ARCTIC
VOL. 73, NO. 2 (JUNE 2020) P. 195–205
https://doi.org/10.14430/arctic70306

Human Interaction and Disturbance of Denning Polar Bears on Alaska's North Slope

Wesley G. Larson,[1,2] Thomas S. Smith,[1] and Geoff York[3]

(*Received 23 August 2018; accepted in revised form 28 January 2020*)

ABSTRACT. Across the central coast of Alaska's North Slope, human-polar bear interactions concern both industry and wildlife managers alike. In response to sea ice reductions due to climate change, parturient polar bears (*Ursus maritimus*) in the Southern Beaufort Sea subpopulation are increasingly accessing coastal topography for suitable denning habitat. Land-denning bears are more susceptible to anthropogenic stressors, chiefly in areas with high levels of energy exploration, extraction, and production. For over 30 years, denning polar bears in the Southern Beaufort Sea subpopulation have been monitored directly or through opportunistic observations. Scientists have opportunistically recorded polar bear responses to aircraft, snow machines, track vehicles, heavy machinery, trucks, dogs, and humans afoot within the denning area. The long-term nature of this work and associated human-bear interaction observations represent a unique dataset that provides insight to wildlife managers into the way polar bears have responded to anthropogenic stimuli in active oil fields. Our objective here is to analyze the different disturbance stimuli at den sites and the associated bear responses. To do so, we subdivided potential stimuli into four groups based on the size, noise levels, and motion of each. Both field notes and video recordings of interactions were analyzed and ranked by response intensity where available. We found significant probabilities for disturbance among all stimulus classes, with aircraft showing the highest potential for initiating den abandonment. However, while all human activities elicited varying degrees of response, the overall response intensity was less than anticipated, even under high-use scenarios. Our data indicate that the current guideline of a 1.6 km (1 mile) buffer zone effectively minimizes disturbance to denning polar bears. These data will provide both wildlife managers and industry with information that can be used to promote polar bear conservation through minimizing disturbance and informing the development of alternative actions for dealing with bears denned near industrial activity.

Key words: Alaska; anthropogenic stressors; Arctic; disturbance; human-bear conflict; North Slope; polar bears; *Ursus americanus*; *Ursus maritimus*

RÉSUMÉ. Le long de la côte centrale de la North Slope de l'Alaska, les interactions entre les humains et les ours polaires concernent tant l'industrie que les gestionnaires de la faune. En raison de la réduction de la glace de mer découlant du changement climatique, les ourses polaires parturientes (*Ursus maritimus*) faisant partie de la sous-population du sud de la mer de Beaufort optent de plus en plus souvent pour la topographie côtière pour trouver un habitat adéquat de mise bas. Les ourses aux tanières maternelles côtières sont plus sensibles aux agents stressants anthropiques, surtout dans les aires exigeant beaucoup d'énergie pour l'exploration, l'extraction et la production. Depuis plus de 30 ans, la sous-population d'ourses polaires en tanières du sud de la mer de Beaufort fait l'objet d'une surveillance directe ou d'observations fortuites. Opportunément, les scientifiques ont réussi à consigner la réaction d'ours polaires aux aéronefs, aux motoneiges, aux véhicules à chenilles, à la machinerie lourde, aux camions, aux chiens et aux humains à pied traversant les aires de tanières. La nature à long terme de ce travail et l'observation des interactions connexes entre les humains et les ours fournissent un ensemble de données unique qui permet aux gestionnaires de la faune d'obtenir des connaissances sur la façon dont les ours polaires réagissent aux stimuli anthropiques dans les champs pétrolifères actifs. Notre objectif consiste à analyser les différents stimuli de perturbation aux aires de tanières et les réactions connexes des ourses. Pour ce faire, nous avons subdivisé les stimuli potentiels en quatre groupes, en fonction de l'ampleur, du niveau sonore et du déplacement de chacun. Nous avons analysé les notes prises sur le terrain et les enregistrements vidéo des interactions, et les avons classés en fonction de l'intensité de la réaction, lorsque celle-ci était apparente. Nous avons constaté d'importantes probabilités de perturbation au sein de toutes les classes de stimuli, les aéronefs présentant les plus grandes possibilités d'abandon des tanières. Cependant, bien que toutes les activités humaines aient entraîné des réactions de degrés variés, l'intensité de la réaction globale était moindre que prévu, même pour les scénarios de grande utilisation. Selon nos données, la directive actuelle faisant appel à une zone tampon de 1,6 km (1 mille) minimise efficacement la perturbation des ourses polaires en tanières. Grâce à ces données, les gestionnaires de la faune et l'industrie disposeront d'information dont ils pourront se servir pour promouvoir la conservation des ours polaires, et ce, en minimisant

[1] Wildlife and Wildlands Conservation Program, 5049 LSB, Brigham Young University, Provo, Utah 84602, USA
[2] Corresponding author: vezul22@gmail.com
[3] Polar Bears International, PO Box 3008, Bozeman, Montana 59772, USA

les perturbations et en éclairant l'élaboration de mesures de rechange pour s'attaquer à la question des ourses dont la tanière se trouve près d'activités industrielles.

Mots clés : Alaska; agents stressants anthropiques; Arctique; perturbation; conflit entre les humains et les ours; North Slope; ours polaires; *Ursus americanus*; *Ursus maritimus*

Traduit pour la revue *Arctic* par Nicole Giguère.

