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Seal and polar bear behavioral response to an icebreaker vessel in northwest Greenland

Kate Lomac-MacNair, CCMAR, Centro de Ciências do Mar, Universidade do Algarve Campus de Gambelas, 8005-139 Faro, Portugal *klomacmacnair@gmail.com*
José Pedro Andrade, CCMAR, Centro de Ciências do Mar, Universidade do Algarve Campus de Gambelas, 8005-139 Faro, Portugal
Eduardo Esteves, CCMAR, Centro de Ciências do Mar and Instituto Superior de Engenharia, Universidade do Algarve. Campus da Penha, 8005-139 Faro, Portugal

Abstract: Icebreaker vessels are important scientific tools, enabling access and research within the polar regions of the world, including the High Arctic. These vessels have the potential to overlap with marine mammal habitats in infrequently studied areas. Marine mammal behavioral responses to icebreaker vessel presence and distance at which responses occur are not well documented or understood. During the Petermann 2015 Expedition on the icebreaker *Oden*, seal and polar bear (*Ursus maritimus*) data were collected in Petermann Fjord (Northwest Greenland), the adjacent Nares Strait region, and transit to and from Thule, Greenland over 31 days (July 30 to August 30, 2015). We examined behavioral responses from 4 pinniped species: bearded seal (*Erignathus barbatus*), ringed seal (*Pusa hispida*), harp seal (*Pagophilus groenlandicus*), and hooded seal (*Crystophora cristata*), as well as the polar bear to an icebreaker vessel in a rarely studied region of northwest Greenland. We investigated the rate of flush response, entering the water from a previously hauled out (i.e., resting) location on ice in relation to seal distance to the vessel. Our results showed a significant difference (independent *t*-test, $P \leq 0.001$) between seal distance to the vessel when a flush response occurred (mean = 467.1 m, SD = 212.39 m) and when no flush response occurred (mean = 1334.0 m, SD = 433.89 m). There were fewer flush responses by seals to the icebreaker at distances >600 m and no flush responses by seals to the icebreaker at distances >800 m. We used a logistic model to describe the relationship between the proportion of seals that flushed and distance from the icebreaker. Results of the logistical model showed the estimated distance at which 50% of the seals flushed to be 709.45 m (SE = 9.24, $t = 76.8$, $P < 0.0001$). Three polar bears were recorded during the transit, and a behavioral response (e.g., look, approach, move away) was recorded for all 3 sightings. Our preliminary findings are relevant to assess potential impacts of increasing vessel activity in the High Arctic and to assist in the development of effective monitoring and mitigation strategies.

Key words: bearded seal, behavioral response, *Crystophora cristata*, *Erignathus barbatus*, harp seal, hooded seal, icebreaker, *Pagophilis groenlandicus*, Petermann Fjord, *Pusa hispida*, polar bears, ringed seal, *Ursus maritimus*

Icebreaker vessels are essential scientific tools, facilitating access and research in the polar regions of the world. Research and expeditions aboard icebreakers have furthered our collective knowledge of many fields, including but not limited to climate science, oceanography, and marine biology in these difficult-to-reach regions including the High Arctic. Additionally, these vessels are used for industry activities (e.g., oil and gas exploration and polar shipping). The recent decrease in Arctic sea ice along with climate model projections of future ice reductions have fueled speculations of potential new trans-Arctic shipping routes linking the Atlantic and Pacific Oceans (Smith and Stephenson 2013) and a rise in vessel presence in the High Arctic. The Arctic is generally divided into the Low Arctic and High Arctic based on environmental and biological characteristics (tundra is more prevalent in the Low Arctic, and polar barrens dominant in the High Arctic). The High Arctic is inhabited by many pagophilic ("ice loving") marine species, including marine mammals such as seals (Kovacs and Lydersen 2008, Lydersen et al. 2014) and polar bears (*Ursus maritimus*; Stirling 2009). The expected increase in commercial vessels, icebreaker operations, and Arctic vessel traffic has the potential to overlap with Arctic seal and polar bear habitats and is predicted to lead to increased interactions with marine mammals (Laidre et al. 2015*a*). The impact of icebreakers on Arctic marine mammals is poorly explored, generally opportunistic, and mostly unpublished. Adverse impacts include collisions, separation of pups from mothers (seal specific) and displacement (i.e., flushing into the water and habitat fragmentation; Wilson et al. 2017). Additionally, curiosity and approach are potential behavioral responses (i.e. polar bears; Stirling 1988). Behavioral responses to icebreaker vessel data have been collected for a few species in a limited scope of conditions. The few published studies indicated icebreaker operations to elicit behavioral responses from seals (Wilson et al. 2017) and polar bears (Smultea et al. 2016). Previously documented behavioral responses by seals to icebreaker operations include displacement and separation of mothers and pups (Wilson et al. 2017). Polar bear behavioral responses include walking or running away, swimming (i.e., fleeing into water), approach, and vigilance (Smultea et al. 2016).

Seal and polar bear data were collected in Petermann Fjord, the adjacent Nares Strait region, and transit to and from Thule, Greenland during late summer on the Petermann 2015 Expedition on the icebreaker *Oden*. Located in an extremely remote region of the northern Arctic, Petermann Fjord has been rarely studied or visited, with no shipping lanes and little to no vessel traffic. No dedicated marine mammal studies had taken place in Petermann Fjord before the 2015 expedition; therefore, it was unknown which species would be recorded and further how they would respond to vessel presence. One of the objectives of our study was to assess potential behavioral responses by seals and polar bears to the icebreaking vessel *Oden* during both the transit and survey in the remote and rarely visited region of northwest Greenland. A previously published manuscript (Lomac-MacNair et al. 2018) provided an initial look at how Arctic seals use Petermann Fjord and how physical variables influence their distribution in one of the few remaining ice-tongue fjord environments. In this manuscript, we focus on our objective of assessing behavioral responses relative to the icebreaker vessel representing a potential risk to marine mammals.

