining 11.5% per decade since 1979 (Comiso and Hall 2014). This drives ice-obligate and ice-associated marine mammal species northward and opens space for temperate species to also shift poleward. Larger and more rapid shifts are to be expected, especially if the Arctic is predicted to be ice free in the summers by the 2030s (Kwok *et al.* 2009, Wang and Overland 2012). Previous research has shown that several marine mammal species that spend some or all of their life cycles in the Arctic (bowhead, gray, and beluga whales; and bearded and ribbon seals) adjust their distributions, mating, and migrating behaviors concurrently with ice cover changes, such as ice retreating midwinter compared to being continuously present (Grebmeier and Dutton 2000, Miksis-Olds *et al.* 2013, Miksis-Olds and Madden 2014, Hauser *et al.* 2016). Scientific names of these species include *Balaena mysticetus* (Linnaeus, 1758), *Eschrichtius robustus* (Lilljeborg, 1861), *Delphinapterus leucas* (Pallas, 1776), *E. b. nauticus* (Pallas, 1881), and *Histriophoca fasciata* (Zimmerman, 1783), respectively. Passive acoustic monitoring (PAM) was key in these studies because ship-based visual surveys are not possible during ice cover, and even airborne visual surveys are dangerous to carry out in inclement weather. Furthermore, both types of visual surveys are only possible

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during daylight. PAM is the only safe way to monitor species presence in the Arctic year-round and overnight.

Until recently, FAM was constrained by power capacity and storage-limited sampling rates (typically up to 44.1 kHz), leading acoustical studies in the Arctic to use intermittent recordings limited to only those species that vocalize below 22 kHz. For any species that vocalizes higher than 22 kHz, distribution and presence studies have been limited to visual surveys, stranding data, and whaling records. In this study, Passive Acoustic Listeners (PALs) were used because they can sample at 100 kHz with year-round duty cycling for power saving capabilities in cold waters (Nystuen 1998). To allot power throughout an entire year, the PALs record 4.5 s WAV files every 2 or 10 min, depending on whether a target signal was or was not detected in the previous file, respectively (Denes *et al.* 2014). This leads to very low duty cycles (0.75% and 3.75%), so presence is likely under-sampled. It should be noted that duty cycling inherently leads to missing information since the environment is not monitored continuously. In killer whales, for example, it has been shown that lower resolution data with a high duty cycle is most efficient (Riera *et al.* 2012). While high-frequency clicks and buzzes are short enough to be fully captured in 4.5 s files, PAL files being spaced at least two minutes apart is not always sufficient in providing context to aid in species identification. Therefore, a cautious manual identification methodology was used so as to not overstate the results.

The first high-frequency acoustic data set collected by PALs from the Bering Sea is now a decade long. Some high frequency vocalizations of odontocetes that typically inhabit only temperate waters (referred to as “typically temperate” species in this note) have been found in this data set. In this note, we document acoustic detections of three typically temperate odontocete species at two sites in the Bering Sea and one site in the Chukchi Sea. While not prolific due to the PAL sampling protocol, these detections suggest the possibility that temperate species range more poleward than documented in the literature. Future visual and acoustic survey efforts will better refine the observations presented here as technology develops and research interest in the Arctic expands.

PALs were deployed as part of larger, subsurface, vertical mooring assemblages by the U.S. National Oceanographic and Atmospheric Administration as part of its Ecosystems and Fisheries-Oceanography Coordinated Investigations program in the Bering and Chukchi Seas at four locations for parts of all years between September 2007 and September 2017 (Table 1). Mooring labels and locations were: M2 at

Table 1. Available data: a timeline of PALs deployed at four sites in the Bering and Chukchi Seas. “x” denotes data available for at least part of the year.