INTRODUCTION

The response of wildlife to human activities is a well-studied component of wildlife management and conservation. Understanding the effect that human-wildlife interactions have on different species is key to effective management. While any co-occurrence of humans and wildlife could constitute an interaction (Hopkins et al., 2010), not all interactions result in disturbance. However, anthropogenic stressors that lead to changes in reproductive success, behavior, and physiology are classified as disturbance (Tarlow and Blumstein, 2007). To understand how disturbance may lead to biologically significant effects, information regarding the following is needed: 1) type of stimulus, 2) context of the encounter, and 3) the behavioral and physiological strategies the animal uses when threatened (Frid and Dill, 2002). Additionally, when disturbance studies are conducted, it is equally important to document when no apparent response occurs. Because non-responses to stimuli can be difficult to identify, they are often under-reported. Failure to document non-responses, as well as overt responses, may lead to the inaccurate conclusion that a species is sensitive to a particular type or intensity of human activity, when in fact it is not.

In many carnivore species, the most energetically efficient response to a perceived threat is to move from the area of concern (Linnell et al., 2000). However, denned, parturient bears are an exception and less likely to abandon a den site because of the negative consequences for reproductive success (Linnell et al., 2000). Nonetheless, polar bear (*Ursus maritimus*) den abandonment due to human disturbance has been documented (Belikov, 1976; Lentfer and Hensel, 1980; Amstrup, 1993; Lunn et al., 2004). When considering den abandonment in polar bears, it is important to make a distinction between "abandonment," which is an early departure from a maternal den, often as a result of disturbance, and "departure," which is the undisturbed, normal departure from the maternal den. Additionally, the theory of residual reproductive value (Frid and Dill, 2002) predicts that young female bears should have a higher likelihood of abandoning a den and their offspring than older females have, as younger bears have a higher residual reproductive value and much more to lose. While empirical evidence for the effect of residual reproductive value in denning polar bears is lacking, it could be affecting denning behavior; further research would be needed to confirm that possibility. A number of studies have sought to determine the distance at which a species will flee from a disturbance stimulus, commonly defined as the flight initiation distance (FID), and the factors leading to flight initiation for a variety of species (Walther, 1969; Frid and Dill, 2002). While some studies have addressed FID in bear species (Andersen and Aars, 2008; Smith et al., 2012), disturbance thresholds and FID in polar bears have been largely unstudied. We would predict, however, that the younger the parturient bear, the more risk-averse they would be with respect to perceived disturbance, as evidenced by larger FIDs.

In late fall and early winter in the Southern Beaufort Sea (SBS), parturient polar bears construct dens in a matrix of snow and ice that provides protection from predators and insulation from outside noise, low temperatures, and other weather conditions (Blix and Lentfer, 1993; MacGillivray et al., 2009). Altricial polar bear cubs are born from late December through early January (Ramsay and Stirling, 1988) and require more than two months of den protection post-partum before emerging in late March or early April (Ramsay and Stirling, 1988; Amstrup and Gardner, 1994; Smith et al., 2007). Historically, a majority of dens constructed in the SBS population occurred on offshore pack ice, near pressure ridges where deep snow accumulates. However, the proportion of dens constructed on pack ice has declined from 62% (1984–94) to 37% (1998–2004) (Fischbach et al., 2007). This decrease in pack-ice denning was likely in response to reductions in multiyear pack ice and a lengthening of the ice-free season (Fischbach et al., 2007). With a higher percentage of terrestrial denning activity, polar bears are at a higher risk of conflict with humans, particularly along the central part of Alaska's North Slope where petroleum industry activity is widespread.

Polar bears may be particularly vulnerable to den disturbance among the bear species, as fasting periods can last up to eight months (Ramsay and Dunbrack, 1986; Atkinson and Ramsay, 1995; Derocher and Stirling, 1998), during which time females may lose up to 43% of their body weight (Atkinson and Ramsay, 1995). Increased nutritional stress and subsequent decreases in cub survival, litter size, and reproductive periods have been documented and correlated to losses in sea ice (Stirling et al., 2004; Regehr et al., 2006; Rode et al., 2007; Molnár et al., 2011). Human-bear interactions add to denning females' stress and can lead to den abandonment and reproductive failure. Premature den abandonment is particularly costly for denned (fasting) female bears and subjects offspring to exceptionally harsh weather conditions, thus lowering their chances of survival. As such, it is important that stress be minimized for denned bears along Alaska's North Slope.

To strengthen protections for marine mammals, the U.S. Congress passed the Marine Mammals Protection Act (MMPA) in 1972 and re-released it in 2004 (MMPA, 2004). The MMPA clearly specifies the types of disturbance that must be reported to U.S. management authorities. A disturbance event that falls under the MMPA classification of a "take" includes acts that "harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal," and a class of event referred to as "harassment' includes an act that "has the potential to injure a marine mammal or marine mammal stock in the wild … or has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns" (MMPA, 2004: 3, 4).

Non-sanctioned "takes" can lead to the suspension of work and associated financial burdens for commercial activities. Commercial operators, such as Alaska's oil and gas industry, can request Letters of Authorization (LOA) from the U.S. Fish and Wildlife Service (FWS) that allow incidental "takes" of polar bears during specified activities. When working in polar bear denning habitat, LOA permittees are required to make an effort to locate polar bear dens and avoid exclusion zones around known polar bear dens. To locate polar bear dens within areas of operation, forward-looking infrared (FLIR) cameras (which detect heat from denned bears through the snow), polar bear scent-trained dogs, or radio-telemetry of collared bears are used. Once identified, observed or suspected polar bear dens must be reported to the FWS prior to initiation of industrial activity. Additionally, industry must observe a 1.6 km (1 mile) exclusion zone around all known polar bear dens during the denning season (November–April) or until the female and cubs leave their dens, unless otherwise directed by FWS. The FWS evaluates newly discovered dens on a case-by-case basis to determine the best mitigation options and conservation outcomes (FWS, 2016). To implement the Incidental Take Program without placing an undue burden on industry, FWS managers need to understand bears' responses to the various types and intensities of human activities that may occur near den sites.