Early wildlife behavioral response research conducted by Hediger (1934) attempted to understand animal behavioral responses to both human activity and natural predators through a focus on flight activity and flight distance, defined as the distance at which a human could approach a wild animal without activating the flight response. Later studies on flight activity with terrestrial mammals (big game, Altmann 1958; gazelles, Walther 1969) contributed to the development of the optimal escape theory by Ydenberg and Dill (1986). Ydenberg and Dill (1986) predicted that animals choose the optimal distance at which to flee from an approaching predator by assessing the costs of fleeing (e.g., lost foraging opportunity, increased energy expenditure, risk of detection, etc.), and that the optimal distance occurs at the point where the risk of predation equals the cost of escape. To investigate seal flight activity relative to the icebreaker, we recorded behavioral responses of 4 seal species: bearded seal (*Erignathus barbatus*), ringed seal (*Pusa hispida*), harp seal (*Pagophilus groenlandicus*), and hooded seal (*Crystophora cristata),* as evidenced by seals exhibiting flight activity, herein referred to as flush response (i.e., entering the water from the floating ice on which they were resting). In attempt to assess flight distance, we investigated the rate of flush response in relation to vessel distance and seal species. Additionally, we provide descriptive analyses of polar bear behavior in response to the vessel as evidenced by the bears observing, approaching, and moving away from the icebreaker.

Understanding and assessing the impacts of human activities on Arctic wildlife is a key issue in current management and conservation strategies for many species. In the United States under the U.S. Endangered Species Act and Marine Mammal Protection Act, anthropogenic activities that may result in behavioral harassment, harm, injury, or death to marine mammals is prohibited unless specifically permitted by the National Marine Fisheries Service (all marine mammals) and U.S. Fish and Wildlife Service (polar bears). The regulatory permitting process typically requires project-specific mitigation, monitoring, and reporting. Furthering our overall understanding on behavioral reactions of seals and polar bears to icebreakers will support implementation of applicable and effective monitoring and mitigation strategies—the legally required

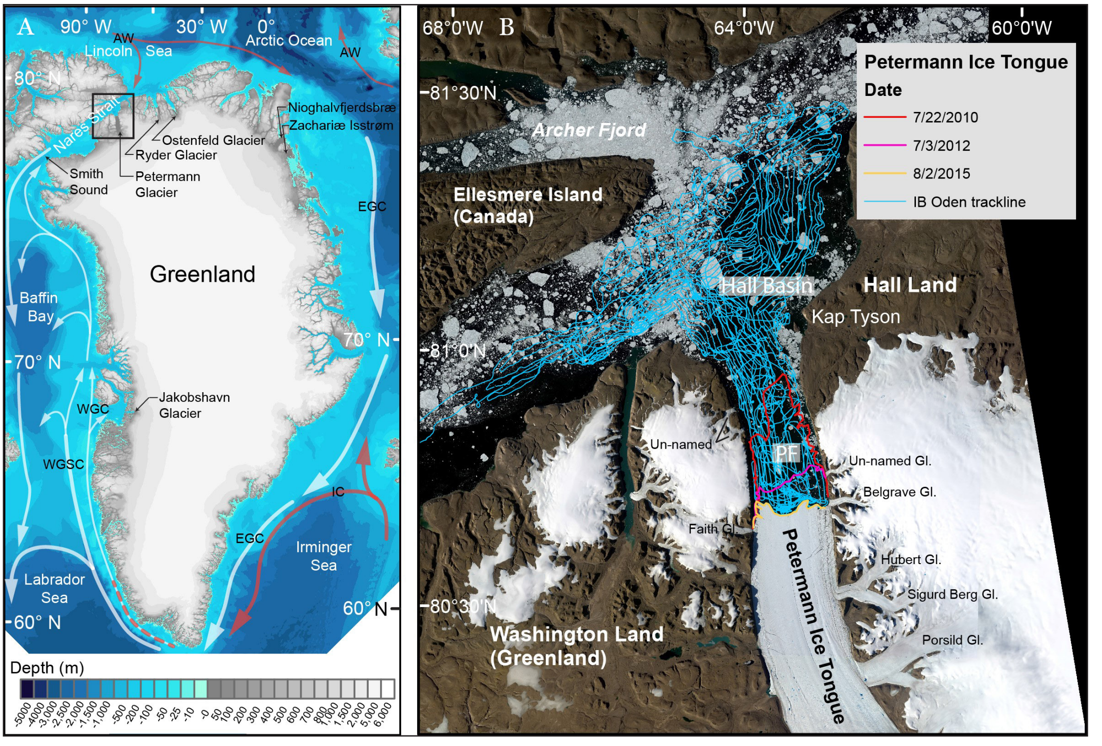

Figure 1. Maps of Petermann Fjord located in northwestern Greenland. (A) Overview of Greenland with the main study area outlined by a black box. The general ocean circulation patterns are illustrated by flow arrows (AW = Atlantic Water, EGC = East Greenland Current, IC = Irminger Current, WGC = West Greenland Current, WGSC = West Greenland Slope Current). Bathymetry from International Bathymetric Chart of the Arctic Ocean (Jakobsson et al. 2012). (B) The main study area during the Petermann 2015 Expedition including Petermann Fjord, adjacent Hall Basin in Nares Strait, and survey track of the icebreaker *Oden* (blue lines). Red (2010), pink (2012), and yellow (2015) lines depict the retreat of the ice-tongue margin from July 2, 2010 to August 2, 2015. The past extents of the Petermann Ice Tongue are digitized from Landsat images.

component of obtaining permits for human activities in U.S. waters.