[illegible]

56°52.202'N, 164°03.935'W; M5 at 59°54.646'N, 171°43.854'W; M8 at 62°11.62'N, 174°40.06'W; and CH at 67°54.671'N, 168°11.695'W. The first three were in the Bering Sea; the fourth was in the Chukchi Sea. All sites were on a continental shelf approximately 70 m deep, and the sensors were suspended roughly 10 m above the ocean floor. There have been dedicated visual efforts in the Arctic, largely north of Point Lay, Alaska, that have not yet documented typically temperate species, but have shown evidence of sub-Arctic marine mammal species moving poleward (Aerts *et al.* 2013, Clarke *et al.* 2013, Brower *et al.* 2018). For reference, the mooring sites in this note have been placed in the Pacific Arctic corridor north of the Aleutian archipelago and south of the areas with well-documented visual surveys.

Most of the clicks and buzzes recorded by the PALs were from sperm whales (*Physeter macrocephalus*), beluga whales, killer whales (*Orcinus orca*), and/or were too faint to be classified as anything but an unidentifiable odontocete, which was expected given that these are the known ice-associated and ice-obligated species. Some wav files, however, had peak and notch patterns like those produced by Risso's dolphins (*Grampus griseus*, G. Cuvier 1812) and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*, Gill 1865) as reported by Soldevilla *et al.* (2008) and northern right whale dolphins (*Lissodelphis borealis*, Peale 1848) similar to those from Rankin *et al.* (2007). Acousticians with experience detecting and classifying such species using a variety of recording instruments were contacted for guidance.² To separate Risso's clicks and buzzes from those of Pacific white-sided dolphin, the following steps were taken:

1. The spectrum of each click and buzz above ~6 dB SNR was generated and electrical noise bands were noted to prevent confusion with actual peaks of the clicks and buzzes.
2. Peaks and notches of the spectra were recorded, means calculated for each file, and compared to the training data set parameters from Soldevilla *et al.* (2008) for classification.
3. If at least four of the seven peaks or notches fell within Soldevilla *et al.*'s testing set ranges (even if electrical noise excluded a peak), the file was considered to contain a vocalization.
4. All peaks and notches from files that passed rule 3 were then averaged and standard deviations were calculated by species and compiled into Table 2.

Sixty-four files passed these classification requirements for Risso's or Pacific white-sided dolphins. (For comparison, killer whales were identified in 812 files and beluga whales in 672.) Most peaks and notches from the PAL data sets align very closely with the means presented by

²Personal communications from Ann E. Bowles, 2595 Ingraham Street, San Diego, CA 92109, September 2016; Shannon Coates, 364 2nd Street, Suite #3, Encinitas, CA 92024, October 2016; Emily T. Griffiths, <http://www.emilytgriffiths.com>, April 2018; E. Elizabeth Henderson, 53560 Hull St, San Diego, CA 92152, April 2018; Marc O. Lammers, 726 S. Kihei Road, Kihei, HI 96753, June 2017; Bruce Martin, 202-32 Troop Avenue, Dartmouth, NS B3B 1Z1, Canada, April 2018; and Melissa Soldevilla, 75 Virginia Beach Drive, Miami, FL 33149, August 2016.

Table 2. Mean frequencies and standard deviation (kHz) of click and buzz peaks and notches classified as Risso’s (Gg) or Pacific-white sided (Lo) dolphins on PALs as compared to the testing and training data sets of Soldevilla *et al.* (2008).

	Peak No. Mean kHz (SD)				Notch No. Mean kHz (SD)		
	1	2	3	4	1	2	3
Soldevilla training Gg	22.1(0.7)	25.6(0.7)	30.3(0.8)	39.0(0.8)	19.8(0.7)	27.5(0.9)	35.8(1.1)
Soldevilla test Gg	22.4(0.8)	25.5(1.0)	30.5(1.1)	38.8(1.1)	19.6(1.3)	27.7(1.1)	35.9(1.2)
PAL Gg	21.3(1.2)	24.9(1.1)	31.1(1.4)	38.9(1.1)	19.9(1.3)	27.1(1.5)	34.6(1.6)
Soldevilla training Lo	22.1(0.6)	26.7(1.0)	33.1(1.4)	37.3(1.1)	19.5(0.9)	24.5(0.8)	29.8(1.4)
Soldevilla test Lo	22.2(0.6)	26.6(0.9)	33.7(1.4)	37.3(1.4)	19.0(1.1)	24.5(0.9)	29.7(1.4)
PAL Lo	21.5(0.6)	26.4(1.1)	32.9(1.1)	37.4(0.9)	19.3(0.9)	24.2(1.4)	29.8(1.4)

