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SHORT NOTE

Comparing marine mammal acoustic habitats in Atlantic and Pacific sectors of the High Arctic: year-long records from Fram Strait and the Chukchi Plateau

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Abstract During the International Polar Year (IPY), acoustic recorders were deployed on oceanographic moorings in Fram Strait and on the Chukchi Plateau, representing the first coordinated year-round sampling of underwater acoustic habitats at two sites in the High Arctic. Examination of species-specific marine mammal calls recorded from autumn 2008–2009 revealed distinctly different acoustic habitats at each site. Overall, the Fram Strait site was acoustically complex compared with the Chukchi Plateau site. In Fram Strait, calls from bowhead whales (*Balaena mysticetus*) and a variety of toothed whales (odontocetes) were recorded year-round, as were airgun pulses from seismic surveys. In addition, calls from blue whales (*Balaenoptera musculus*) and fin whales (*B. physalus*) were recorded from June to October and August to March, respectively. Conversely, at the Chukchi Plateau site, beluga (*Delphinapterus leucas*) and bowhead whale calls were recorded primarily from May to August, with airgun signals detected only in September–October. Ribbon seal (*Phoca fasciata*) calls were detected in October–November, with no marine mammals calls at all recorded from December to February. Of note, ice-adapted bearded seals (*Erignathus barbatus*) were recorded at both sites, primarily in spring and summer, corresponding with the mating season for that species. Differences in acoustic habitats between the two sites were related to contrasts in sea ice cover, temperature, patterns of ocean circulation and contributions from anthropogenic noise sources. These data provide a provisional baseline for the comparison of underwater acoustic habitats between Pacific and Atlantic sectors of the High Arctic.

Keywords Marine mammals · Acoustics · Seismic surveys · International Polar Year

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Introduction

The rapid loss of Arctic sea ice over the past decade (e.g., Comiso et al. 2008) has precipitated concern regarding the negative impact that concomitant increases in anthropogenic activities such as commercial shipping, oil and gas development, scientific research and tourism might have on marine mammals (Huntington 2009). In addition to the possibility of disturbance, injury or mortality from ship strikes, the reliance of marine mammals on sound as a primary sensory/communication modality raises concerns regarding the masking of signals important to the animals by sounds from anthropogenic sources (Clark et al. 2009). Sound from commercial shipping and seismic surveys is now ubiquitous in many temperate and tropical oceans (e.g. Hildebrand 2009), with airgun signals recorded >80% of days/months and at distances up to 5,000 km from the source in the North Atlantic basin (Nieukirk et al. 2004). Until recently, the Arctic was thought to be a comparatively pristine environment with regard to anthropogenic noise, but increases in human activities in the region suggest a need for the integration of passive acoustic sampling into ocean observatories to provide a means to track changes in the underwater acoustic environment (Dushaw et al. 2010).

Over the past decade, long-term deployments of passive acoustic recorders have provided new baselines on the seasonal occurrence of various species of large whales in polar ocean regions (e.g. Moore et al. 2006; Širović et al. 2009). In the Arctic, passive acoustic sampling has identified both whale calls and sounds from anthropogenic sources such as ships and seismic surveys, activities that are expected to increase with diminished sea ice cover (AMSA 2009). In the IPY year 2008, passive acoustic recorders were deployed at two oceanographic mooring sites in the High Arctic. The resultant data represent the first coordinated year-round sampling for marine mammal calls in the High Arctic and provide a baseline for comparison between Atlantic and Pacific Ocean sectors. Here, we provide an overview of seasonal detections of sounds for both marine mammals and airguns, as a precursor to a more coordinated and robust effort to quantify Arctic underwater acoustic habitats.