From 1975 to the present, researchers from the United States Geological Survey (USGS), FWS, Brigham Young University (BYU), and Polar Bears International (PBI) have conducted polar bear research or monitoring activities within the Prudhoe Bay Operations Area and adjacent habitats. During that time, human-polar bear interactions at den sites have been opportunistically observed and documented. The purpose of this paper is to present those interactions and accompanying bears' responses in an effort to contribute to our understanding of polar bear response to human activity within the context of denning (Ramsay and Stirling, 1986; Amstrup, 1993; Lunn et al., 2004; Perham, 2005; Andersen and Aars, 2008). Our hope is that this information will aid managers in their efforts to minimize negative human-bear interactions when industry and others operate in polar bear habitat. Specifically, we will examine whether available data support the 1.6 km (1 mile) buffer guideline currently in place for oil industry operators in denning habitat. In addition, our results will help to direct future research efforts so we can better understand the effects of anthropogenic stressors on polar bear denning.

STUDY AREA

The study area encompasses the Prudhoe Bay Operations Area, which extends 111 km east of Prudhoe Bay to the Arctic National Wildlife Refuge and 133 km west to the Eskimo Islands (Fig. 1). Within this area, small bluffs (< 4 m) on barrier islands, riverbanks, and the coastal plain provide topographical relief where snow drift accumulation is sufficient for polar bear denning sites (Benson, 1982; Durner et al., 2003). Habitat across the North Slope has been analyzed for suitable polar bear denning habitat and subsequently mapped (Durner et al., 2006).

METHODS

Dens were located through a combination of Very High Frequency (VHF) telemetry and Global Positioning System (GPS) radio collar relocation, from results of both aerial and ground surveys using FLIR camera technology (Amstrup et al., 2004; Robinson et al., 2014), direct observation by local observers, and from polar bear scent-trained dogs (Perham and Williams, 2003). It should be noted that VHF- and GPS-collared bears had been handled previously, and we may expect to see differences in intensity of response to human interactions between previously handled and unhandled bears. Human interactions at den locations were opportunistically recorded by personnel working for the USGS, FWS, BYU, and PBI on a variety of polar bear research projects. Along with long-term capture and tracking research, the USGS initiated a polar bear den emergence study in 2002, which has been subsequently led by BYU and PBI (Smith et al., 2007, 2013). For the first two years of the study, researchers used observation blinds to directly observe bears at den sites. However, these small tent camps occasionally elicited increased vigilance and other responses by bears to human activities, so in 2005, autonomous video systems were deployed to reduce the potential for human-bear interaction (Smith et al., 2013). Autonomous video capture proved to be a more effective and less intrusive means for documenting denning behavior (Smith et al., 2013).

For the purposes of this study, we compiled all human-bear interactions observed at den sites in a database. For each human-bear interaction, we recorded the date, time, location, type of anthropogenic stimulus (e.g., human afoot, snow machine, truck), distance from bear to stimulus, bear cohort (e.g., male, female, female with cubs), response intensity, and other ancillary data (e.g., weather, number of persons involved). For analysis, each human-bear interaction was assigned to a specific distance category,

