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Source: Ursus, 2021(32e8) : 1-14

Published By: International Association for Bear Research and Management

URL: https://doi.org/10.2192/URSUS-D-20-00023.2

Polar bear behavioral response to vessel surveys in northeastern Chukchi Sea, 2008–2014

Kate Lomac-MacNair[1,5], Sheyna Wisdom[2], José Pedro de Andrade[1], Julia E. Stepanuk[3], and Eduardo Esteves[4]

[1]*CCMAR, Centro de Ciências do Mar, Universidade do Algarve Campus de Gambelas, 8005-139 Faro, Portugal*
[2]*Fairweather Science LLC, 301 Calista Court, Anchorage, AK 99518, USA*
[3]*Department of Ecology and Evolution, Stony Brook University, Stony Brook, NY 11794, USA*
[4]*CCMAR, Centro de Ciências do Mar and Instituto Superior de Engenharia, Universidade do Algarve Campus da Penha, 8005-139 Faro, Portugal*

Abstract: Evaluating the impacts of anthropogenic activities on Arctic wildlife is a key issue in current management and conservation strategies. With global climate change, expanding shipping routes, and increasing industrial development in the Arctic, the polar bear (*Ursus maritimus*) faces new challenges to its survival. Polar bear behavioral response to vessel presence is not well-documented. During the 2008–2014 Chukchi Sea Environmental Studies Program (CSESP), polar bear occurrence and behavioral data were collected during summer–autumn vessel surveys. We examined polar bear occurrence and behavioral response to vessel presence by distance. During this study, 56,901 km of observation effort occurred from 3 survey vessels and 42 groups (50 individuals) of polar bears were recorded. Over half of the groups exhibited a behavioral response (i.e., vigilance or flee) including all groups of mothers with cubs. The mean distance at which bears responded to vessels (805 ± 648 m) was closer than the mean distance at which no response was observed (2,001 ± 1,368 m). Logistic regression analysis revealed that response was associated with distance and our model indicated the estimated distance at which 50% of the polar bears would exhibit a behavioral response to be 1,645 m. Our findings are relevant to assess potential impacts of increasing vessel activity in the Arctic and to assist in the development of effective monitoring and mitigation strategies for polar bears.

Key words: anthropogenic response, Arctic, behavioral responses, Chukchi Sea, flee, flight, polar bear, *Ursus maritimus*, vigilance

DOI: 10.2192/URSUS-D-20-00023.2 ***Ursus 32:article e8 (2021)***

Arctic waters are rapidly changing as a result of global climate change, increased industrial activities, and expanded transpolar shipping routes (Johannessen et al. 2004, Wassman et al. 2011). The reduction of sea ice allows for new and developing Arctic activities in areas previously considered remote and inaccessible (Bennett et al. 2020). The rise of these anthropogenic activities is predicted to result in increased vessel interactions with Arctic wildlife (Huntington 2009, Laidre et al. 2015b). These human-driven pressures have the potential to initiate changes in the distribution, behavior, and energetics of Arctic marine mammals. This is particularly true for those species dependent on sea ice habitats, such as the polar bear (*Ursus maritimus;* Amstrup et al. 2008, Wilson et al. 2014).

The total estimated number of polar bears globally is 26,000 bears (Wiig et al. 2015); however, polar bears are not evenly distributed throughout the Arctic nor within a single population. The International Union for Conservation of Nature and Natural Resources (IUCN) Polar Bear Specialist Group designated polar bears worldwide into 19 discrete "subpopulations" (Durner et al. 2018). Two recognized subpopulations are found in Alaska, USA; the Chukchi Sea (CS) subpopulation and the Southern Beaufort Sea (SB) subpopulation. Polar bears of the CS subpopulation are distributed in the northern Bering, Chukchi, and eastern portions of the East Siberian seas (Garner et al. 1990, 1994, 1995). The western boundary of the CS subpopulation is Chaunskaya Bay in northeastern Russia and the eastern boundary is Icy Cape, Alaska (Amstrup et al. 1986, 2004a, 2005; Amstrup and DeMaster 1988; Garner et al. 1990). Polar bears in the SB subpopulation are distributed between Paulatuk and

[5]email: klomacmacnair@gmail.com

Baillie Island, Northwest Territories, Canada, and Icy Cape, Alaska, USA. Overlap between the SB and CS subpopulations is known to occur near Point Barrow, Wainwright and Icy Cape, Alaska (Amstrup et al. 2004, 2005). A study using satellite radiocollars suggested that half of the bears encountered near Point Barrow were from the SB subpopulation and half were from the CS subpopulation (Amstrup et al. 2004, 2005). Both subpopulations are part of the Divergent Ecoregion, characterized by the extensive formation of annual sea ice transported out of the polar basin through Fram Strait (Amstrup et al. 2008). Previously, CS subpopulation size and status were unknown (Durner et al. 2018), though a recent study estimated numbers to be nearly 3,000 bears (Regehr et al. 2018). The SB subpopulation is thought to be declining and is currently listed at 907 bears (Bromaghin et al. 2015). Polar bears are listed as "threatened" under the Endangered Species Act (ESA 1973, as amended) because the sea ice on which they depend for hunting, feeding, reproduction, and seasonal movements is declining (50 CFR 17). Polar bears are considered "depleted" under the U.S. Marine Mammal Protection Act, and "vulnerable" on the IUCN's Red List (Wiig et al. 2015).