Methods

Passive acoustic recorders (Aural-M2, http://www.Multi-Électronique.com[1]) were deployed on two sub-surface oceanographic moorings (Fig. 1) in Fram Strait (78.8°N, 5°W) and on the Chukchi Plateau (75.1°N, 168°W) in September and October 2008, respectively. The recorders provided a year of sub-sampled data (9 continuous minutes of each 30), with a sampling rate of 16 kHz providing an effective bandwidth of 5 Hz to 4 kHz, which encompasses the frequency band of most whale and ice-seal calls. In both cases, the recorders sampled outer continental shelf habitats, at deployment depths of 82 and 120 m, respectively. The instruments were recovered 1 year after deployment, and data were downloaded for analysis. Calls from both arctic and sub-arctic species were identified, with details on the diagnostic aspects of these signals available online (http://www.dosits.org) and described in Richardson et al. (1995). Low-frequency signals (blue and fin whales and airguns) were detected by the use of the spectrogram correlation modality in Ishmael (Mellinger and Clark 2000; Mellinger 2001), while higher-frequency signals (bowhead whale, bearded seal and odontocete whale calls) were identified using a tonal detector in Ishmael (Mellinger et al. 2011). As is true of any passive acoustic sampling, only sound-producing animals and activities were detected such that the data reflect presence-only, not presence–absence.

In addition to acoustic sampling, the recorders also sampled water temperature at deployment depth for each site. Sea ice concentration, measured via satellite as tenths of surface cover, was obtained for both sites via the National/Naval Ice Center (http://www.natice.noaa.gov). Additional environmental data including temperature, salinity, ice thickness and a record of planktonic backscatter were obtained for the Chukchi Plateau site (http://imb.crrel.usace.army.mil/iceinstr.htm) to provide an example of integration of marine mammal calling data with other more-standard oceanographic measures. Similar environmental data for the Fram Strait will be incorporated in subsequent reports of multi-year results from this project.

Results and discussion

At the Chukchi Plateau site, calls from beluga and bowhead whales were recorded consistently from May through August, with a few detections in March–April and October–November (Fig. 2a). The consistency of call detections on the Plateau from late spring through summer are surprising in that they occur outside the well-documented spring migration corridors and summering areas for both species (e.g., Moore et al. 1993; Moore and Laidre 2006). A suggestion that some bowhead whales may summer in the northern Chukchi had previously precipitated an opportunistic dipping-hydrophone acoustic survey in July 2005 that extended from Barrow, Alaska, to the Northwind Ridge (roughly 200 km west of the Chukchi Plateau site), but no beluga or bowhead calls were detected there (Moore et al. 2010), making the results of the current study even more unexpected. One bowhead whale equipped with a satellite tag did swim from the Canadian Beaufort Sea to the vicinity of the Chukchi Plateau recorder between 6 and 16 August 2009 (http://www.adfg.alaska.gov/marinemammalprogram/bowhead), documenting that these whales can range over broad areas of the Beaufort and Chukchi Seas during summer. In addition, ribbon seal calls were detected at the Chukchi Plateau site in October and November 2008. These call detections correspond with the track of a ribbon

[1] Use of trade names does not imply endorsement.