Soldevilla *et al.* (2008), but a few fell into the more extreme ranges that those authors reported (Table 2). A combination of factors contribute to these discrepancies: (1) different air spaces in PALs and the instruments used by Soldevilla *et al.* (2008) create different reverberation patterns in the devices, resulting in different peaks and notches;³ (2) different distributions of main and side lobes could have been recorded on the PALs and other instruments due to variability in the orientation of the animals passing the recorders; (3) different propagation environments exist where the PALs (Arctic) and Soldevilla *et al.*’s instruments (Southern California Bight) were deployed; and (4) individual and population level variation of clicks and buzzes in Risso’s and Pacific white-sided dolphins are unknown.

Detections of these species are interesting given the historical documentation of their temperate-only distributions. Risso’s dolphins have only been visually reported north of the 51st parallel once (Clark 1945), resulting in Leatherwood *et al.* (1980) reporting that sighting as spurious. The Leatherwood *et al.* (1980) Risso’s dolphin study performed visual surveys from May through September on ships of opportunity with a U.S. National Marine Fisheries Service fur seal research program and identified a reasonable northern species limit at the 52nd parallel. These months align with information in the gray literature that any Risso’s dolphin sighting north of the 42nd parallel occurred between March and October during warm-water intrusions (Brueggeman 1989). Jefferson *et al.* (2014) followed with the most comprehensive study of sighting and capture records, starting with 1939 observations made by Vibe (1950) through 2012. They noted six single-animal sightings between the 52nd and 64th parallels worldwide but considered those “extralimital” and concluded that “research in [the Bering Sea] has been

³Personal communication from Marc O. Lammers, 726 S. Kihei Road, Kihei, HI 96753, June 2017.

extensive and only a handful of records have been documented...there is no evidence that [Risso's dolphins] reach as far North as the Aleutian Islands or extend into the Bering Sea."

There are drawbacks to visual sighting documents, like the inability to survey during inclement weather and heavy ice cover. Survey vessels in the Arctic Ocean are sparse even during good weather due to its remote location, so it should not be interpreted that a lack of visual sightings is equivalent to a complete historical absence of these species in the Bering and Chukchi Seas. It is possible that the species reported in the present study have travelled into the Arctic Ocean in the past, making use of seasonal ice free areas, but were undetected. They may be continuing to do so, and technological advances to track them are now coincident with the expansion of ice free areas in warming waters.

It is notable that the Jefferson *et al.* (2014) study concluded with records from 2012 when a cold climatic regime in the Bering Sea, which started in 2009, shifted to a warm climatic regime (Stauffer *et al.* 2015). These four cold climate years from 2009 to 2012, and particularly 2012, saw more expansive and thicker ice that retreated later in the season, stratifying the water column earlier and more tightly coupling the biomass of primary production with hydrographic conditions (Stauffer *et al.* 2015). During cold climate years, the Oscillating Control Hypothesis (OCH) states that fisheries are controlled by bottom-up mechanisms and biomass is transported to benthic communities instead of pelagic fishery populations (Hunt *et al.* 2002). When biomass, like particulate organic matter (POM), is concentrated in the benthos during cold regime years, the benthic food web only has three steps (benthic primary producer > POM > benthic consumer). This creates an abundance of benthic fishes for consumption by marine mammals at higher trophic levels. Conversely, biomass shifting to the pelagic ecosystem during warm regime years enhances the food web with two additional steps (pelagic primary producer > POM > pelagic consumer > pelagic consumer > benthic consumer) and reducing food availability for marine mammals at higher trophic levels. With stable carbon isotope studies, Christianen *et al.* (2017) indicated that benthic primary producers are the most important energy source for high-trophic level consumers like whales. Therefore, cold climate years when biomass is concentrated in the benthos makes food more available to marine mammals.