There has been extensive research on the CS subpopulation, both historically (e.g., Garner et al. 1990, 1994) and more recently (e.g., Wilson et al. 2014, 2016; Rode et al. 2015; Regehr et al. 2018). Polar bears of the CS subpopulation are known to migrate as much as 1,000 km to stay with the southern edge of the pack ice (Garner et al. 1990) when sea ice moves north from the Bering and Chukchi seas during summer. Rode et al. (2015) compared CS polar bear land use between 1986–1995 and 2008–2013 and revealed that bears are increasingly using land habitats in response to loss of sea ice habitat associated with climatic warming. In the Chukchi Sea, the polar bear's range is in areas where sea ice retreats away from land toward the Arctic basin in the summer, compelling bears to choose whether to stay on land or remain with the retreating ice during the summer. Additionally, the polar bears that remain on the ice or away from land masses throughout the summer may have reduced access to prey (Rode et al. 2014, Ware et al. 2017, Whiteman et al. 2018). However, Wilson et al. (2014, 2016) found that CS polar bears have not changed their habitat selection preferences, despite large reductions in sea ice. Similar to CS polar bears, Atwood et al. (2016) and Pongracz and Derocher (2016) found that SB polar bears are likewise spending significantly more time on land with the reduction of sea ice. Polar bears of the SB subpopulation are thought to feed on the subsistence-harvested bowhead whale (*Balaena mysticetus*) remains near Prudhoe Bay industrial infrastructure and near the community of Kaktovik (Herreman and Peacock 2013, Rogers et al. 2015).

The recent decrease in Arctic sea ice along with climate model projections of imminent ice reductions have resulted in new trans-Arctic shipping routes linking the Atlantic and Pacific Oceans and an overall rise in vessel presence in the Arctic (Smith and Stephenson 2013, Bennett et al. 2020). The continued increase in commercial vessel operations and Arctic vessel traffic overlaps with polar bear habitats and will likely lead to increased vessel–bear interactions (Huntington 2009, Laidre et al. 2015b). When examining the vulnerability of Arctic marine mammals to vessel traffic in the Northwest Passage and Northern Sea Route, Hauser et al. (2018) found disproportionate attention focused on cetacean sensitivity to vessel effects and few studies focusing on polar bears. Polar bear behavioral responses to anthropogenic stressors in the wild have been little studied and in a limited scope of conditions. Previous studies focusing on polar bear behavioral response have found they appear to be disturbed by snow machines, (i.e., avoidance behavior; Andersen and Aars 2007), by icebreaker vessels (i.e., vigilance, walking or swimming away, fleeing into water, and approach; Smultea et al. 2016, Lomac-MacNair et al. 2019), and exhibit approach behaviors to offshore drill ships (Stirling 1988).

Marine mammal studies in the Chukchi Sea have spanned over the past 40 years. One of the impetuses for marine mammal–focused research in the Chukchi Sea has historically been to collect adequate data in effort to predict potential impacts of oil and gas (O&G) exploration and development activities and to identify mitigation measures to minimize those impacts. Additionally, marine mammal research is often conducted to inform subsistence management, as well as interactions with humans in a variety of contexts including tourism, fisheries, and in the case of polar bears, bear–human interactions. Various agencies have been involved in conducting studies to obtain information on marine mammal distribution, feeding ecology, and behavior (e.g., Burns and Eley 1978; Lowry et al. 1978, 1980a, 1980b; Burns et al. 1981; Lowry and Burns 1981; Burns and Seaman 1988; Gilbert 1989a, 1989b; Gilbert et al. 1992; Ljungblad et al. 1987, 1988; Clarke et al. 1989; Clarke and Ferguson 2010). A renewed interest in O&G activities, combined with the potential threats to the Arctic marine ecosystem, has spurred a recent focus on research in the Chukchi Sea. As part of industrial activities (e.g., O&G exploration; seismic surveys) in the Chukchi Sea, marine mammal monitoring and acoustic programs were

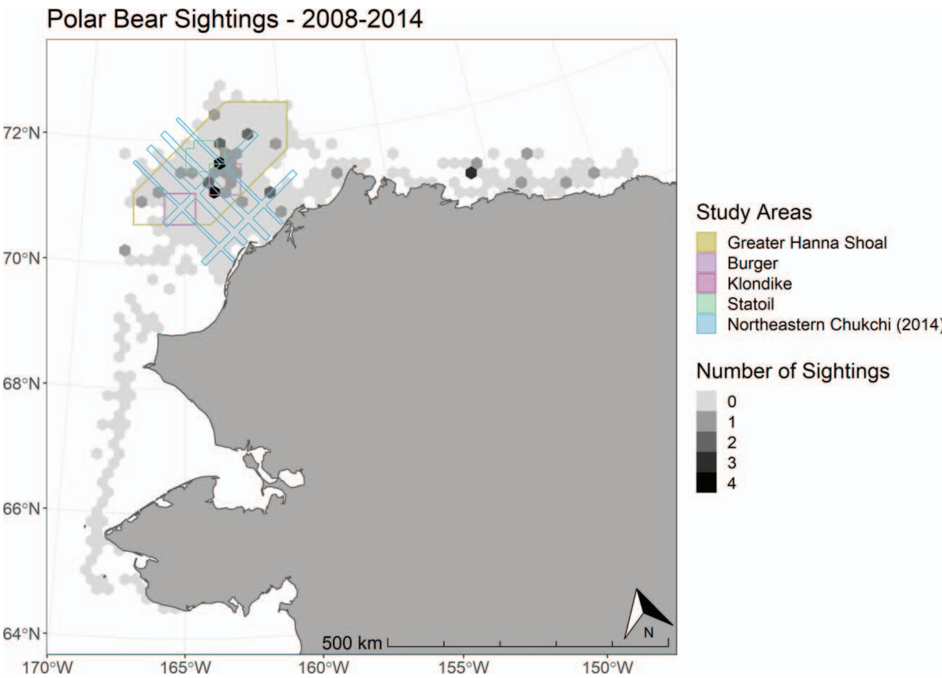

Fig. 1. Distribution of polar bears (*Ursus maritimus*) during the Chukchi Sea Environmental Studies Program (CSESP) 2018–2014. The CSESP study areas including the 4 primary study areas: Klondike, Burger, Statoil, and GHS (Greater Hanna Shoal), and modified study design in the Northeastern Chukchi Sea (2014).