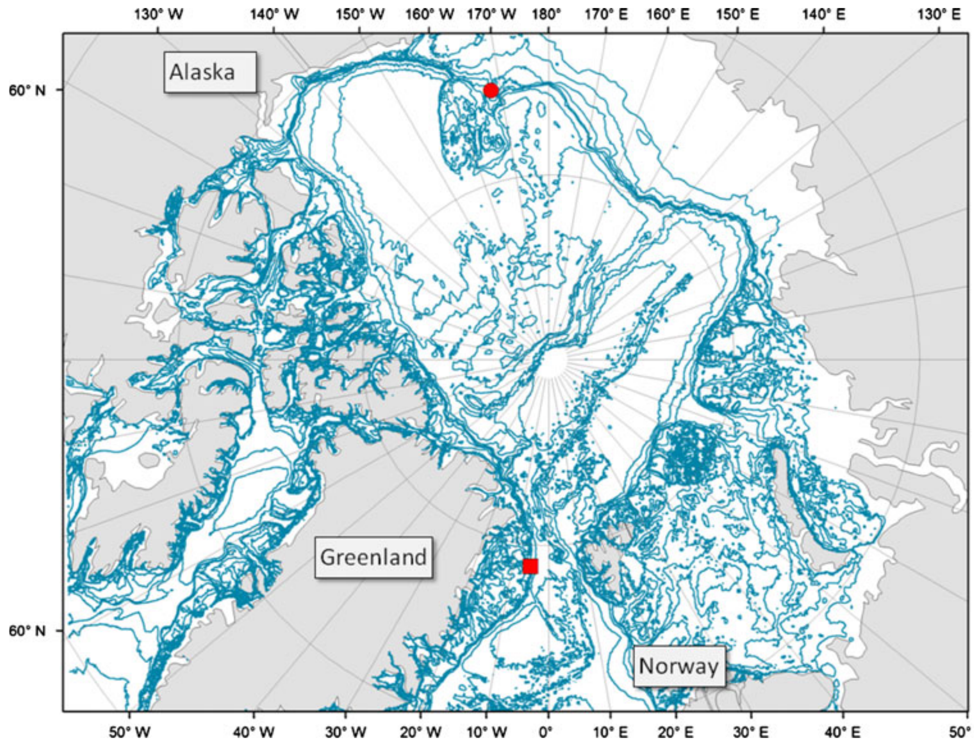

Fig. 1 Location of passive acoustic recorders on moorings in Fram Strait and on the Chukchi Plateau

seal equipped with a satellite tag in 2007 (Boveng et al. 2008) and contribute to the growing body of information on the seasonal range of this comparatively poorly known species.

The acoustic record was considerably more complex at the Fram Strait site. Odontocete echolocation (of unknown source) and calls, comprised primarily of signals from beluga and narwhals (*Monodon monoceros*), as well as calls from bowhead whales, were recorded throughout most of the year (Fig. 2b). One consistency between the two sites was the recording of distinctive long-melodic trills from bearded seals in late spring and summer (Fig. 2a, b), as anticipated for this breeding-related call (Van Parijs et al. 2001). Conversely, the consistency in the detection of fin whale calls from August to March and the lack of calls from this species during spring and early summer were not anticipated, in part due to January–April peaks in fin whale call detections in waters near Bermuda (ca. 32° 22′N, 64° 38′W) reported by Watkins et al. (1987) and interpreted as evidence that the whales swam to warmer waters in winter. This interpretation was reinforced by reports of summertime peaks in fin whale calling north of 50°N latitude in the central North Pacific (Moore et al. 1998). Detection of blue whale calling from June to November (Fig. 2c) was more in keeping with what is expected for summer residency of migratory baleen whales in the Arctic (Stern 2009). Seasonal calling records are known for these two species from long-term recorders deployed in the North Atlantic (e.g. Nieukirk et al. 2004), but not for waters as far north as Fram Strait.

In Fram Strait, airgun signals from seismic surveys were recorded *every day* from July to September, 80–95% of days/month from March to June and 30–65% of days/month from October to February (Fig. 2c). This contrasts with the comparatively short, but intense (85–100% days/month), period of airgun detections in September–October on the Chukchi Plateau (Fig. 2a).The nature of the airgun sounds varied with much stronger and more consistent signal strength received at the Chukchi site compared with the Fram Strait site, differences that likely correspond to the proximity of the seismic surveys. With only a single recorder deployed at each sites, actual distances to the seismic surveys could not be estimated. However, airgun sounds have been detected in all months and from sources 1,000 s km distant on hydrophones deployed in the deep sound channel along the mid-Atlantic ridge (Nieukirk et al. 2004), so long-range transmission of these signals in the High Arctic certainly appears possible.

Differences in acoustic habitats between the two sites can be related to contrasting bathymetric and oceanographic conditions, all of which can influence species occurrence (e.g. Moore et al. 2000) and sound transmission properties (e.g., Richardson et al. 1995). The Fram Strait is quite oceanographically complex. It is influenced year-round by southward outflow of sea ice and cold Arctic Water in the west along the NE Greenland coast, while in