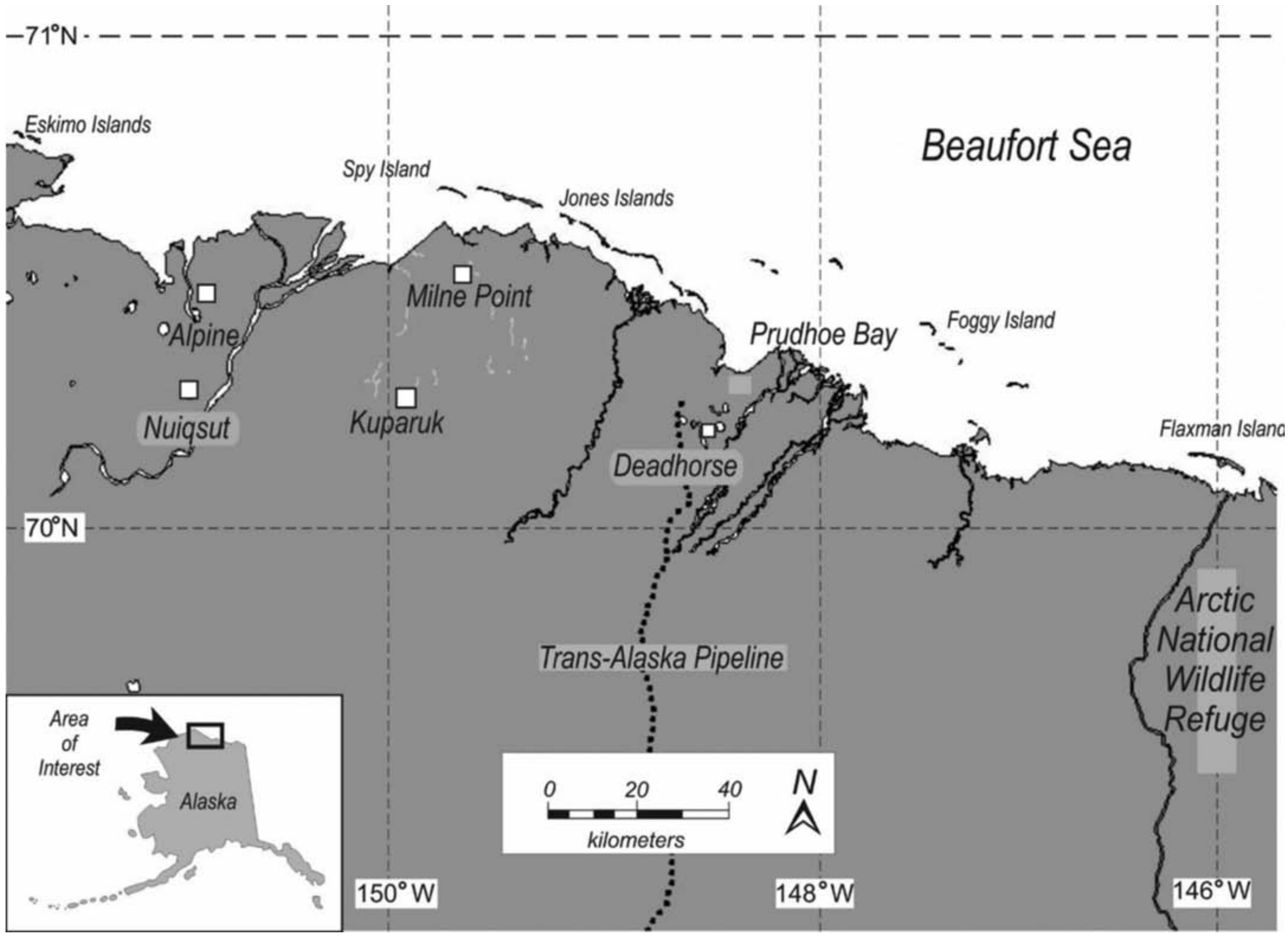

FIG. 1. The southern Beaufort Sea study area where polar bear den site observations were made (2002–16).

stimulus group, response intensity ranking, and response intensity group.

Distances from stimulus to bear were often estimated. To account for the lack of precise distance measurements, we used the following broad groups: Distance Group 1 included all interactions that occurred between 0 and 150 m, Distance Group 2 contained interactions that occurred between 151 and 300 m, and Distance Group 3 contained all interactions at distances over 300 m. These distance groups were selected based on industry and research limitations and guidelines provided by USFWS, (i.e., all research-related snow machine approaches were to be at distances no closer than 150 m from an occupied den).

We assigned each interaction to a stimulus group based on the physical size of the stimuli (e.g., a human on foot was considered a small stimulus whereas a Rolligon® vehicle, a large stimulus), the motion (speed), and noise level associated with it. Stimulus Group 1 (SG1) included all aircraft involved in human-bear interactions (both fixed and rotary wing). Stimulus Group 2 (SG2) included large industrial machinery (Rolligon®, Tucker Sno-Cat® (Fig. 2), snowplow, semi-truck, etc.) Stimulus Group Three (SG3) included smaller machinery (4-wheel drive pickup truck, snow machine), and Stimulus Group 4 (SG4) included only humans on foot. Table 1 presents the 4 anthropogenic stressors observed near polar bear den sites and associated group identifiers.

Human-bear interactions were subdivided into three groups based on the estimated noise level, motion of stimuli, distance from stimulus, duration of interaction, and directionality of approach associated with each incident. Directionality of approach is important when considering bear responses to stimuli, as bears are likely to respond differently to a direct approach as opposed to a more angled, indirect approach. For the purposes of this study we categorized directionality of approach by the approach to the entire den site, not the individual bear. Intensity of interaction was more difficult to quantify, as we did not have data for all variables affecting intensity rankings for every interaction. To insure consistency, however, we carefully reviewed all notes associated with each interaction, and then evaluated each individually. We classified stimulus intensity on a scale of one to three, with a score of one representing a low-intensity interaction that involved quiet, slow-moving stimuli, with shorter interaction times (less than 1 min, i.e., a passing truck or snow machine with

FIG. 2. A Tucker Sno-Cat® (Stimulus Group 2) approaches a polar bear at a den entrance on Flaxman Island, North Slope, Alaska.

TABLE 1. Anthropogenic stressors observed interacting with polar bears on Alaska's North Slope, 1975–2017.

Group Number	Stimulus type	Stimulus examples
1	Aircraft	Chemical immobilization from helicopter, fixed-wing plane
2	Large machinery	Semi-truck, Tucker Sno-Cat®, cat train, tractor, gravel truck
3	Small machinery	Pickup truck, snow machine
4	Humans on foot	Survey teams, researchers in tents

no extended stop) and less direct approaches at greater distances (> 300 m). A score of two represented a moderate-intensity stimulus that occurred with faster, louder stimuli for a longer duration (greater than 1 min, i.e., a research team installing cameras, prolonged industry activity) and more direct approaches at shorter distances (151–300 m). A score of three was assigned to high-intensity interactions that occurred with rapid moving, loud stimuli for longer durations (greater than 1 min), direct approaches, and at relatively close distance (< 151 m).