implemented from 1989 to 1991 and annually since 2006, primarily as mitigation, but also to document potential impacts from anthropogenic activities (e.g., Brueggeman et al. 1990, 1991). In 2008 the Chukchi Sea Environmental Studies Program (CSESP) was initiated to address the need for an integrative research program in the northeastern Chukchi Sea prior to offshore O&G exploration. The CSESP was designed to be a multiyear, interdisciplinary research program that was ecosystem-based, integrating survey components from physical and chemical oceanography, plankton, benthos, fish, seabird, marine mammal, and acoustic studies. The study evolved over the 7-year program, initially including 3 prospect-specific study areas, chosen based on offshore interest to sponsors (ConocoPhillips, Shell, and Statoil), and expanded to a broader region to include Hanna Shoal, a shallow natural shoal in the Chukchi Sea that is considered to be biologically productive area (Kuletz et al. 2015). Most survey effort was conducted in the northeastern Chukchi Sea and additional data were recorded in the Bering and Beaufort Seas during transits, crew changes, and other CSESP discipline operations (i.e., deployment and retrieval of acoustic moorings). As part of the CSESP effort, polar bear occurrence and behavior data were collected during summer and autumn from 2008 to 2014 (Fig. 1). In order to gain a better understanding of polar bear occurrence in this region, sighting rates were assessed seasonally (i.e., monthly) in the Chukchi Sea and Southern Beaufort Sea. The main objective of this portion of the study was to investigate polar bear behavioral responses to vessel presence in relation to distance and group composition (i.e., mothers with cubs).

Study area

The Chukchi Sea is bordered to the west by the East Siberian Sea, to the south by the Bering Sea, to the east by the mainland of Alaska and the Beaufort Sea, and to the north by the Arctic Ocean. The Chukchi Sea has an approximate area of 595,000 km^2. It is a relatively shallow body of water with water depths <50 m in 56% of the total area. The geomorphology of the Chukchi Sea shelf and the flow of summer water masses influence the local temperature and salinity ranges of surface and bottom waters. The CSESP study area is typically ice-covered from late autumn to early summer and in some years

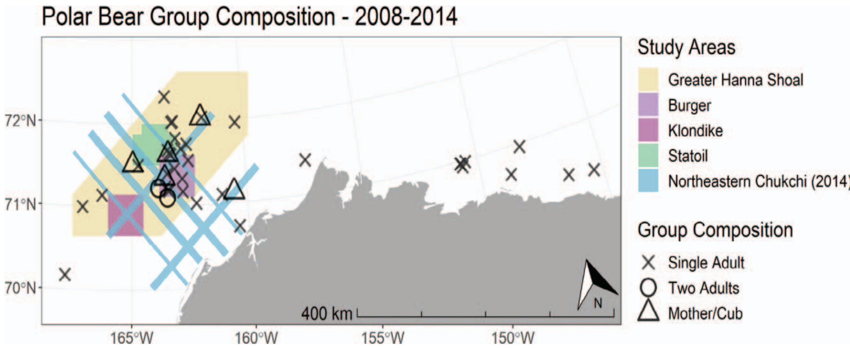

Fig. 2. Location of polar bears (*Ursus maritimus*) by group composition during the Chukchi Sea Environmental Studies Program [CSESP] 2018–2014. The CSESP study areas including the four primary study areas: Klondike, Burger, Statoil, and GHS (Greater Hanna Shoal), and modified study design in the Northeastern Chukchi Sea (2014).

intermittently throughout summer. Sea ice generally retreats northward during July and August and advances southward during November and December. Ice movement is largely driven by the prevailing seasonal winds. The dynamics of ice movement are highly variable among years in the Chukchi Sea; thus, environmental conditions can have a dramatic effect on the species abundance and composition of marine mammals inhabiting the study areas (Brueggeman et al. 1990, 1991, 1992).

In the Chukchi Sea, CSESP personnel surveyed 3 prospect-specific study areas (Klondike, Burger, and Statoil) based on offshore prospects of interest to sponsors (ConocoPhillips, Shell, and Statoil, respectively). Each of the study areas was approximately 3,000 km^2 and CSESP personnel delineated 2 types of transect lines: primary and secondary lines, both oriented in a north–south direction. The spacing between the primary transect lines was 3.7 km. Secondary transect lines were spaced at 1.85 km from the primary transect lines and were only surveyed when primary transect lines were not accessible (e.g., because of presence of sea ice) or if time allowed extra transect lines to be surveyed. During 2008 and 2009, CSESP personnel surveyed Klondike and Burger. During 2010, they surveyed Klondike, Burger, and Statoil. In 2011 and 2012, CSESP was expanded to additionally encompass the biologically productive region of Hanna Shoal, referred to as GHS (Greater Hanna Shoal), an approximate area of 38,000 km^2 (Figs. 1 and 2). During 2013, survey effort again focused only on the 3 prospect-specific study areas and did not occur in the larger region of GHS. In 2014, the survey design was modified further to focus on a greater area of the northeastern Chukchi sea, consisting of 6 primary transect lines to collect data along latitudinal and nearshore–offshore gradients. Four of the 6 transect lines were perpendicular to the northwestern Alaskan coastline, oriented in a northwest–southeast direction, spaced approximately 39 km apart and originated nearshore, between Wainwright and Point Lay, and extended offshore for lengths of approximately 232–267 km. These transect lines were developed to be consistent with the Pacific Arctic Group (PAG) Distributed Biological Observatory (DBO) program. The PAG established the DBO as the organizing framework for research that consists of standard stations and transect lines for consistent sampling of select physical, chemical, and biological measurements as a "change detection array" along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc (Grebmeier et al. 2016). The other 2 transect lines were located parallel to the coastline, oriented in a northeast–southwest direction, spaced approximately 98 km apart and approximately 232 km in length.