Because the three traditionally temperate species under consideration in this note reside mostly south of the Aleutian Archipelago, an impetus to move farther North into a richer food web must exist. This impetus could be in the form of a negative phase in the Pacific Decadal Oscillation (PDO) which is the dominant basin-wide oceanographic driver (Mantua *et al.* 1997, Mantua and Hare 2002, Newman *et al.* 2016). When the PDO is in a negative phase, it produces relatively large warm water anomalies (up to +0.8°C) in the western Gulf of Alaska and most of the Northern Pacific (Mantua *et al.* 1997). In 2012 the PDO shifted from a 6 yr negative (warm) phase to a strong positive (cold) phase. In fact, 2008 and 2012 marked the most negative PDO values recorded in the previous six decades (Mantua *et al.* 1997). Therefore, while the Bering Sea was in a cold climatic (benthic-driven food web) regime from 2009

to 2012, the PDO was in a negative (warm waters in the Gulf of Alaska/-North Pacific) phase from 2006 to 2012. With warmer waters expanding the inhabitable temperature range northward because of a negative phase PDO, and a cold regime in the Bering Sea providing more food because of a benthic-drive web, the two processes could be working in tandem to grant typically temperate species more access into the Arctic corridor.

As both the PDO and the Bering regime shifted in 2012, Risso's dolphins were acoustically detected at M2 9 d and at M5 14 d, mainly during late spring and fall, since 2009. They were not detected again at either site until 2017 (Fig. 1) following the 2014 to 2016 warm climate regime that began attenuating after a warm peak in 2015 (Duffy-Anderson *et al.* 2017). In fact, nearly all of the clicks and buzzes from typically temperate species occurred in the PAL data sets from 2008 to 2012, then were not detected again until 2017 coincident with the PDO easing out of its strong positive phase. In the Chukchi, which did not have high-frequency acoustic data collection until 2016, Risso's dolphins were detected on one day in the fall of 2016.

The northern right whale dolphin is a cool-temperate species that prefers water temperatures between 7.8°C and 18.9°C (Leatherwood and Walker 1979, Forney and Barlow 1998). In the most recent review of their distribution by Baird and Stacey (1991), the authors considered visual sighting records until 1988. They concluded that aside from a few sightings in the Gulf of Alaska north of the 55th parallel, and one in the Central Aleutian Islands (Kajimura and Loughlin 1988), that British Columbian waters are the outermost limits of the species' normal distribution and "the large number of records in recent years [off British Columbia] either indicates an unusual extension into northern waters, or...reflects increases in sighting effort." This may still be largely true because only two acoustic detections (one each at M2 and M5) in the PAL data sets were classified as northern right whale dolphins (Fig. 2). Again, these occurred in 2012 near the end of a cold regime in the Bering Sea that coincided with a turn from a negative PDO phase.

The Pacific white-sided dolphin is another temperate water species that has been sighted only up to the 61st parallel (the northern-most point) in the Gulf of Alaska, albeit more often than the other species discussed in this note (Leatherwood *et al.* 1984). Although Leatherwood *et al.* (1984) did not enter the Bering Sea, they asserted that white-sided dolphins usually do not go beyond the Aleutian Islands, while Kajimura and Loughlin (1988) state there are a few records of them being present in the southern portion of the Bering Sea. Other studies have pointed out that warming waters throughout the Pacific have been shifting white-sided dolphin distributions elsewhere. Dahlheim and Towell (1994) found an increase in their presence in near-shore waters off Southeast Alaska and suggested warmer-than-average sea surface temperatures as the driving force. Similarly, Salvadeo *et al.* (2010) found that the white-sided dolphin southern range limit in the Gulf of California had moved poleward away from warming tropical water temperatures.