Bear responses to each interaction were grouped by intensity, on a scale of 1 to 4: level 1 represented an apparent "non-response" following an interaction, level 2 represented a low-intensity response (increased vigilance, change from sitting to standing posture), level 3 represented a moderate-intensity response (rapid movement, retreat to den), and level 4 represented a high-intensity response (den abandonment). While a bear may have responded internally to a given stimulus (e.g., changes in heart rate, respiration, or release of stress hormones), our non-response category 1 means that observers were unable to visually detect an overt change in behavior as a result of a particular human-bear interaction.

Finally, we examined each stimulus group, distance, cohort, intensity of interaction, and resulting bear reactions for trends. To accomplish this, we built and compared models in Program R (R Development Core Team, 2008) with the Akaike Information Criterion selection adjusted for small sample size (AIC_c; Akaike, 1973). Given multiple categorical variables, we used multinomial logistic regression, then ran a post-hoc Tukey comparison using the lsmeans package to analyze top models. Within our top model, we compared each variable against all others and associated polar bear responses to construct probabilities of observing categorized bear response intensities (1–4), when approached by categorized stimulus classes (1–4), at varying disturbance intensities (1–3).

RESULTS

We analyzed 138 human-bear interactions that spanned a 42-year period (1975–2017). All data were collected during the denning period in the SBS, roughly 15 November to 15 April. Interactions involving aircraft (SG1) accounted for 26.1% (*n* = 36) of interactions, large machinery (SG2) comprised 17.4% (*n* = 24) of all interactions, smaller machinery (SG3) accounted for 37.0% (*n* = 51) of interactions, and people afoot (SG4), 19.6% (*n* = 27). Of all interactions, 23.2% (*n* = 32) elicited no discernible response (level 1) from bears, 39.6% (*n* = 55) led to a change in posture or increased vigilance response (level 2), 29.0% (*n* = 40) elicited a rapid movement response (level 3), and 8.0% (*n* = 11) led to a den abandonment response (level 4). We present counts of each bear response level for all stimulus groups in Figure 3. Within our distance groups, we recorded 40 interactions within group 1, 46 interactions within group 2, and 52 interactions within group 3.

Figure 4 shows the distribution of bear responses for each stimuli type within our three distance categories. Non-responses were shown to occur at greater distances for most stimuli groups, with 81% of interactions resulting in no response from bears occurring at distances over 300 m (*n* = 25). Conversely, the large majority of human-bear interactions that led to abandonment occurred at close distances, with 91% occurring less than 150 m from a den site (*n* = 10).

Model selection and comparison with AIC identified a top model that accounted for 90% of the cumulative model weight and was therefore the only one that received enough support to be included in our analysis. This model contained "bear reaction to stimuli" as the response variable, with intensity level and stimulus group as explanatory variables. Table 2 presents the top model and the second highest-ranked model in our AIC analysis.

Multinomial logistic regression and post-hoc Tukey comparison returned statistically significant probabilities (95% confidence interval that does not cross zero) in multiple (*n* = 17) comparisons of variables. The top model for bear response contained both stimulus group and stimulus intensity level as important explanatory variables, but our sample size was too small for specific combinations of the response variable with both explanatory variables. Consequently, combinations with response as the dependent variable and stimulus group and stimulus intensity as dependent variables with fewer than six data points were removed from analysis. The following discussion includes

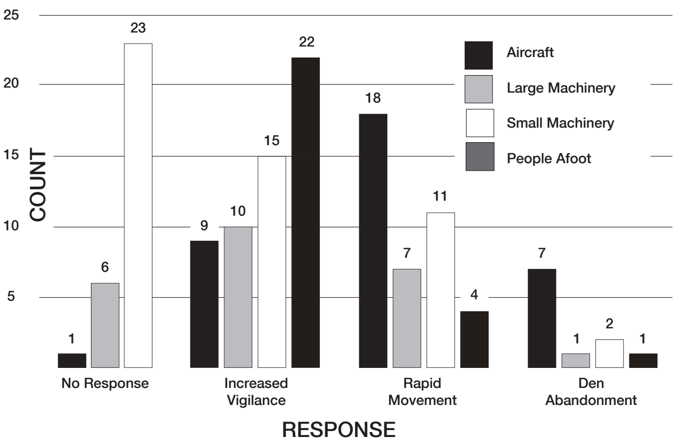

FIG. 3. Counts of bear responses at all response levels for each stimulus class.

only those stressors for which adequate sample size allowed statistical analysis.

Low-Intensity Stressors

Low-intensity stimuli provided our most robust data set (Table 3). Large machinery had a 27.5% probability (95% CI = 7.38 – 47.5) of eliciting no response from denning bears, a 42.0% probability (95% CI = 20.1 – 64.0) of eliciting increased vigilance, and a 30.5% (95% CI = 10.0 – 51.0) probability of eliciting a rapid movement response. Small machinery had a 51.5% probability (95% CI = 33.8 – 69.2) of eliciting no response, a 26.9% probability (95% CI = 11.7 – 42.1) of eliciting increased vigilance and a 21.6% probability (95% CI = 07.6 – 35.7) of initiating a rapid movement response. People afoot had a 91.9% probability (95% CI = 80.0 – 100) of eliciting increased vigilance in denning polar bears. All other low-intensity stimulus group interactions were not statistically significant or did not have a large enough sample size ($n > 6$) to be included.