During all years (2008–2014) survey effort occurred in the Bering and southern Chukchi seas (south of 68°N) during transits to and from Wainwright and Nome. During 2012–2014, additional effort occurred in the Beaufort Sea (east of 156.5°W) when vessels were conducting other CSESP operations. For the purpose of this paper and to include all polar bear sightings, we use all effort and sightings, both on transect and off transect, from the entire CSESP survey.

Methods

Data collection

The CSESP occurred during summer and autumn (Jul–Oct) during the open-water season from 2008 to 2014.

Three research vessels were used over the course of the 7-year survey period: *M/V Bluefin* (54 m), *R/V Westward Wind* (47 m), and the *Norseman II* (35 m). One dedicated observer conducted visual surveys for marine mammals during daylight hours from either the bridge or flying bridge of the vessel. The observer conducted surveys at an estimated eye height of approximately 5.2–6.5 m above sea level. The observer systematically scanned a 180° area, centered on the vessel's trackline, with the naked eye and Fujinon 7 × 50 reticle binoculars while the vessel traveled at speeds ranging from 5 to 9 knots (9.3–17 km/hr). Observers alternated watch every 2 hours during daylight. Observers surveyed lines for approximately 10–14 hours/day depending on weather conditions, day length, and sampling for other scientific disciplines. An Iñupiat marine mammal observer, who was located on the bridge, assisted in the monitoring effort and reported sighting information to the dedicated observer. Leupold BX-3 Mojave 12 × 50 mm binoculars were available for observers to verify species identification or behavior when needed. A Canon SLR camera with a 120–400-mm zoom lens was available to take photographs of marine mammals, and observers occasionally used photographs to assist in species identification.

Sighting data

When a polar bear was sighted, the observer recorded group size, number of cubs (determined based on size or presence of mother), position and heading relative to the vessel, behavioral category, movement, pace (relative swimming or walking speed), habitat (water or ice), distance of the animal from the vessel when first sighted, and when a behavioral response was observed. The vessel did not approach animals to collect these data. A group was defined as >1 bears behaving similarly within 10 adult polar bear body lengths of one another (i.e., approx. 20 m; Stirling 2009). Group composition was determined visually by size and relative size. The category 'single adult' consisted of a full-sized bear, the category 'adult pair' consisted of 2 full-sized bears, and the category 'mother with cub(s)' consisted of an adult female with either a yearling (approx. one-half the size of the mother) or with a cub-of-the-year (approx. one-third the size of the mother).

We analyzed data to describe initial behavioral responses by polar bears with regard to distance from vessel group composition and habitat (i.e., in water or on ice). For the purpose of this analysis, behavioral responses were categorized into 3 groups: no response, flee, and vigilance. When no clear behavioral response was observed (i.e., the polar bear did not change its behavior), we categorized it as no response. Flee behavioral response included 'change speed and/or direction,' 'dive,' 'flush' (i.e., from ice into water), and 'swim away.' We defined vigilance behavioral response as "a motor act, which corresponded to a head lift interrupting the ongoing activity" and included a visual scanning of the surroundings beyond the immediate vicinity (Quenette 1990, Treves 2000). When examining possible effects of tundra vehicle activity on polar bears in Canada, Dyck and Baydack (2004:344) defined vigilance as "a visual scanning of the surroundings beyond the immediate vicinity." We included the behavioral event 'look' when the polar bear(s) appeared to look and/or watch the vessel as part of 'vigilance' behavior (Dyck and Baydack 2004).

The dedicated observer entered sighting information directly onto a Panasonic ToughbookTM computer (Panasonic Corporation, Kadoma, Osaka, Japan) that was equipped with TigerObserverTM data acquisition software specifically developed for this science program. Navigational software (TigerNavTM) continuously logged vessel information, such as date, time, vessel position, vessel speed, and water depth.

Statistical methods

To examine the inter-annual and seasonal variability of polar bear presence, we assessed sighting rates (no. of individuals/100 km of observation effort) for individuals recorded in the Chukchi Sea and those the Southern Beaufort Sea by year (2008–2014) and by month (Jul–Aug). To assess differences in depth and distance to shore for polar bear locations recorded in the Chukchi Sea versus those in the Southern Beaufort Sea, we performed an independent t-test for depth and distance from shore between the 2 regions. We performed a multinomial logistic regression analysis to examine the dependence between categories (no response, vigilance, and flee) on relevant covariate explanatory variables. Three explanatory variables—(1) 'distance to vessel (m)' when behaviors occurred, (2) 'group composition' (single adult, adult pair, and mother with cub[s]), and (3) 'habitat type' (water and ice)—were analyzed relative to the response variable to assess the likelihood of a behavioral response. For group composition we set 'single adult' as the reference level to which 'adult pair' and 'mother with cub(s)' are compared and for habitat type we set 'on ice' as the reference level to which 'in water' was compared. We assessed goodness of fit of the model using P-values for coefficients, a confusion matrix and misclassification error, and Nagelkerke's pseudo-R^2. To further investigate the explanatory variable distance at which vessel presence would elicit a behavioral response,

Table 1. Number of groups, individuals, cubs, and sighting rates of polar bears (*Ursus maritimus*) by year during the 2008–2014 Chukchi Sea Environmental Studies Program.

Year	Total effort (km)	Groups	Individuals	Cubs	Sighting rate[a]
2008	8,714	7	9	0	0.10
2009	7,293	3	4	1	0.05
2010	8,046	3	3	0	0.04
2011	7,552	0	0	0	0.00
2012	11,448	19	23	4	0.20
2013	8,435	7	8	1	0.09
2014	5,413	3	3	0	0.06
Total	56,901	42	50	6	0.09

[a]No. of individuals/100 km effort.

we applied a logistic regression model with binomial errors. We performed a likelihood ratio test and calculated the *P*-value of chi-square test to test the relevance of this model. In addition, it allowed the estimation of distance at which 50% of the polar bears would exhibit a behavioral response (d50). We performed statistical analyses using Program R 3.4.2 in Rstudio 1.0.143 (Rstudio Team 2015) at 0.05 level of significance.