Study area

Petermann Fjord is located in northwestern Greenland at approximately 81° N, 61° W (Figure 1). Petermann Glacier, a major outlet of the northwest sector of the Greenland ice sheet, terminates at the fjord head with a floating ice tongue approximately 50 km long and 18 km wide. The portion of Petermann Fjord accessible with a surface vessel (i.e., not covered by the ice tongue) is approximately 17–20 km wide and 37 km long, measured from the 2015 ice tongue margin to the entrance where the fjord widens and meets Hall Basin in line with Kap Tyson (Figure 1). The fjord continues as a cavity under the ice tongue for nearly 50 km from the 2015 ice tongue margin to the grounding line of Petermann Glacier. Over the last decade, the Petermann Glacier ice tongue has lost substantial mass through major calving events, most notably those in 2010 and 2012, which resulted in a 33-km retreat of the ice tongue and loss of nearly 40% of its former extent (Johannessen et al. 2011, Münchow et al. 2014; Figure 1). The recently observed yearly thinning of the ice tongue and loss of mass has been attributed to the inflow of warmer subsurface water of Atlantic origin through the Arctic Ocean and across Lincoln Sea before entering Nares Strait from the north (Johnson et al. 2011). Although Petermann Fjord is among the few remaining relatively stable ice tongue fjord environments of Greenland, the recent major calving events, together with indications of inflowing warmer subsurface water (Münchow et al. 2014), suggest that it too has a high potential for complete ice tongue breakup.

Methods

The multidisciplinary Petermann 2015 Expedition with the 108-m icebreaker *Oden* investigated the marine cryosphere, ocean-

Table 1. Definitions of seal behavioral responses observed during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

Behavior response	Definition
Look	Seal looks at vessel, can occur both in water and hauled out
Flush	Seal behavior culminating in a succession that began as hauled out, resting on ice and progressed to alert, to moving from on ice location into the water (i.e., changing from a resting behavior out of water to in water; Jansen et al. 2010). An example of flushing behavior exhibited by a bearded seal is depicted in the Figure 2 photo sequence.
Rapid dive/splash	In water, seal dives rapidly, often with a splash
Swim away	In water, seal swims away from vessel
No response	No seal behavioral response observed

ography, and geology in Petermann Fjord and adjacent Nares Strait. The main marine field program consisted of geophysical mapping, sediment coring, and oceanographic station work. The geophysical mapping included a small seismic reflection profiling component using acoustic sources. While in Canadian waters, this seismic component triggered the need for marine mammal monitoring and mitigation; thus, a dedicated marine mammal observation program was included. For the purpose of this study, only data collected during periods of non-seismic effort were included. Marine mammal sighting and behavioral data were collected throughout the entire expedition, including the transit to and from Thule, Greenland and Petermann Fjord over 31 days (July 30 to August 30, 2015). The round-trip transit distance to and from Thule, Greenland and Petermann Fjord was approximately 1,200 km. A single dedicated marine biologist watched for marine mammals from the portside bridge on the sixth deck of the icebreaker *Oden*, with eye height 32 m (above sea level). Observations occurred for approximately 10 hours each day, typically between 0800 and 2100 UTC. Daylight occurred 24 hours per day throughout the July 30 to August 30, 2015 expedition (including transit to and from Thule, Greenland, July 30 to August 2, 2015 and August 28–30, 2015). Icebreaker activities varied depending on ice conditions and survey operations. During icebreaking operations, the vessel activity would either break new routes, or follow existing channels and leads in the ice.

Systematic scanning for marine mammals was alternated between the naked eye, handheld Fujinon 10 x 50 reticle binoculars, and Celestron 25 x 100 tripod-mounted binoculars. Sighting and environmental data were logged using Mysticetus™ Observation Software (Mysticetus) on a laptop linked to a global positioning system (GPS) unit. Mysticetus displayed and logged positions and distances to marine mammal sightings based on bearing and binocular reticle or estimated visual distance entries made by the observer. Marine mammal observations focused forward and to the sides of the vessel in an arc of ~180°, but the observer also regularly checked for marine mammals astern of the vessel. All sighted marine mammals were recorded and photographed for identification purposes when possible.

Upon a sighting (single animal or group of animals), the following data were recorded:

- Environmental data: Beaufort Sea state, ice cover (10% increments in the ~180° forward observation area to a distance of 2 km from the icebreaker), visibility (km), and sun glare (in % of the ~180° forward observation area). Environmental data were recorded at the start and end of each watch and when there was an obvious change in ≥1 environmental variable.
- Seal sighting data: species, minimum/maximum/best estimate of count, number of juveniles/calves, behavior state (see below), bearing and distance of the marine mammal(s) relative to the vessel, and sighting cue. All seals were observed and recorded as individuals. No groups >1 were recorded with the exception of 1 group (6 individuals) of harp seals observed in the water (not hauled out).
- Seal behavior state: behavior included hauled out versus in water.
  - Hauled out is defined as a pinniped behavior of leaving the water onto