Moderate-Intensity Stressors

The majority of moderately intense stimuli was associated with SG3, or small machinery, including pickup trucks and snow machines (Table 3). We identified a 36.6% probability (95% CI = 11.7 – 61.5) of moderate-intensity interactions by small machinery eliciting no response from denning polar bears, and a 39.1% probability (95% CI = 15.1 – 63.1) of initiating increased vigilance. We did not have sufficient sample sizes for other stimulus groups to merit inclusion for analysis at moderate levels of stimuli.

High-Intensity Stressors

While a number of high-intensity stimuli interactions with polar bears were included in the dataset, those that had a sample size large enough for analysis ($n > 6$) were all in the aircraft stimulus group (SG1). High-intensity stimuli associated with aircraft showed a 20.0% probability (95% CI = 05.1 – 34.9) of eliciting increased vigilance, a 57.4% probability (95% CI = 38.9 – 75.9) of initiating rapid movement, and a 22.6% probability (95% CI = 06.8 – 38.4) of causing den abandonment (Table 3). All other high-intensity stimulus group interactions did not have large enough sample sizes to be included.

DISCUSSION

Our data show that denned polar bears on Alaska's North Slope are overtly unreactive (i.e., largely tolerant)

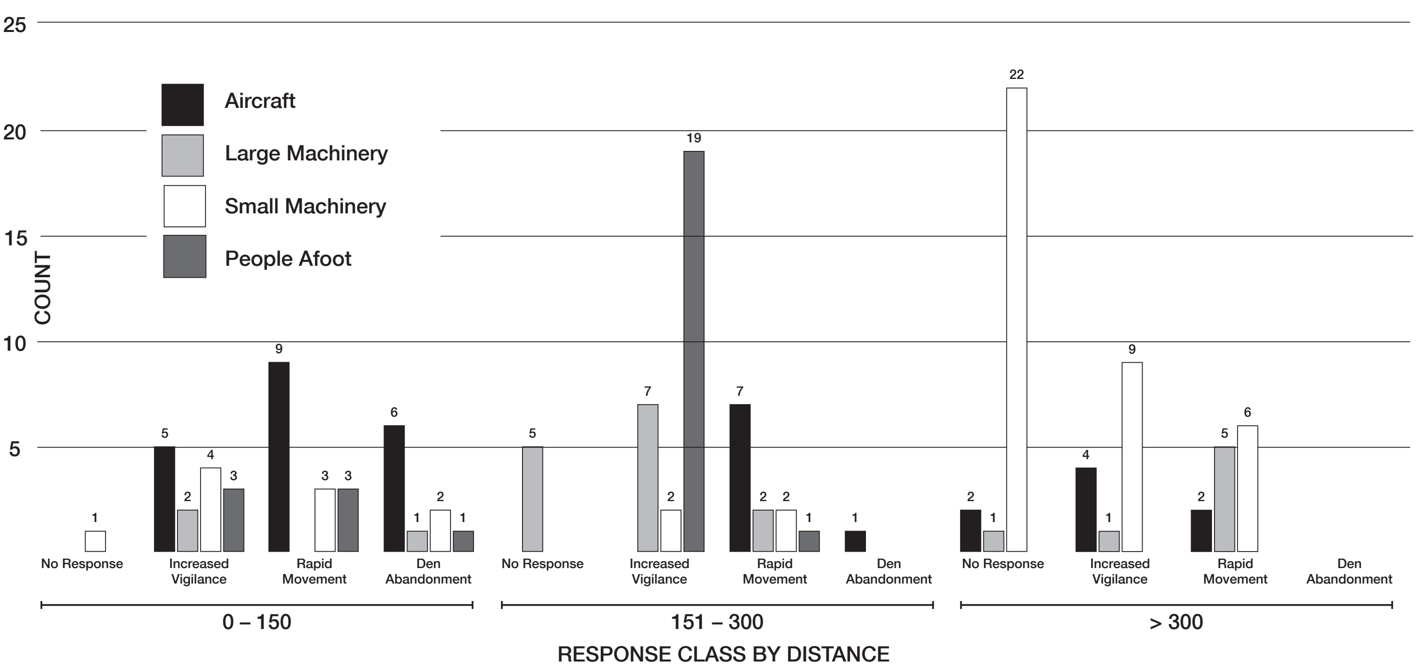

FIG. 4. Counts of bear responses by distance group at all response levels and for each stimulus class. Distance groups are 0 – 150 m, 151 – 300 m and over 300 m.

TABLE 2. AIC model selection. Included is model structure, Akaike's Information Criterion adjusted for small sample size (AIC_c), change in AIC_c from the most supported model, (AIC_c), model weight (w_i), and number of parameters (K).

Response variable	Model structure	AIC_c	ΔAIC_c	w_i	K
Bear reaction to stimuli	Stimulus group + intensity	282.5	0.0	0.90	18
	Stimulus group + distance + intensity	289.0	6.5	0.03	24

TABLE 3. Significant probabilities of categorized bear responses (1–4) for low-, moderate-, and high-intensity disturbance events involving categorized stimulus groups (1–4). A response of 1 represents a non-response, a response of 2 represents increased vigilance or a change in posture, a response of 3 represents rapid movement or escape to the den, and a response of 4 represents den abandonment.