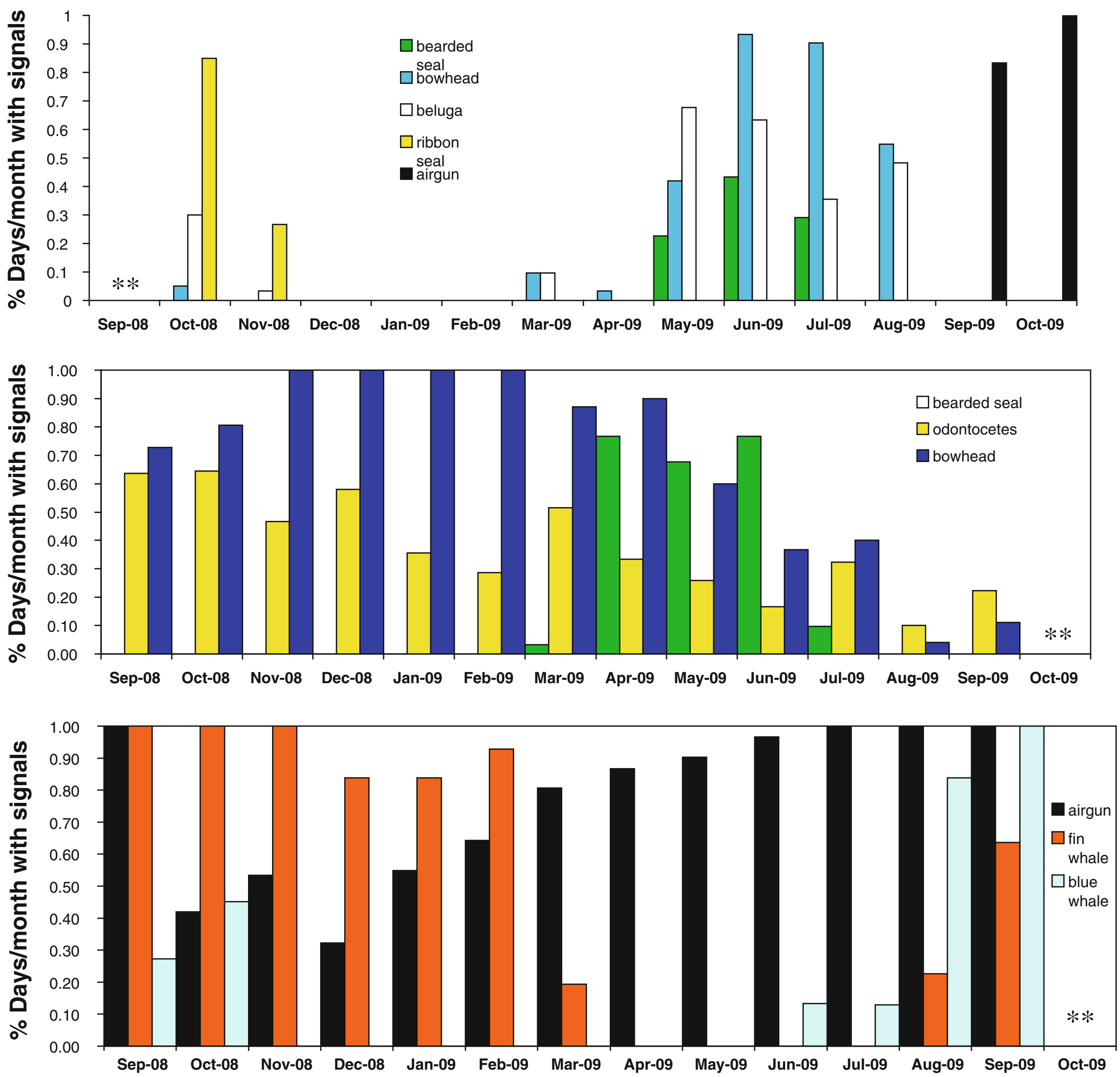

Fig. 2 Indices of marine mammal calls and airgun signals recorded in Fram Strait and on the Chukchi Plateau; ** = no data

the east, there is a contrasting northward inflow of relatively warm Atlantic Water along the Svalbard coast (Spielhagen et al. 2011). The normal dividing longitude at the mooring's latitude is roughly 5°W. Conversely, the Chukchi Plateau lies at the downstream end of inflow of sub-arctic waters through Bering Strait, a signal noted for strong seasonal variability (Woodgate et al. 2006), and is usually ice-covered except for a few weeks in late summer. Sea ice cover was close to 100% at the Fram Strait mooring throughout the 2008–2009 deployment, with a few days of 80–90% cover in May–June (Fig. 3a); however, the ice edge was within 100 km of the site year-round. Conversely, ice covered the Chukchi Plateau mooring until mid-July, dissipating in August to ice-free conditions by September and early October; however, the ice edge was within 100 km to the site only in mid-summer and in winter was as far as 1,900 km to the south in the Bering Sea. Except for a temperature spike in late August, water temperatures at recorder-depths were often colder at the Fram Strait site than at the Chukchi Plateau site (Fig. 3b), where influx of warm water from the northern Bering Sea has been characteristic of recent years (Woodgate et al. 2010). At the Chukchi site, the temperature and salinity record at 42 m depict a seasonal cycle of arrival of comparatively warm saline water, with a particularly abrupt signal evident in mid-September 2009.