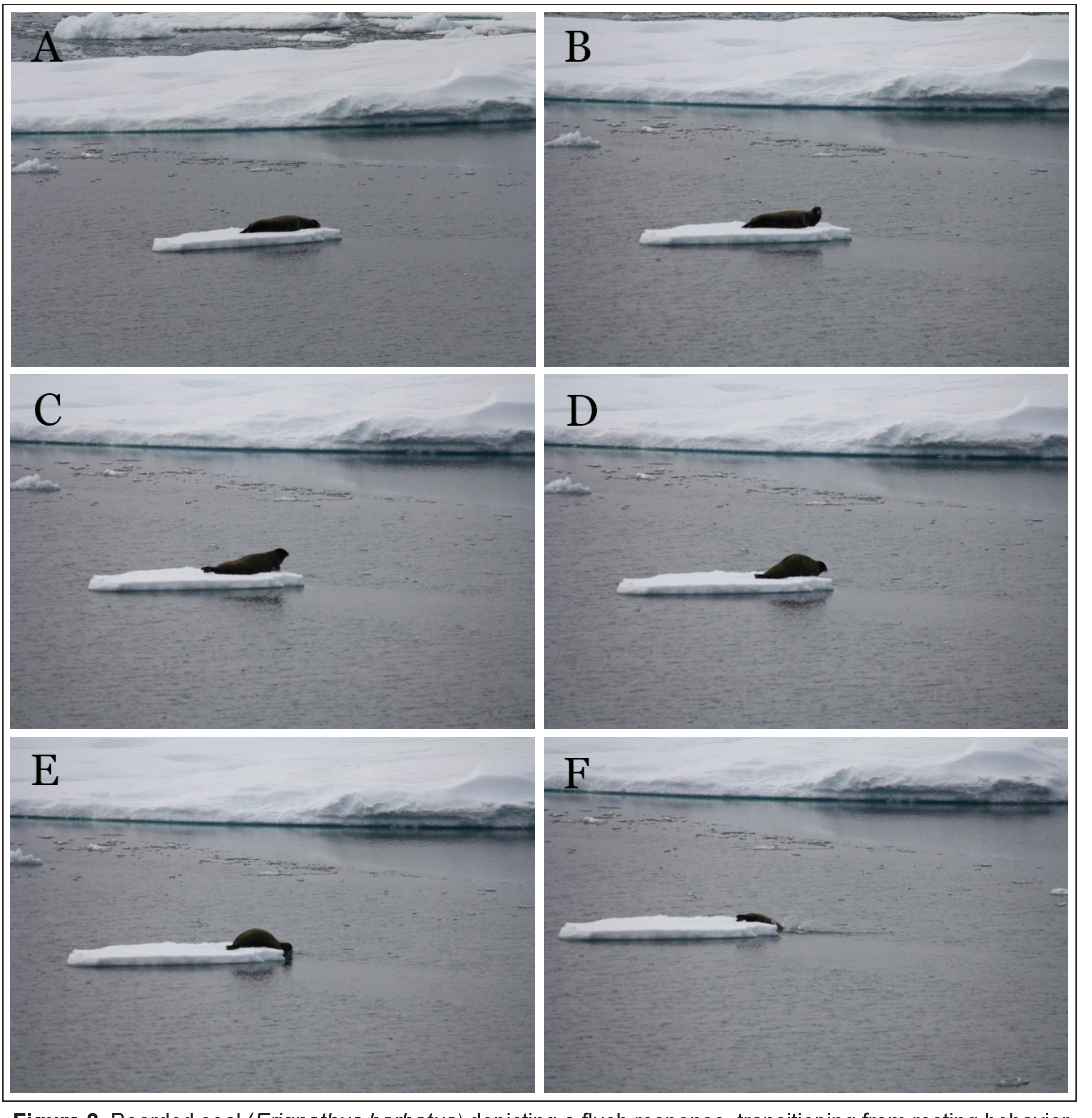

Figure 2. Bearded seal (*Erignathus barbatus)* depicting a flush response, transitioning from resting behavior on ice to in water. The culminating behavior is a succession that progressed from resting (A) to alert (band C), to flushing into the water (D–F). Photos from the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015 (*photos courtesy of K. Lomac-MacNair*).

land or ice generally occurring between periods of foraging activity. Reasons of haul out behaviors include reproduction and rest, mating, predator avoidance, thermoregulation, and social activity.

◦ Seal behavioral response: observed behavioral response to icebreaker vessel including "look," "flush," "rapid dive/splash," and "swim away" (Table 1).

Our focus was on seal flush response following Jansen et al. (2010). Flush response was a clear behavioral change even at the limit of our ~2 km visual range and was considered to have associated energetic costs (Harding et al. 2005). Flush response was the culminating behavior in a succession that began as hauled out and resting on ice and progressed to alert, then to moving from an on ice location into the water (i.e., changing from a resting behavior out of water to in the water; Jansen et al. 2010). An example of flushing behavior exhibited by a bearded seal is depicted in the Figure 2 photo sequence. A no flush response was when the seal remained on the ice and did not change from on ice to in water.

Table 2. Number of marine mammals recorded and proportion of individuals showing behavioral response during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

	Number of individuals			
Species	Total	No. behavioral response observed	Behavioral response observed	Proportion response (%)
Bearded seal	84	64	20	24%
Harp seal	15 [a]	15	0	0%
Hooded seal	12	5	7	58%
Ringed seal	217	172	45	21%
Unidentified pinniped	13	13	0	0%
Polar bear	3	0	3	100%
Total	344	272	75	22%

[a]Includes 1 group (6 individuals)

Table 3. Type and number of behavioral response by seal species during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

Behavioral response type	Bearded seal	Harp seal[a]	Hooded seal	Ringed seal	Total[b]
Look	7	0	3	30	40
Flush	15	0	3	4	22
Rapid dive/splash	0	0	1	16	17
Swim/move away	2	0	0	4	6

[a]No behavioral responses were recorded for harp seals.
[b]It is possible for >1 behavioral response to be recorded for each sighting.