Stimulus Group		Low intensity			Moderate intensity			High intensity	
	Response	Probability	95% CI	Response	Probability	95% CI	Response	Probability	95% CI
1: Aircraft							2	20.0%	0.05–0.35
							3	57.4%	0.39–0.76
							4	22.6%	0.07–0.38
2: Large machinery	1	27.5%	0.07–0.47						
	2	42.0%	0.20–0.64						
	3	30.5%	0.10–0.51						
3: Small machinery	1	51.5%	0.34–0.69	1	36.6%	0.12–0.61			
	2	26.9%	0.12–0.42	2	39.1%	0.15–0.63			
	3	21.6%	0.08–0.36						
4: People afoot	2	91.9%	0.80–1.00						

of human activity near den sites (< 1.6 km), and that den abandonment did not occur when bears were exposed to low levels of disturbance. We found that bears responded differently to each stimulus type as shown in Figure 2. However, a better understanding regarding which stimuli and intensity levels result in den abandonment is of chief importance, as premature polar bear den abandonment could lead to failed recruitment. Within the data available to this study, den abandonment events were rare (n = 11), and almost all abandonments (n = 10) occurred following high intensity interactions involving females without dependent young. Most abandonment events (n = 7) were caused by high intensity interactions (longer duration with distances < 150 m) of low-flying aircraft (both helicopter and fixed-wing aircraft). The majority of these interactions were associated with capture and radio-collaring operations of females at open den sites that had not yet produced cubs (n = 6). In addition, it should be noted that each of these radio-collaring events occurred in the fall when den construction was ongoing and females had less to lose by abandoning those sites following disturbance. From an energetics standpoint, an incomplete den (i.e., a hole in the snow as opposed to a sealed den) likely does not represent a great energetic cost for parturient females and as such was more readily abandoned than a closed den. While radio-collaring operations represent intense interactions, work by Ramsay and Stirling (1986) and by Rode et al. (2014) reported that fall captures of pregnant females did not appear to negatively affect reproduction or cub survival. Ramsay and Stirling (1986) handled 13 pregnant bears at den sites, and all successfully re-denned, with a mean den relocation distance of 17.8 km from the handling location. Results from their study, as well work by Amstrup (1993), showed no significant effect of handling and subsequent increased movement prior to denning on cub survival and weight. Conversely, Lunn et al. (2004) showed that handling pregnant polar bears in the fall might lead to lighter female cub weights, but found no change in male cub weights. In a closed den (i.e., the entrance is filled with snow), polar bear cubs are not likely to survive a forced abandonment event; therefore, collaring operations are not carried out prior to normal den breakout (i.e., first emergence in spring from a sealed den) and abandonment when cubs are healthy enough to leave the den site. We chose to include bears that had previously been handled in collaring operations because we expected that if a difference between handled and unhandled bears occurred, we would see a lower tolerance of disturbance in previously handled bears. By including previously handled bears that might respond to human interactions at a higher-intensity level, we can set a higher bar for establishing a buffer for management of industrial activities. In all of our den site interactions, we documented only one den abandonment involving cubs. This event occurred after USGS researchers excavated a den believed to be abandoned (family groups at 11 other known dens had departed), but was still occupied. Following a high-intensity interaction with researchers at this den site, the female fled the den when the nearby helicopter was restarted. The female was immobilized nearby and her cubs were removed from the den and brought to her. It is unknown if the female and cubs re-denned, though one of the two cubs was recently captured as a healthy adult bear (USGS, Todd Atwood, pers. comm. 2016). Aside from the event mentioned above, all recorded abandonments happened outside the window of normal den departure (Smith et al., 2007); we therefore conclude that they can accurately be classified as abandonments.

The distance between the anthropogenic stressor and polar bear dens is an obvious factor that influences the outcome of an interaction. A bear approached directly to within 10 m by a snow machine is almost certainly going to react differently than one approached no closer than 300 m. Within our observations, some distances were estimated which may explain why the "distance to stressor" variable was not in the top model. However, we included distances between stimuli and bears when assigning intensity rankings for each interaction, and "intensity of interaction" was a potential explanatory variable that was included in the top model. The "distance to bear" variable was of particular importance when we analyzed human-polar bear interactions on the North Slope. The 1.6 km buffer guideline was established to mitigate the potential for unnecessary stress imposed on denning polar bears through human activity in oil development areas. Our data indicate that the 1.6 km buffer represents adequate protection for denned bears from aircraft disturbance. All other stimulus groups elicited markedly lower bear responses at the distances for which we had data (all interactions occurred < 1.6 km).

Within the response groups we created for analysis, groups 3 (rapid response movement) and 4 (den abandonment) fit the MMPA (2004) definition of "harassment" events that lead to a disruption of behavioral patterns. We noted significant probabilities for "harassment" disturbance for both large and small machinery at low intensities and for aircraft at high intensity. Low-intensity interactions associated with large machinery were more likely to initiate a rapid movement in polar bears than a non-response, with probabilities of 30.5% and 27.5% respectively. However, low-intensity interactions associated with small machinery were more likely to lead to a non-response than a rapid movement response with probabilities of 51.5% and 21.6% respectively. Understanding the probability for each stimulus group to cause a "harassment" disturbance is key to the implementation of current industry rules when dealing with den sites in operating areas.

Although our data were opportunistically collected and not evenly distributed (frequency and distance of occurrence for each stimuli group), several trends among the den sites monitored are evident:

1) We found that polar bear dens were not abandoned, even when subjected to intense stressors, such as people digging into them or snow machines parked atop them. Every den site observed in the den monitoring study was approached to within 60 m and occasionally closer with snowmobiles, track vehicles, and humans on foot. No bears in closed dens (i.e., entrances snow-filled) abandoned them, which may be due to the high costs of abandonment (energy and loss of reproductive effort), or the fact that bears in sealed dens are less susceptible to anthropogenic stressors and associated noise and vibration levels (MacGillivray, 2009; Blix and Lentfer, 1992). Acoustically, closed dens represent a highly insulated environment, and sound levels from industrial activities more than 100 m from den sites have not been shown to penetrate the snow and disturb denning polar bears (Blix and Lentfer, 1992; Owen and Bowles, 2011).