Results

Vessel surveys occurred over the span of 7 years (2008–2014; Table 1). A total of 56,901 km of observation effort occurred, comprising 53,615.4 km in the Chukchi Sea (west of Point Barrow) and 3,285.6 km in the Southern Beaufort Sea (east of Point Barrow). Surveyors recorded 42 groups (50 individuals) of polar bears; 33 groups (42 individuals) were in the Chukchi Sea and the remaining 8 were in the Southern Beaufort Sea (Figs. 1 and 2). Although effort occurred as far south as 64°N during transit to or from Nome, Alaska, all polar bear sightings occurred north of latitude 70°N (Figs. 1 and 2). Sighting rates were >3 times higher in the Southern Beaufort Sea (0.24 bears/100 km of effort) than in the Chukchi Sea (0.08 bears/100 km of effort). An independent *t*-test showed that locations of polar bears were significantly ($t = 9.40$, 37.27 df, $P < 0.001$) further offshore in the Chukchi Sea (mean = 136.6 ± 48.3 km, range = 18.6–224.8 km) than in the Southern Beaufort Sea (mean = 45.0 ± 14.5 km, range = 26.3–65.8 km) and in significantly ($t = 4.03$, 13.17 df, $P = 0.001$) deeper waters in the Chukchi Sea (mean = 43.3 ± 15.3 m, range = 23.2–124.5 m) than in the Southern Beaufort Sea (mean = 23.4 ± 11.8 m, range = 8.8–45.0 m). Polar bears were recorded during all years, with the exception of 2011. Sighting rates were highest during 2012 (0.24 bears/100 km effort), followed by 2013 (0.12 bears/100 km effort) and 2008 (0.11 bears/km effort). Polar bears were recorded during July through September (July = 0.13 bears/100 km effort, August = 0.10 bear/km effort, and September = 0.12 bears/100 km effort). Despite >11,000 km of effort during October, no polar bears were recorded.

The majority 74% ($n = 31$) of observations of polar bear groups occurred on ice. The remaining 26% ($n = 11$) of the groups were observed in water (Table 2). Polar bear groups were most frequently observed 'resting' (43%, $n = 18$), followed by 'walking' (33%, $n = 14$), 'swimming' (17%, $n = 7$), and 'feeding' (7%, $n = 3$; Table 2). Three events occurred with observations of bears feeding; during 2008 an adult bear was on ice feeding presumably on a seal; during 2012, a bear was observed on top of a floating carcass of a bowhead whale; and during 2013 a bear was observed swimming in the water next to a whale carcass. Of the 42 groups recorded, 83% ($n = 35$) were single adults, 12% ($n = 5$) were mother with cub(s), and 5% ($n = 2$) were adult pairs (Table 2). Of the 5 groups of mothers with cub(s), we recorded a total of 6 cubs; mother with cub(s) groups consisted of 4 mothers with a single cub and 1 mother with 2 cubs. All mother with cub(s) groups were observed on ice and 4 of the 5 groups were observed resting, with the remaining group recorded walking.

Behavioral response

Of the 42 groups observed, 55% ($n = 23$) exhibited a behavioral response (i.e., 'flee' or 'vigilance'), whereas

Table 2. Location and initial group behavior of polar bears (*Ursus maritimus*) by group composition during the 2008–2014 Chukchi Sea Environmental Studies Program.

		Habitat type		Initial group behavior observed			
Group composition	*n*	On ice (%)	In water (%)	Feeding (%)	Resting (%)	Swimming (%)	Walking (%)
Single adult	35	69	31	9	40	20	31
Adult pair	2	100	0	0	0	0	100
Mother with cub(s)	5	100	0	0	80	0	20
All groups	42	74	26	7	43	17	33

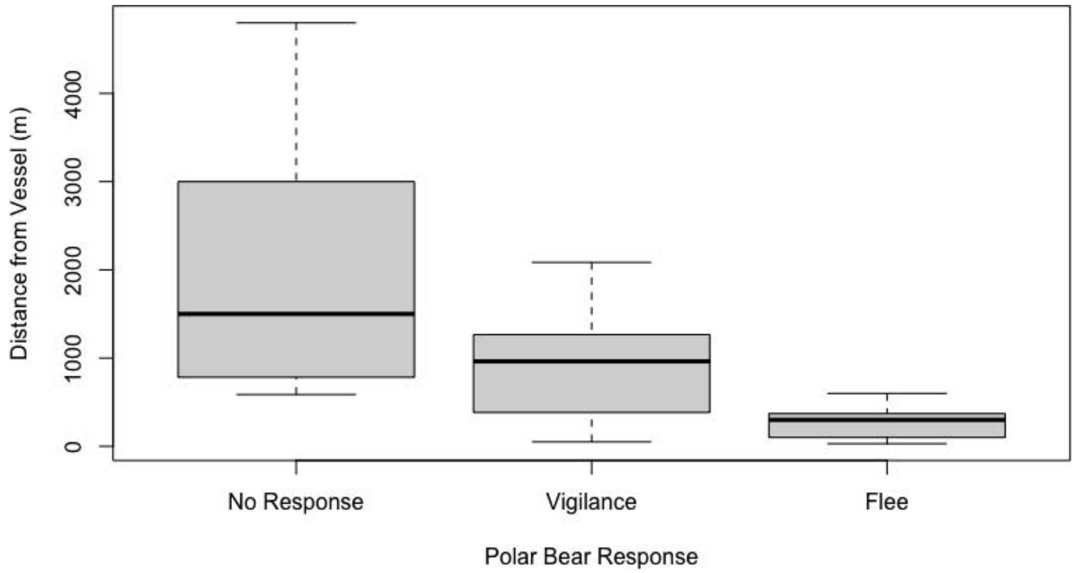

Fig. 3. Boxplot representations of behavioral response ('No Response,' 'Vigilance,' 'Flee') by distance (m) to vessel for polar bears (*Ursus maritimus*) sightings during the 2008–2014 Chukchi Sea Environmental Studies Program. Thick black line represents the median value, the box represents the interquartile range, and the whiskers represent the minimum and maximum values.