In the PAL data sets, Pacific white-sided dolphins were the most commonly detected of the typically temperate Arctic species (Fig. 3). At M2, they were detected for 8 d in the fall of 2009, 17 d throughout 2010,

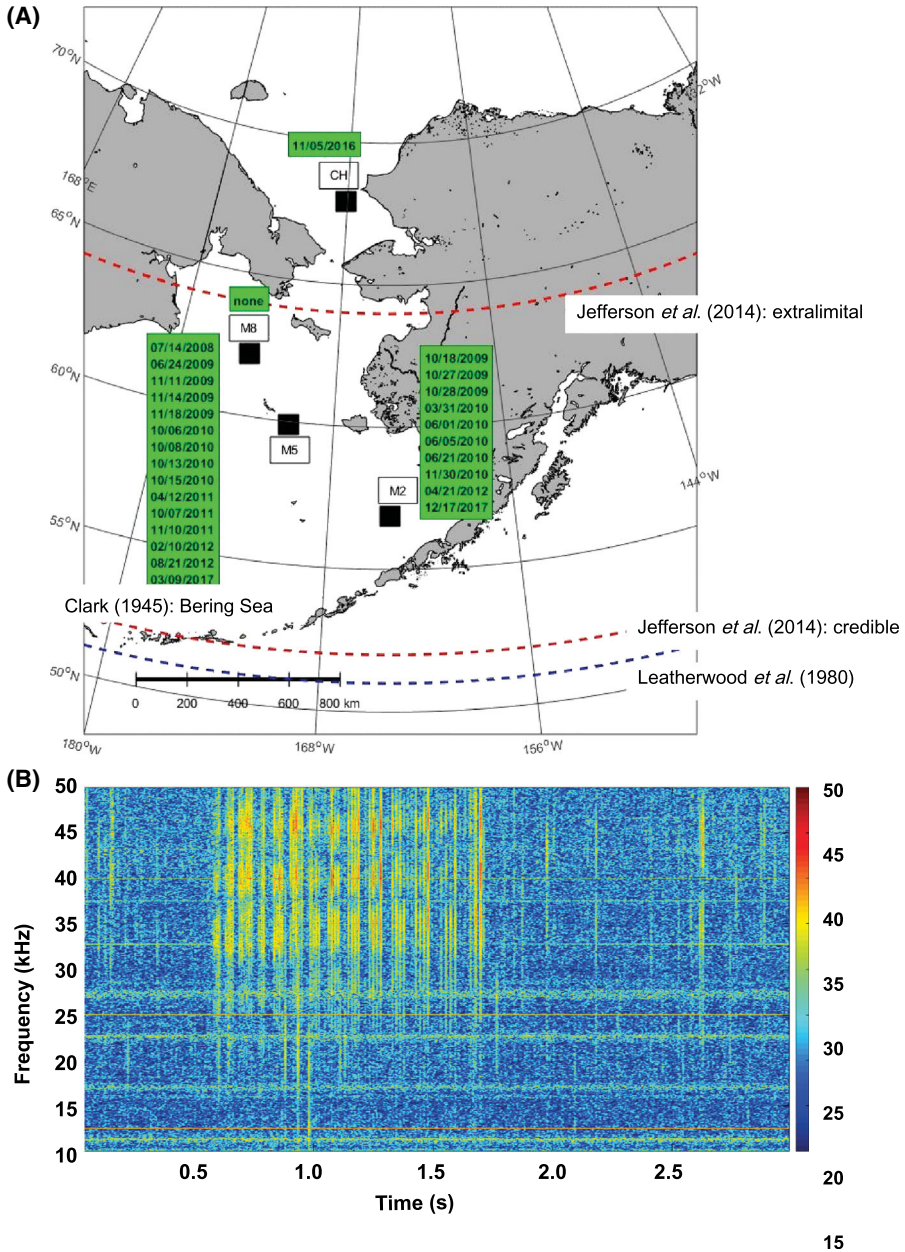


Figure 1. (A) Map of acoustic detections attributed to Risso's dolphins at sites M2, M5, and CH with dotted lines denoting historical range extents. (B) A spectrogram from 31 March 2010, at M2 zoomed into clicks attributed to Risso's dolphins because peaks and notches are centered near the expected frequencies reported in Soldevilla *et al.* (2008). Spectrogram settings are: window = Hanning, Nfft = 2,048, overlap = 99%, min dB = 10 dB, dB spread = 40 dB.