We performed an independent *t*-test between mean distance (m) from the vessel during events when a flush response occurred and events when no flush response occurred. We applied nonlinear least squares regression to fit the 3-parameter logistic model, $Y = a/(1+\exp(b–X)/c)$, where the parameter of interest is b–the distance at which 50% of the seals flushed, for data on distance to icebreaker (X, at 100-m intervals) when flushing occurred (proportion of flushed seals, Y). We performed 1-way ANOVA (analysis of variance) and post hoc Tukey HSD (honest significant difference) tests on seal species by mean distance when flushing occurred. Statistical analyses were performed using R 3.4.2 in RStudio 1.0.143 (RStudio Team 2015) at 0.05 level of significance. Summary statistics were used to describe other behaviors observed.

Results

Observation effort occurred between July 30 and August 30, 2015, including the transit to and from Thule, Greenland for a total of 277 hours (16,620.4 minutes). Beaufort Sea state was recorded at 3 or lower for >95% of the survey duration and thus was not incorporated as a factor affecting sightability. A total of 344 marine mammals were recorded: 341 seals and 3 polar bears (Table 2). Of the 341 seals, 96 individuals were recorded hauled out on ice, and the remaining 245 individuals were observed in water. No groups >1 were recorded with the exception of a single group (6 individuals) of harp seals recorded in water. Behavioral responses were observed in bearded seals (n = 20 individuals, 24%), hooded seals (n = 7 individuals, 58%), and ringed seals (n = 45 individuals, 21%; Table 2). Of the 15 individual harp seals recorded, no behavioral responses were observed, and all harp seals were observed >800 m from the vessel.

Behavioral responses recorded included "look" (n = 40), "flush" (n = 22), "rapid dive/splash" (n = 17), and "swim/move away" (n = 6; Table 3). We focus on the flush response in further detail below. All 3 polar bears

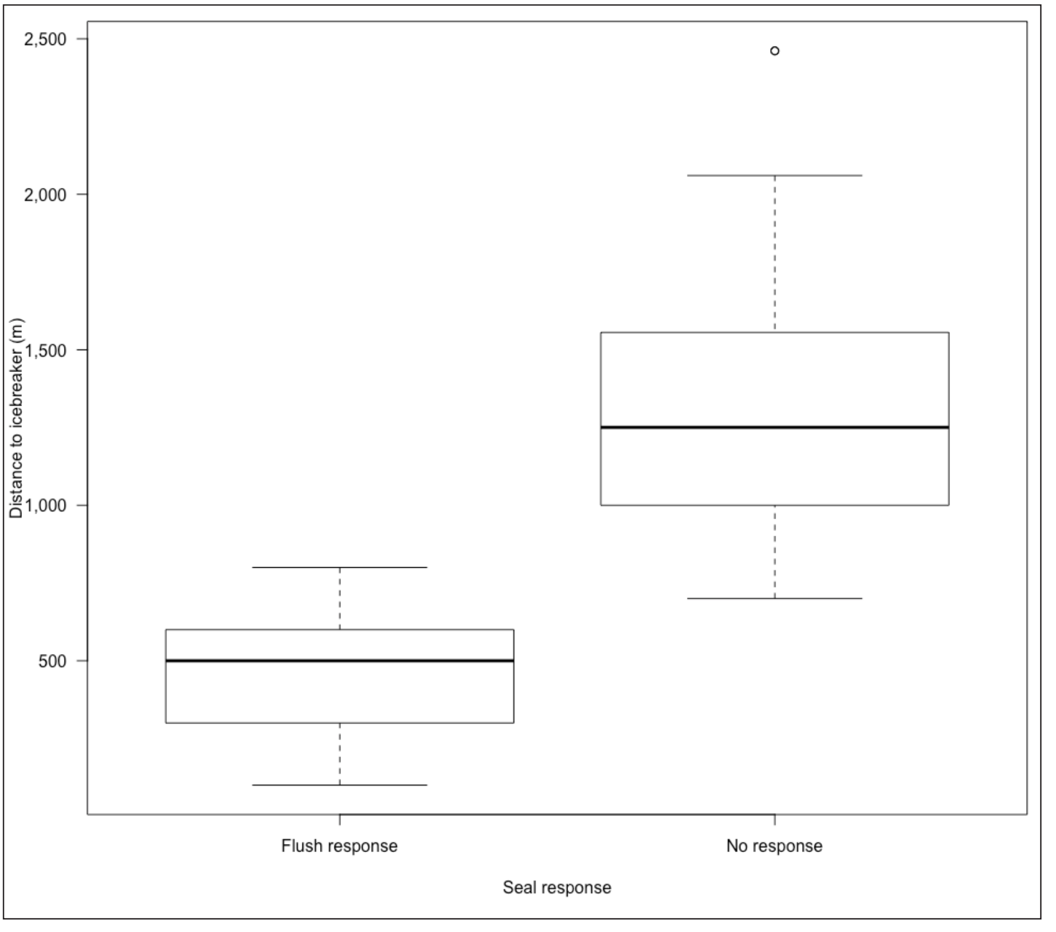

Figure 3. Seal response (flush response or no flush response) by distance (m) to icebreaker from the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

demonstrated a behavior response (Table 2). Due to the small sample size ($n = 3$), we provide only descriptive analyses of the polar bear behavioral responses observed.

Of the 96 seals observed hauled out on ice, 23 % ($n = 22$) exhibited a flush response, where the remaining 75% ($n = 74$) exhibited no response (i.e., remained on ice). Flush responses were recorded for bearded, hooded, and ringed seals (Table 2). We investigated flush response with seal distance (m) from the icebreaker. An independent *t*-test showed a significant difference ($t = 12.79$, df = 73, $P \leq 0.001$) between mean seal distance to the icebreaker when a flush response occurred (mean = 467.1 m, SD = 212.39 m; Figure 3; Table 4) and when no flush response occurred (mean = 1333.0 m, SD = 433.89 m; Table 4). As distance decreased, flush response increased, suggesting more seals exhibited a flush response when the icebreaker was at a closer distance. There were fewer flush responses by seals to the icebreaker at distances approximately >600 m and no flush responses at distances >800 m. Results of the nonlinear regression indicated that there was a significant association between proportion of seals that exhibited a flush response and distance from the icebreaker (Table 5; Figure 4). Our model indicates that the estimated distance at which 50% of the seals would elicit a flush response is 709.4 m (SE = 9.24, $t = 76.8$, $P \leq 0.001$; Table 5; Figure 4).