33% ($n = 14$) exhibited 'no response,' and the remaining 12% ($n = 5$) were unknown. All 5 mothers with cub(s) groups demonstrated a behavioral response: 2 groups exhibited flee and 3 exhibited vigilance. For bears observed on ice, nearly half (45%) exhibited a behavioral response and most (82%) bears in water exhibited a response. We investigated behavioral response with polar bear distance (m) from the vessel; when no response occurred, mean distance was 2,001 m (SD = 1,368.1 m; Fig. 3), when vigilance occurred, mean distance was 951 m (SD = 654.5 m), and when flee occurred mean distance was 280 m (SD = 226.8 m; Fig. 3). All flee responses occurred at distances of <600 m and all vigilance responses occurred at distances of <2,085 m. As distance increased, frequency of behavioral responses decreased (Table 3). The multinomial logistic regression analysis also showed that observed mothers with cub(s) were much more likely to flee or to be vigilant than were single adults (log(odds) = 18.022 and 9.718, with $P < 0.01$; Table 3). Polar bears that were observed in water were more likely to flee when compared with animals observed on ice (log(odds) = 8.394 with $P < 0.01$). The logistic regression model considering only distance as an explanatory variable was significant ($P < 0.001$) and revealed that the occurrence of a behavioral response (flee or vigilance) was significantly and inversely related with distance ($P < 0.01$, 95% CI [−0.0025, −0.0005]; Fig. 4), such that 50% of polar bears exhibited a response at ≤1,645. M (±358.8 m [SE]).

Discussion

Distribution

Overall, a relatively small number of polar bear observations occurred during CSESP. Although >4 times as many groups were recorded in the Chukchi Sea ($n = 33$ groups) as in the Southern Beaufort Sea ($n = 8$), sighting rates were >3 times higher in the Southern Beaufort Sea than in the Chukchi Sea. Overlap between the CS and SB subpopulations is known to occur near Point Barrow, Wainwright, and Icy Cape (Amstrup et al. 2004, Amstrup et al. 2005); thus, it was not possible to confirm whether bears observed in this region were from the CS versus SB subpopulations. No polar bears were recorded south of 70°N, although CS subpopulation polar bears are found as far south as St. Lawrence Island and occasionally the Kuskokwim Delta (63°N; ADFG 2020).

In the Chukchi Sea, polar bears were recorded both in the nearshore (<20 km) habitat as well as >220 km offshore, and in the Southern Beaufort Sea, all bears were recorded <70 km of the coast. However, overall polar bears in the Chukchi Sea were found further

Table 3. Results (log(odds) ± SE) of multinomial logistic regression model between response variable's categories (flee and vigilance vs. no response) and explanatory variables (distance, group composition [adult pair and mother with cub(s) vs. adult], and habitat type: in water vs. on ice), derived from data on polar bear (*Ursus maritimus*) numbers and behavior collected during the 2008–2014 Chukchi Sea Environmental Studies Program.

	Response variables[a]			
	Flee		Vigilance	
Explanatory variables	Coeff.	SE	Coeff.	SE
Distance (m)	– 0.004	0.003	– 0.001*	0.001
Group composition: adult pair	0.854***	0.000	– 11.482***	0.000
Group composition: mother with cub(s)	18.022***	0.588	9.718***	0.588
Habitat type: in water	8.394***	0.746	0.792	1.001
Constant	– 5.812***	0.781	1.258	0.852
Akaike's Information Criteria		66.165		
Nagelkerke Pseudo R^2		0.601		

[a] *$P < 0.10$; **$P < 0.05$; ***$P < 0.01$. SE = 0.000 denote SE < 0.001.

offshore and in deeper water than those in the Southern Beaufort Sea. Historically, CS polar bears are known to move with the pack ice as it advances in the winter and recedes in the summer; when the sea-ice disappears during the open-water season, bears have been recorded to migrate as much as 1,000 km to stay with the southern edge of the pack ice (Garner et al. 1990, 1994). Recent studies have suggested increased land use by CS subpopulation polar bears (Rode et al. 2015, Ware et al. 2017) and SB subpopulation polar bears (Atwood et al.