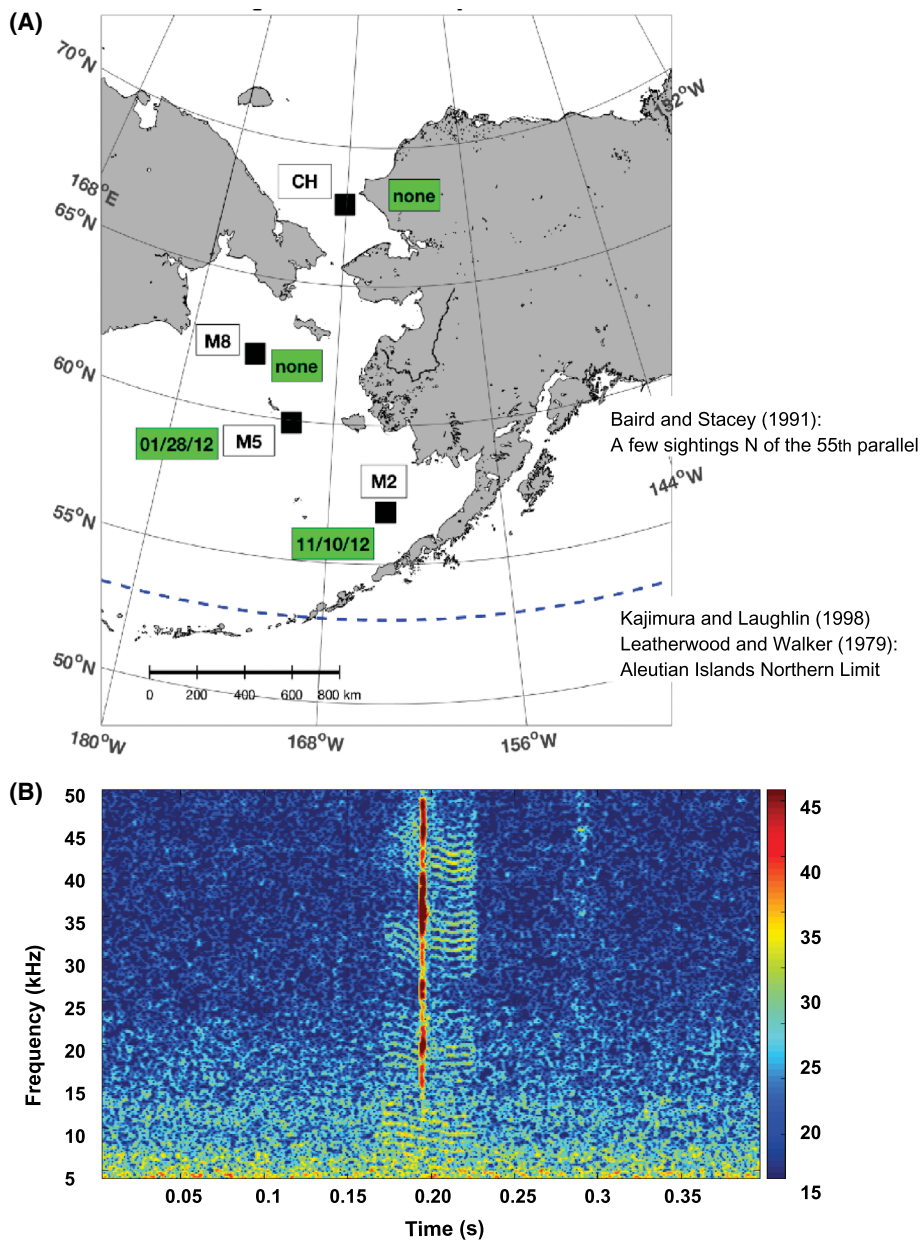


Figure 2. (A) Map of the acoustic detections attributed to northern right whale dolphins at sites M2 and M5 with dotted lines denoting historical range extents. (B) A spectrogram from 10 November 2012, at M2 of a downsweeping, harmonic click/buzz at 0.5 s with is characteristic of northern right whale dolphins (despite being masked by the ping of another instrument on the mooring). Spectrogram settings are: window = Hanning, Nfft = 512, overlap = 99%, min dB = 11 dB, dB spread = 35 dB.