Seal distance to icebreaker that elicited a flush response varied by species (Figure 5). Harp seals that were hauled out ($n = 7$) were recorded at distances >800 m from the vessel and exhibited no flush response (Table 4). Flush response mean seal distance to the icebreaker

Table 4. Number of seals recorded hauled out (on ice) and proportion of individuals exhibiting a flush response during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

			Distance from icebreaker (m)	
	Species	Number (%)	Mean (SD)	Range
Flush response	Bearded seal	15 (23%)	410.1 (177.64)	100–602
	Hooded seal	3 (50%)	791.7 (14.43)	775–800
	Ringed seal	4 (29%)	437.5 (213.60)	200–700
	Total	22 (23%)	467.1 (212.39)	100–800
No response	Bearded seal	51 (77%)	1,383.2 (393.11)	742–2,461
	Harp seal	7 (100%)	1,000.0 (264.57)	800–1,500
	Hooded seal	3 (50%)	1,535.2 (354.13)	1,200–1,906
	Ringed seal	10 (71%)	1,000.1 (315.40)	700–1,500
	Unidentified pinniped	3 (100%)	2,190.05 (235.02)	2,048–2,461
	Total	74 (77%)	1,334.0 (433.88)	700–2,461

Table 5. Parameters of the logistic model estimated using nonlinear least squares regression for data on distance to icebreaker (X, at 100-m intervals) when flush response occurred (proportion of flushed seals, Y) during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

Parameter	Estimate	SE	*t*-value	P
a	1.0	0.02	46.868	≤0.001
b[a]	709.4	9.24	76.816	≤0.001
c	-59.2	8.09	-7.312	≤0.001

[a]Represents the X value at the inflection point of the curve; estimated distance at which 50% of the seals flush.

was smallest (i.e., closest to the icebreaker) for bearded seals (mean = 410.1 m, SD = 177.64 m, range 100–602 m, n = 15) followed by ringed seals (mean = 437.5 m, SD = 212.39 m, range 100–800 m, n = 4) and highest (i.e., furthest from the icebreaker) for hooded seals (mean = 791.7 m, SD = 14.43 m, range 775–800 m, n = 3; Table 4; Figure 5). For seals that exhibited flush responses (bearded, hooded, and ringed) we found a statistically significant difference in mean distance of seals exhibiting flush response between species (1-way ANOVA, F = 6.041, P = 0.009). A post hoc Tukey test showed that flush response mean distance differed significantly between hooded-bearded seals (P = 0.007) and hooded-ringed seals (P = 0.039). However, flush response mean distance to the vessel did not differ significantly between ringed and bearded seals (P = 0.958).

Three polar bear sightings were recorded during the north transit from Thule to Petermann Fjord during early August. None were recorded within Petermann Fjord and none in the water. Two were recorded in the southern end of Kane Basin in Smith Sound Straight on August 1, and a single polar bear was recorded approximately 50 km southwest from the entrance to Petermann Fjord close to Washington Land on August 4. All 3 observations included bears walking on thick pack ice. In all 3 observations, a behavioral response was recorded:

- On August 1, 2015, 0440 UTC, a polar bear was observed approximately 800 m from the vessel, walking on ice. At the time of the sighting, the vessel was in 90% ice coverage and vessel activity included drifting with the ice (i.e., the vessel was not engaged in icebreaking activities). The polar bear approached the vessel at the bow and walked toward the stern where the bear placed its forepaws on the vessel hull. After approximately 12 minutes investigating (e.g., sniffing, etc.) the icebreaker, the polar bear walked in the direction it was originally observed.
- On August 1, 2015, 1720 UTC, a polar bear was observed approximately 970 m from

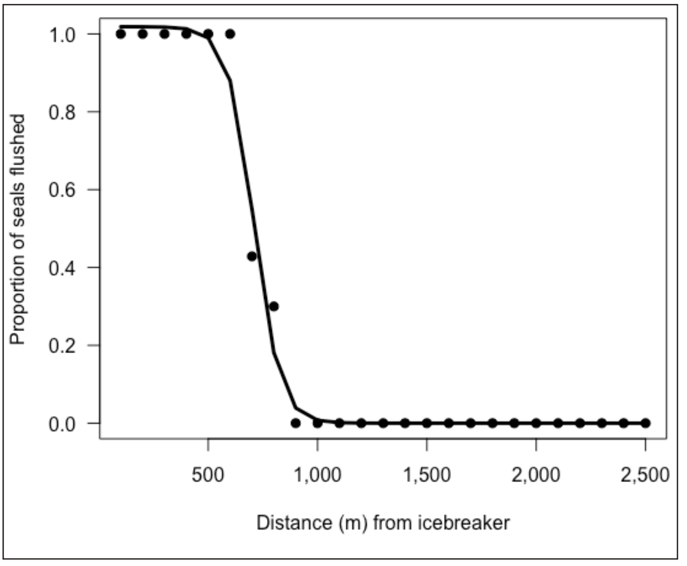

Figure 4. Proportion of seals flushed by distance (m) from icebreaker with superimposed logistic model obtained using nonlinear least squares regression: Y = a/(1+exp((b–X)/c)), where a = 1.02 ± 0.02 SE, b = 709.45 ± 9.24 SE, and c = -59.15 ± 8.09 SE. From the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