2) During the multiyear den monitoring study, we did not observe any premature den abandonments that may have led to reproductive failure. Females were observed leaving den sites with offspring, and no remains of young were observed in dens when examined following abandonment.

3) While den sites near sustained human activity in 2002, 2006, and 2009 were vacated three days after den breakout, these departures fell within established norms for bears departing dens at undisturbed sites (3–13.2 d) as reported by Smith et al. (2007). Human activity may have been a factor in these den departures, but we have insufficient evidence to determine its potential contribution. In each of these instances, cubs were observed leaving the den site with the female. Previous work on denning phenology in the Prudhoe Bay Operating Area has established windows for natural den departures, and all departures that fell within those established time periods could not be reasonably classified as abandonments and were therefore not included in the analysis.

4) Individual bears responded differently to the same stimuli on numerous occasions. We noted a range of responses to the same stimuli by single bears, underscoring the difficulty in making conclusions based on limited observations. In its pilot year, the den monitoring project monitored two groups of polar bear dens, some near industrial activity ($n = 2$) and some not ($n = 4$). Researchers found that bears exposed to frequent industrial activity (e.g., heavy trucks on ice roads near the den) spent less time scanning their surroundings (i.e., vigilant behavior) than bears at den sites in undisturbed areas (Smith et al., 2007). This difference was attributed to habituation, a waning of wariness, since prolonged exposure resulted in no negative consequences. This varying level of response between individual bears could be explained by a number of factors, including age, life experience, the process of habituation, and den site location.

5) A change in posture, increased vigilance, rapid movement and abandonment all represent behavioral changes that are easily recognizable. A non-response is much more problematic to document, as there is no clear start or stop point to the non-interaction. Response level 1 (non-response) included observations of interactions with bears at open den sites that elicited no overt behavioral response. While we recorded a number of these non-responses ($n = 31$), many more likely went unrecorded, and denning polar bears may actually be far more tolerant to anthropogenic interaction than shown here.

It is possible that polar bears denning within the greater Prudhoe Bay area are more tolerant of disturbance than those denning in areas with a reduced human presence; thus, results from this study may not be applicable in areas where bears have not been conditioned to human activity. Increased tolerance of human activity may even lead to bears denning near anthropomorphic features to utilize them as a type of human shield to discourage predators. Berger (2007) showed that parturient moose (*Alces alces*) in the greater Yellowstone Ecosystem increasingly selected birth sites closer to paved roads where traffic-averse grizzly bears (*Ursus arctos*) were less likely to be found. Other animals have been shown to adopt similar strategies to use human presence as a type of predation shield, and it is possible that female polar bears in the SBS are employing a similar tactic when denning close to industrial activity. Male polar bears represent the main den predator on the North Slope (Amstrup et al., 2006), and if males actively avoid industrial areas, females could possibly select those same areas to heighten den security. A comparison of male polar bear movement patterns within industrially active areas with those in areas devoid of human activity may address the question of whether males are more likely to actively avoid human activity.

CONCLUSIONS AND RECOMMENDATIONS

These findings demonstrate that the 1.6 km buffer rule has been effective for minimizing den disturbance in industrially active areas on the North Slope. Additionally, we found that occupied dens are less vulnerable to disturbance than previously thought, and complete cessation of industrial activity in proximity to den locations may not be necessary. A recent case demonstrates how informed mitigation can result in success for managers, industry, and polar bears. In March 2017, BYU and PBI deployed an autonomous camera unit near a confirmed den site adjacent to a bridge with vehicular traffic to a nearby oil and gas facility. The bear had denned within 10 m of this bridge; rather than completely suspend all traffic, the den was continuously monitored by remote camera for emergence activity. When bears were within the den, vehicles were permitted to cross the bridge. When the adult female emerged from the den on 18 March, all use of the roadway was temporarily suspended until the family group departed their den on 30 March, two weeks later. Work by Smith et al. (2007) shows that after den breakout, bears remain in their dens, with only brief periods of activity out of the den. As such, human activity could be coordinated rather than halted all together, particularly at night when bears have not been observed outside of dens (Smith et al., 2007). In locations where real-time den monitoring is not possible, the 1.6 km buffer is an effective means of avoiding potential disturbance during periods when den sites may be open.

Because of the small sample size and a lack of replication of stressor distances and frequencies, our data provide limited insight regarding polar bear response to human activity at den sites. Future research at den sites with experimentally controlled distances and stimuli would provide a much clearer understanding of denned polar bear responses to human activity.

ACKNOWLEDGEMENTS

We'd like to acknowledge the large amount of work that went into generating this paper by many different parties and organizations. Data for this study were collected by a number of individuals including Steven Amstrup, BJ Kirschhoffer, Todd Atwood, Rusty Robinson, and Jay Olson. Funding, lodging, and logistical support were in large part provided by BP Corporation, as well as Conoco Philips, Exxon Mobil, and Hilcorp. Among those involved, special thanks should be given to Bill Streever, Chrissy Pohl, Deb Heebner, Stefan Gogosha, Neil Hermon, and Rob Murray, all of whom provided invaluable help to our field teams.

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