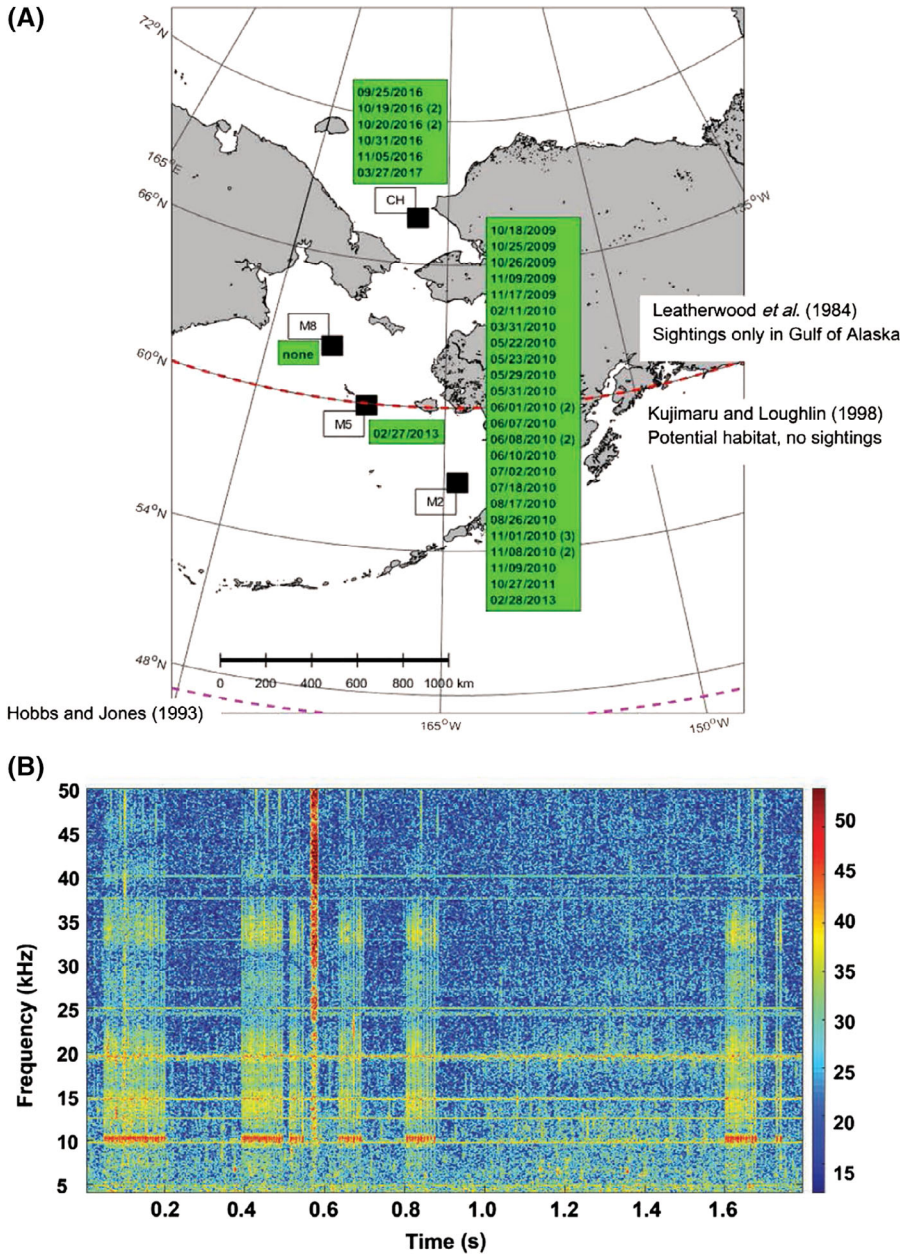


Figure 3. (top) Map of acoustic detections attributed to Pacific white-sided dolphins at M2, M5, and CH with dotted lines denoting historical range extents. Number of files with detections each day are in parentheses if >1. (bottom) A spectrogram from 25 October 2009, at M2 of buzzes with peaks and notches as expected for Pacific white-sided dolphins according to Soldevilla *et al.* (2008). Spectrogram settings are: window = Hanning, Nfft = 1,024, overlap = 99%, min dB = 12 dB, dB spread = 42 dB.

and once in both 2011 and 2013. At M5, they were detected once in February of 2013. In the Chukchi, 6 d contained detections of Pacific white-sided dolphins: five in fall 2016 and one in spring 2017.

These acoustic documentations are farther south than the bulk of published visual surveys from the Arctic Ocean, which have not yielded sightings of these typically temperate species. Clarke *et al.* (2013) performed visual surveys at Klondike, Burger, and Statoil sites north of Point Lay (ours were south of Point Lay) and documented a handful of extralimital Dall's porpoises—coincidentally during 2008–2009 when the PDO and Bering Sea combination occurred. Another visual survey project (Brower *et al.* 2018) also did not document the species reported in this note, but the area of effort of that study did not overlap with our recordings in time nor space. Brower *et al.* note, however, that in recent years (2008–2016), it has become increasingly common for sub-Arctic cetacean species (humpback, fin, minke, and killer whales) to be sighted and recorded in the eastern and central Chukchi Sea from several platform types (Bakhmutov *et al.* 2009, Aerts *et al.* 2013, Clarke *et al.* 2013, Delarue and Martin 2013, LGL 2014, Berchok *et al.* 2015, Crance *et al.* 2015, Tsujii *et al.* 2016). Corresponding taxonomic names include *Megaptera novaeangliae* (Borowski 1781), *Balaenoptera physalus* (Linnaeus 1758), *Balaenoptera acutorostrata* (Lacépède 1804), and *Orcinus orca* (Linnaeus 1758), respectively. Acoustic recorders in these reports either did not use or did not report sampling at rates high enough to capture the delphinid species