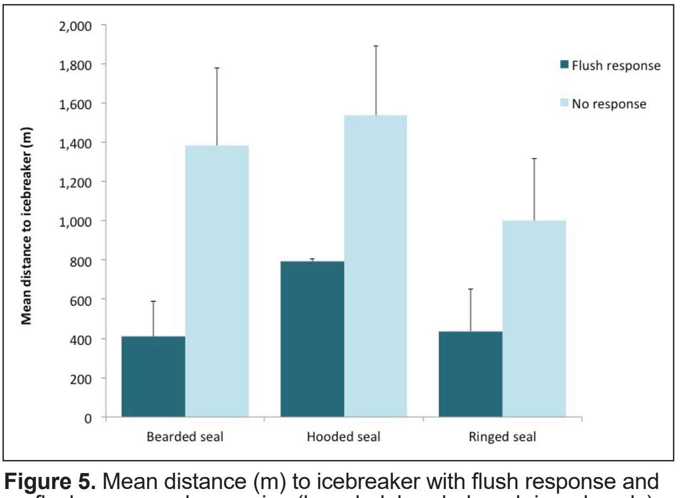

Figure 5. Mean distance (m) to icebreaker with flush response and no flush response by species (bearded, hooded, and ringed seals) during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to and from Thule, Greenland during July 30 to August 30, 2015.

the vessel. At the time of the sighting, the vessel was in 80% ice coverage and was engaged in icebreaking activities. The polar bear looked at the vessel multiple times and continued to walk at a slow gait in parallel to the vessel direction.

- On August 4, 2015, 1746 UTC, a polar bear was observed approximately 1,200 m from the vessel. At the time of the sighting, the vessel was in 90% ice coverage and was engaged in icebreaking activities. The polar bear looked at the vessel multiple times then walked away from the vessel at a medium gait.

Discussion

Due to the challenges inherent with High Arctic research, there are only a handful of studies that have investigated the interactions between marine mammals and icebreaker vessels in these seldom-visited regions (Smultea et al. 2016, Wilson et al. 2017). Our study provides a preliminary look at the potential behavioral responses and flight activity by Arctic seals and polar bears relative to an icebreaker vessel in a rarely studied region of northwest Greenland. Our findings suggest that seal flight activity (i.e., flushing response behavior) increased as seal–vessel distance decreased; we found fewer flush responses at distances >600 m and no flush responses at distances >800 m; all flush responses were <800 m. Additionally, seal distance to vessel that elicited a flush response varied by species. Harp seals, all recorded at distances >800 m from the vessel, showed no behavioral response consistent with our findings that responses were relative to vessel distance, and no responses were recorded >800 m from the vessel.

These results corresponded well to the findings of previous studies showing distance-based flush responses from icebreaker vessels (Wilson et al. 2017), as well as other vessel types including cruise ships (Jansen et al. 2010, Mathews et al. 2016) and smaller vessels including power boats and kayaks (Johnson and Acevedo-Gutierrez 2007, Mathews et al. 2016). A study dedicated to the impact of icebreaker operations on Caspian seals (*Pusa caspica*) found disturbance and displacement of mother-pup pairs from their resting position within 200 m of the vessel, whereas a distance of >250 m and speeds ≤2.2 knots (4.1 km/hour) were found to minimize disturbance (Wilson et al. 2017). Jansen et al. (2010) conducted a study on harbor seals (*Phoca vitulina*) and cruise ships in Disenchantment Bay, Alaska, USA and found that the risk of disturbing harbor seals increased when ships approached within 500 m; seals approached as close as 100 m were 25 times more likely to enter the water than seals 500 m from a ship. Mathews et al. (2016) conducted a study on vessel disturbance of harbor seals from tidewater glacial ice in Tracy Arm, Alaska and found the seals were most sensitive to cruise ships and kayaks; the odds of a seal entering the water were 2 times higher when vessels were present, 3.7 times higher when vessels were within 100 m, and 1.3 times higher when a pup was present. Johnson and Acevedo-Gutierrez (2007) studied harbor seals off Yellow Island in the state of Washington, USA and assessed the number of harbor seals that flushed from a land-based haul out site into the water in response to stopped powerboats and kayaks. They found that the distance at which seals were disturbed averaged 91 m for kayaks and 190.5 m for stopped powerboats. The distances we found to elicit a flush response ranged from 100 m (bearded seal) to 800 m (hooded seal) and on average were ~470 m. When the icebreaker maintained >800 m distance, no flushing occurred; however, seal alertness (i.e., look) was recorded. The estimated median distance at which seals flushed was 709 m. Additionally, we found the distance to be species-dependent with hooded seals flushing at greater distances (average ~800 m) and bearded and ringed seals flushing at closer distances (average ~410 and 440 m, respectively), possibly suggesting that hooded seals are more sensitive to disturbance than bearded and ringed seals. Due to our limited sample size, further studies would be needed to validate these potential species sensitivities. The expedition occurred during the summer season, coinciding with known post-breeding and molting season for all 4 seal species. Therefore, we did not encounter pups, haul out colonies, or any groups >1, with the exception of 1 group (n = 6 individuals) of harp seals recorded in water. It is possible that behavioral reactions to icebreakers could vary by season and breeding or pupping status. Anderson et al. (2012) conducted a study on harbor seals in the Anholt seal reserve in Danish waters and found that the state of the seal (e.g., reproductive state or general condition) influenced its response to disturbances. Harbor seals were less responsive during the breeding season by not showing signs of alertness until disturbances (pedestrians or vessels) were within relatively close range and overall were more reluctant to flee. Anderson et al. (2012) attributed this weaker response to the seal's focus on breeding-related activities such as pupping, nursing, and mating.