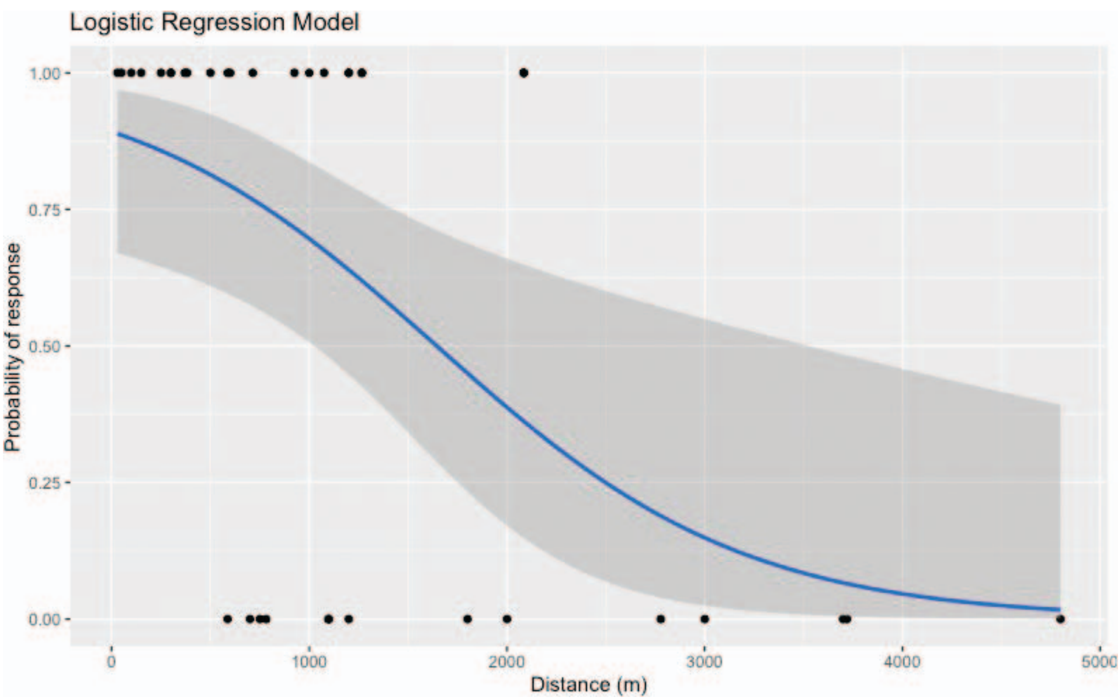

Fig. 4. Probability of response ('No Response' vs. 'Response' [i.e., flee or vigilance]) by distance (m) to vessel for polar bear (*Ursus maritimus*) sightings during the 2008–2014 Chukchi Sea Environmental Studies Program. The blue line represents the fitted logistic regression line and the shading represents the 95% confidence intervals.

2016, Ware et al. 2017) in response to sea ice loss associated with climate warming. This has also been recorded with the East Greenland subpopulations (Laidre et al. 2015a). Rode et al. (2015) found that CS subpopulation polar bears are increasing land use as a response to sea-ice loss, both by coming onto shore earlier and by exhibiting longer onshore durations (Rode et al. 2015). Similarly, Ware et al. (2017) found that, with both the CS and SB subpopulations, land-use behavior has become more prevalent and bears are spending longer potions of the year in lower quality habitats. Atwood et al. (2016) also found increased use of the terrestrial habitat in the SB subpopulation and that distribution was influenced by the ability to scavenge bowhead whale carcasses from subsistence hunts. During a 1979–2005 study on the SB subpopulation, Gleason and Rode (2009) found an eastward and landward shift in polar bear distribution during September and October, due to a decrease in ice extent (Gleason and Rode 2009). The combination of increasing seasonal 'onshore' distribution along with the known northern migration to remain with the ice edge made the likelihood of encountering large numbers of polar bears in the offshore pelagic waters low during our open-water study period. However, our results did indicate that polar bears were indeed present in this pelagic environment during the open-water season, in the Chukchi Sea, and closer to shore in the Southern Beaufort, albeit in relatively low numbers. Over the 7-year period, we only encountered 3 feeding occurrences in the Chukchi Sea and none in the Southern Beaufort Sea. Of these events, one bear was observed feeding presumably on the carcass of a seal (2008). During 2012 and 2013 polar bears were observed feeding on floating whale carcasses at distances of 119 km and 27 km, respectively, from shore.

When assessing sighting rates by year we found polar bear sighting rates were highest during 2012, 2008, 2013, and 2014 and lowest during 2009, 2010, and 2011. In 2011 no polar bears were recorded despite >7,000 km of effort. During 2011, an early ice retreat, combined with a greater heat flux through the Bering Strait, resulted in warmer water temperatures in the upper 15 m of water in the Chukchi Sea than in previous years (Weingartner et al. 2011, 2013). This could suggest that the lack of polar bear presence during 2011 was tied to unfavorable environmental conditions. In contrast, during 2012, when sighting rates were highest, ice retreat and melting progressed more slowly than in previous years (Weingartner et al. 2013) and scattered sea ice remained in the project area until late September. Monthly sighting rates were similar for July through September, but there were no sightings during October, even with >4 times as much effort as in July. This seasonal variability and absence of polar bears later in the open-water season during our study could potentially be due to polar bear movement north to meet the ice edge or movement further eastward and onshore; however, additional studies would be needed to further validate this.

Behavioral response

Our study showed that polar bears in the Chukchi and Southern Beaufort seas reacted to vessel presence with the behavioral responses 'flee' and 'vigilance' and that the variables distance, group composition, and habitat type affected the probability of a response. Although the sample size in this study was small, our data showed that, as distance to the vessel decreased, the probability of polar bear response increased. All mothers with cub(s) exhibited a response, and groups in the water had a higher probability of response than those on ice. Of the total recorded polar bears groups, over half exhibited a behavioral response and of those the majority (78%) exhibited vigilance. Similar to our study, when examining polar bear reaction to icebreaker vessels in the Chukchi Sea, Smultea et al. (2016) found vigilance to be the most frequently recorded polar bear behavioral response. Although they found no significant difference between their mean reaction distance and that of groups without cubs, 78% of the groups with cubs exhibited behavioral changes in response to the icebreaker's presence (Smultea et al. 2016). Dyck and Baydack (2004) studied the effect of wildlife viewing from tundra vehicles on polar bear vigilance and found females appeared to be more "comfortable" with tundra vehicles than males, although the authors suggested that males may perceive tundra vehicles as a threat and females may use them as a "safety buffer" to protect their offspring from male bears. Polar bears approached by snowmobiles in Svalbard, Norway, displayed vigilance-like behaviors, along with avoidance at relatively long distances, comparable to those found in our study. The average distance of the bears' reaction to or alert to snowmobiles was 1,164 m and avoidance occurred at an average distance of 843 m. Also parallel to our findings, they found that females with cubs reacted at greater distances and more strongly than other groups (Andersen and Aars 2007). Along with vigilance and avoidance, previous studies have shown that polar bears will exhibit approach behaviors with icebreaker vessels (Smultea et al. 2016, Lomac-MacNair et al. 2019) and drillships (Stirling 1988). However, during our study, no bears approached the vessel nor exhibited any behaviors of curiosity. This is likely due to vessel activity; the vessel speed during our study varied at 5–9 knots generally in a straight line, whereas an icebreaker often moves slower or is stationary like a drillship, allowing the opportunity for bears to exhibit curiosity behavior. Our finding of increased likelihood of behavioral response in water versus on ice suggests that polar bears on ice are more comfortable with vessel presence than those in water. Generally, bears on ice or land spend the majority of their time resting to conserve energy (Knudsen 1978). Potentially there is a larger energetic cost in the disruption of rest and shift to movement, although additional studies would need to be performed to validate this.