discussed in this note. Their observations of sub-Arctic low-frequency-producing species in unexpected areas, however, gives credence to the possibility that typically temperate species are also shifting their ranges northward. Brueggeman (1989) mentions a sighting by Scammon of northern right whale dolphins in 1874 and states that the species tended to be observed during cold-intrusions in the Gulf of Alaska. They follow with the point that previous northward expansion of Risso's dolphins may have been a result of long-term warming of oceanic waters.

Overall, visual survey efforts have been more intense in the Chukchi and Beaufort Seas (north of our sites) than in the Bering Sea. Relying on visual surveys for tracking distribution changes in Arctic species is difficult because ships cannot sail during inclement weather as ice moves in and out, engine noise may illicit avoidance behavior, and coverage is limited in such a remote area. Given that we know little about how each of these three species responds to acoustic disturbance, it would seem reasonable to assume that these animals may be too skittish to be observed visually from the ship. Therefore, passive acoustic surveys are a vital tool for gaining a more complete picture of animal presence. Because of technological limitations, passive acoustic monitoring studies in the Arctic Ocean with a high enough sampling rate to detect the echolocation signals of typically temperate species have been limited. With PALs, though, that has changed. This high-frequency-sampling acoustic study over the last decade suggests that Pacific white-sided dolphins, Risso's dolphins, and northern right whale dolphins (in order of extremity) may be shifting into Arctic waters during coincident years of significant warm water invasion from the Gulf of Alaska and cold regimes in

the Bering Sea. It is conceivable that acoustic detections at M2, M5, and CH are indications of what future visual surveys in the Bering, Chukchi, and Beaufort Seas could confirm. Visual and acoustic surveyors in the coming years will ideally work together to verify and/or refine any habitat shifts.

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