The seasonal record of marine mammal call detections at the Chukchi Plateau site varied with sea ice thickness (Fig. 4). Bearded seal calls corresponded with the period of thickest sea ice (2–3 m), while ribbon seal calls were recorded only when there was a significant fraction of thin ice (<35 cm) during autumn 2008. Beluga and bowhead calls were detected during periods of both thin and thick ice cover, with the greatest fraction of calls corresponding to

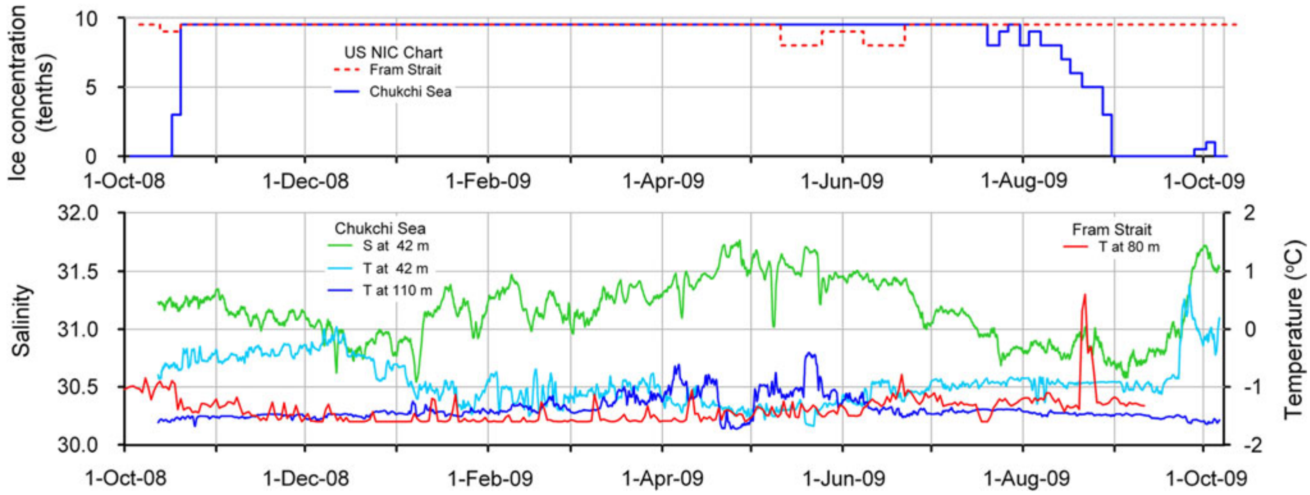

Fig. 3 Sea ice concentration (**a**) and temperature/salinity (**b**) at the mooring sites. Ice concentration is that linked to the ice-chart polygon overlying each mooring (http://www.natice.noaa.gov/products/weekly_products.html). Salinity and temperature were measured by SBE37 (Sea Bird Electronics) at 42 m depth on the Chukchi mooring and deeper temperatures measured by the AURAL-M2 on both moorings