In general, disruption of an animal's activity has associated energetic costs and, thus, polar bear behavioral responses of vigilance and flee could potentially interrupt rest and feeding opportunities, possibly increasing polar bear energy expenditure (Watts et al. 1991, Dyck and Baydack 2004). In previous wildlife behavioral response studies, vigilance behavior has been associated with the detection of predators (Elgar 1989; Arenz and Leger 1999a, 1999b; Toïgo 1999); detection and observation of mates, competitors, and conspecifics (Caine and Marra 1988, Baldellou and Heinzi 1992, Cowlishaw 1998, Roberts 1988); and avoidance of infanticide (Steenbeek et al. 1999). Vigilance conflicts with other routine behavioral activities, such as resting, feeding, mating, and thus is considered costly because it requires limited resources of time and visual attention (Altmann 1974, Dukas 1998).

Management implications

Although sea ice loss is the primary threat to polar bears, little can be done to mitigate its effects without global efforts to reduce greenhouse gas emissions. Other factors, however, could exacerbate the impacts of sea ice loss on polar bears, such as exposure to increased anthropogenic activities. The Polar Bear Range States (nations that exercise jurisdiction over the polar bear range [i.e., Norway, Canada, Greenland, the Russian Federation, and the United States]) adopted a 10-year Circumpolar Action Plan (CAP) in 2015 (Polar Bear Range States 2015). The CAP highlights international cooperation on the conservation of polar bears across their range and one of its main objectives is to manage human–bear interactions, including disturbance from shipping, O&G industry, and tourism (Polar Bear Range States 2015). The IUCN Polar Bear Specialist Group identified that "increasing industry, tourism, and commerce in the Arctic brings humans and polar bears into closer proximity and increases the potential for negative interactions" (Durner et al. 2018:vii). As a result of the challenges inherent with offshore Arctic research, there are only a handful of studies investigating the interface between marine mammals and vessels in these remote regions (Smultea et al. 2016, Wilson et al. 2014, Lomac-MacNair et al. 2019) and fewer specific to polar bear behavioral response to human vehicles (Dyck and Baydack 2004, Andersen and Aars 2007). Results from this study reveal that polar bears respond to vessel presence through vigilance and avoidance; and distance, group composition, and habitat type affect the response. Findings from this study could be used to further develop the framework for bear–vessel interaction and avoidance strategies, including setback distances. Additionally, this study highlights the need to consider these interactions on Arctic marine mammals from vessels transiting through these newly accessible areas. Continuing to develop a more in-depth understanding of polar bear behavioral response to anthropogenic disturbances and subsequent mitigations may lead to more successful management.

Conclusion

Our study provides a description of polar bear occurrence from vessel-based surveys in the Chukchi and Southern Beaufort Seas. Although polar bears are thought to migrate north with the retreating ice or move onto land during the open water season, our results indicate that, in the Chukchi Sea, some polar bears remain in the pelagic environment. Our results indicated that polar bears responded to vessel presence through 'vigilance' and 'flee' behaviors and that behaviors were related to distance from the vessel, group composition, and habitat type. Both behavioral responses have potential associated energy expenditure costs. These findings on behavioral response could be used to ensure appropriate implementation of effective monitoring and mitigation strategies for vessel traffic. 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 continue to inform management and policy decision-makers and assist in the development of effective mitigation strategies in a rapidly developing Arctic.

Acknowledgments

This work was performed as part of the Chukchi Sea Environmental Studies Program (CSESP) 2008–2014. We would like to thank ConocoPhillips, Shell Exploration & Production Company, Statoil USA Exploration & Production Inc., and Olgoonik Fairweather, LLC for funding. In particular, we appreciate the support of C. Rea, Dr. M. Macrander, and Dr. S. Eldøy. We are also grateful for support and guidance from Chief Scientists Dr. R. Day and Dr. J. Burns Sr., and marine mammal principal investigators L. Aerts and J. Bruggeman. We thank Resource Data Inc. for data management. We would also like to thank Captains & crew of the R/V *Bluefin,* R/V *Westward Wind,* and R/V *Norseman II*. Finally, we were fortunate to have an extraordinary data set because of our wonderful data collection team: Iñupiat communicators and observers (C. Adams, M. Akpik, F. Garfield, J. Goodwin Jr., W. Leavitt Sr., N. Lie, A. Penayah, R. Suvlu, H. Tagarook, F.Wemark, and S. Wood) and marine mammal observers (S. McFarland, A. Ajmi, H. Barnett, J. Butcher, J. Cate, C. Christman, A. Cyr, G. Hadley, S. Hanlan, C. Hesselbach, C. Hoefer, Z. Klyver, D. Moore, J. Moffi, B. O'Brien, B. O'Donnell, B. Ringstad, V. Schaefer, J. Schwab, P. Seiser, S. Sitkeiwicz, F. Smith, S. Talbert, and B. Watts). Additionally, we thank L. Aerts for her review and input on this manuscript as well as the *Ursus* peer-review and editorial team for their helpful assessments and feedback.

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Received: July 8, 2020
Accepted: October 13, 2020
Associate Editor: M. Obbard