Our low number (n = 3) of polar bear observations was likely because polar bears in this region of the Arctic are thought to spend the summer season predominantly on land (Laidre et al. 2015*b*). This seasonal onshore distribution made the likelihood of encountering high numbers of polar bears low during our study period. Although our polar bear sample size was too small to statistically draw any meaningful conclusions, we found it relevant that all 3 polar bears recorded demonstrated behavioral reactions to the icebreaker, including 1 polar bear that approached, circled, and touched the icebreaker. Very little has been published about the interactions of polar bears and icebreakers or vessel activity in general (Peacock et al. 2011, Smultea et al. 2016). A study in the Chukchi Sea, Alaska quantifies initial reactions and behaviors of polar bears as observed from an icebreaker; more bear groups reacted to icebreaker presence (79%) than not (21%). Behavioral responses were brief (<5 minutes) and "vigilance" was the most commonly observed reaction, followed by walking or running away. Similar to the 1 bear in our study that approached the icebreaker, Smultea et al. (2016) found 4 observed approach reactions and 1 bear that placed its forepaws on the vessel while sniffing burning trash on the deck (Smultea et al. 2016). Both the bear in this study and our own suggest curious and investigative behaviors by the bears to the icebreaker vessel, although neither showed any signs of aggression. Despite our small sample size (n = 3), our preliminary polar bear findings are relevant to further understand the impacts of vessel activities on polar bears. This is especially true given the paucity of such information and the increasing vessel traffic in the Arctic.

It is important to note the number of factors that limit interpretation and applicability of our study results, including the restricted duration and timeframe of the study. Our observations occurred only from 1 icebreaker and only during summer to autumn of 1 year (July to August 2015). Results were also limited by the observer's field of view (up to 2 km from the icebreaker). It is possible that seals and polar bears beyond this distance reacted to the icebreaker by flushing or moving away before the observer sighted them. It is also possible that seal and polar bear reactions vary dependent on the icebreaker type and operations occurring (i.e., transiting through open leads vs. breaking ice).

The suggestion that icebreakers could have impacts on marine mammals from collisions or displacement was introduced in the early 1980s (Davis 1981, Stirling and Calvert 1983). However, there has been little dedicated focus on these potential impacts. Arctic waters are rapidly developing due to increased exploration and extraction for oil, gas and minerals, polar tourism, and new transpolar shipping routes. Sea ice reduction allows for new and growing arctic activities in areas previously considered remote and inaccessible. The rise of these human activities is predicted to result in increased vessel interactions with marine mammals (Laidre et al. 2015*a*). Our study highlights the need to consider these interactions on Arctic marine mammals from icebreakers transiting through these newly accessible areas. Our findings on seal response and types of impact seen could be applied to other vessel activities and species.

Conclusion

Icebreaker vessels are indispensable tools for any country with an Arctic presence. Icebreaker vessels are vital for furthering polar research in the scientific field as well as important equipment for industry and polar shipping. Activities in the Arctic are rapidly increasing to support industrial growth and new shipping routes. This is expected to lead to increased interactions with marine mammals. In the United States, addressing potential behavioral reactions of marine mammals to industry-related activities is a legally required component when obtaining regulatory permits. Studies like ours could be used to support the permitting process and ensure appropriate implementation of effective monitoring and mitigation strategies. Additionally, as arctic activities expand, the need for cumulative effects assessments will be imperative for the future protection of Arctic marine mammals. Thus, more studies like this will be needed to better inform management and policy decision-makers and assist in the development of effective mitigation strategies in a rapidly developing Arctic.

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Associate Editor: Carl Lackey

Kate Lomac-MacNair earned her B.S. degree in environmental sciences at Union Institute & University in 2006 and M.S. degree in environmental science and policy at Johns Hopkins University in 2015. She is currently a Ph.C. graduate at the University of Algarve in Faro, Portugal, focusing on Arctic marine mammal habitat use. She has >14 years of experience as a biologist specializing in marine science, marine mammal research, and marine mammal monitoring. Her experience as a field biologist is widespread in the United States (Alaska, Hawaii, California, Oregon, Washington, Florida, and the north Atlantic) as well as internationally in the Northern Marianas Islands, Costa Rica, New Zealand, and Greenland.

José Pedro Andrade earned his B.S. degree in biology at the University of Lisbon in 1982 and Ph.D. degree in fisheries biology at the University of the Algarve in 1990 and habilitation in fisheries biology at the University of the Algarve in 1998. He has been a member of the teaching staff of the University of the Algarve since 1982 and leads the Fisheries Biology and Hydroecology research group at the Centre of Marine Sciences (University of the Algarve). His current research is directed toward the development of the scientific and technical basis for cuttlefish (Sepia officinalis) culture and population genetics and conservation of seahorse populations (Hippocampus guttulatus and H. hippocampus) in the Ria Formosa lagoon (South Portugal).

Eduardo Esteves earned his B.S. degree with honors in marine biology and fisheries at the University of Algarve in 1995. He went on to work on fish biology and ecology for 10+ years, earning an M.S. degree in ecology at the University of Coimbra in 1999 and Ph.D. degree in population ecology at the University of Algarve in 2006. In the last 10 years, he has also been working on topics related to seafood quality, making his primary interests coincide with his current appointment, wherein he conducts research and teaches undergraduate and graduate courses in seafood technology/processing and quality, sensory analysis (sensometrics), statistical process control, and data analysis and experimental design. The underlying topic of his research interest has to do with statistical modeling of a) life-history data and environmental conditions, and b) changes in seafood quality after processing and during storage.