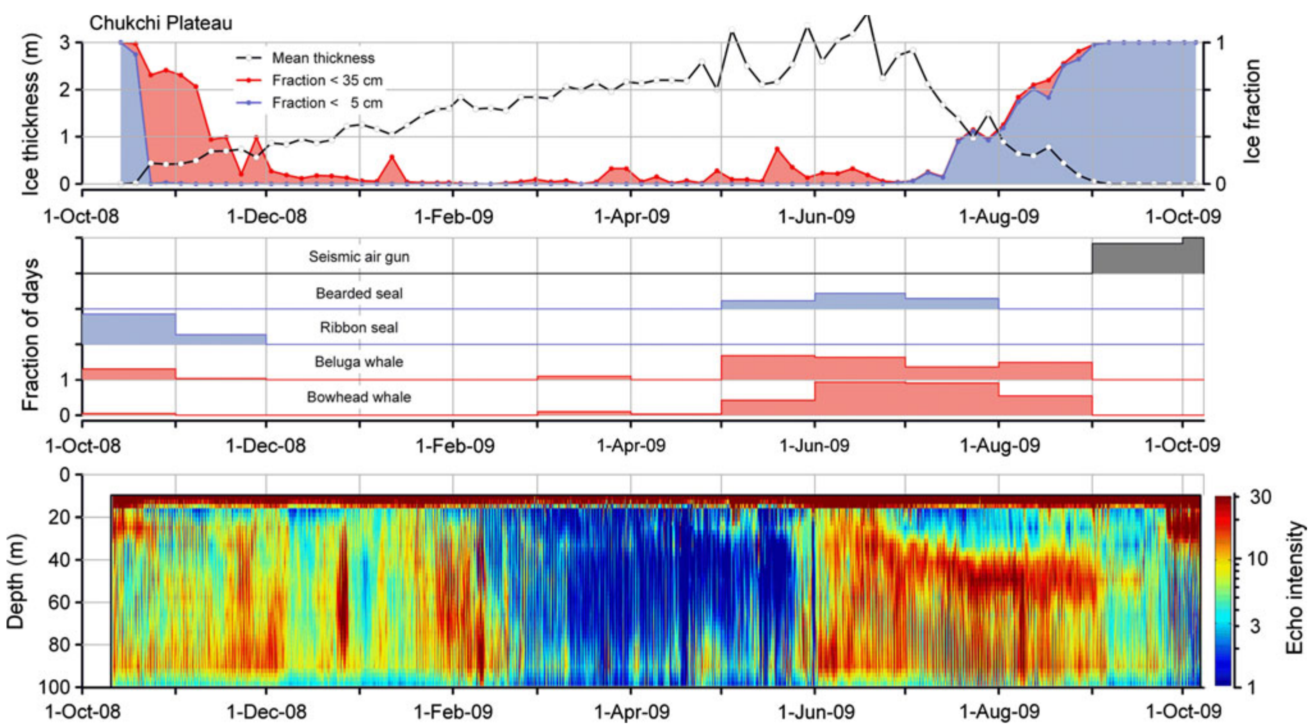

Fig. 4 Call frequencies and environmental data at the Chukchi recorder site. The *top panel* displays the mean thickness of pack ice and the fractions of ice thinner than 5 and 35 cm during contiguous 5-day windows, derived by ice profiling sonar (IPS4: ASL Environmental Sciences Inc). The *middle panel* displays the fraction of days per month with identified sounds of various sources, recorded by AURAL-M2. The *bottom panel* shows the relative intensity of echoes from plankton, received by 307-kHz Work Horse ADCP (Teledyne RDI) deployed at 110 m depth, ca. 10 m above the recorder, corrected for spreading loss and attenuation with increasing range. The returns have been averaged over 8 m in depth and 20 min in time; the sonar beam was tilted 20° off the zenith

the May–August period when the area fraction of thin ice plus open water was generally <10%. This in itself is not surprising, as both species are strongly ice-adapted and bowheads can create breathing holes though ice up to roughly 45 cm. However, it is noteworthy that the calls of both pagophilic species remained high through August, while the sea ice cover decreased from 30% to zero. One explanation for this may be found in the record of planktonic backscatter, the signal for which suggests very high zooplankton prey abundance through August. The cessation of beluga and bowhead whale call detections at the site corresponds with the abrupt drop in planktonic backscatter and complete disappearance of sea ice in September. Integrated records of whale calling and environmental conditions such as these are rare (e.g. Stafford et al. 2010), but are essential to the study of causal relationships and advanced understanding of High Arctic ecosystems.

The provisional results presented here provide 1-year snapshots of the acoustic habitats of two oceanographically distinct regions of the High Arctic. Including passive acoustic sampling on the moorings during the IPY provided a unique opportunity to sample these remote regions for marine mammal calls and anthropogenic sounds over the course of a full year. The robust data set generated by this opportunistic study provides a foundation for detailed analyses of marine mammals calling behaviors and support for the opinion that passive acoustic sampling should become a standard tool in ocean observing systems (Dushaw et al. 2010). Specifically, the inclusion of passive acoustic sampling in the Arctic Observing Network (http://aoncadis.org) is essential to provide a cost-effective tool to track changes in the marine ecosystem, which are anticipated to be rapid and strongly influenced by offshore human commercial activities.

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