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Original Article

Polar Bear Attacks on Humans: Implications of a Changing Climate

JAMES M. WILDER,[1] *U.S. Fish and Wildlife Service, Marine Mammals Management, 1011 E. Tudor Road, Anchorage, AK 99503, USA*

DAG VONGRAVEN, *Norwegian Polar Institute, Fram Center, N-9296 Tromsø, Norway*

TODD ATWOOD, *U.S. Geological Survey, Alaska Science Center, 4210 University Road, Anchorage, AK 99508, USA*

BOB HANSEN,[2] *Government of Nunavut, Igloolik, NU X0A 0L0, Canada*

AMALIE JESSEN, *Government of Greenland, Department of Wildlife and Agriculture, P.O. Box 269, 3900 Nuuk, Greenland*

ANATOLY KOCHNEV, *Russian Academy of Sciences, Far East Branch, Institute of Biological Problems of the North, Mammals Ecology Lab, 18 Portovaya Street, 685000 Magadan, Russia*

GEOFF YORK, *Polar Bears International, PO Box 3008, Bozeman, MT 59772, USA*

RACHEL VALLENDER, *Canadian Wildlife Service, Environment Canada, 351 St. Joseph Boulevard, Gatineau, QC K1A 0H3, Canada*

DARYLL HEDMAN, *Manitoba Conservation and Water Stewardship, Northeast Region, Box 28, Thompson, MB R8N 1N2, Canada*

MELISSA GIBBONS, *Wapusk National Park and Manitoba North National Historic Sites, Parks Canada, Box 127, Churchill, MB R0B 0E0, Canada*

ABSTRACT Understanding causes of polar bear (*Ursus maritimus*) attacks on humans is critical to ensuring both human safety and polar bear conservation. Although considerable attention has been focused on understanding black (*U. americanus*) and grizzly (*U. arctos*) bear conflicts with humans, there have been few attempts to systematically collect, analyze, and interpret available information on human-polar bear conflicts across their range. To help fill this knowledge gap, a database was developed (Polar Bear-Human Information Management System [PBHIMS]) to facilitate the range-wide collection and analysis of human-polar bear conflict data. We populated the PBHIMS with data collected throughout the polar bear range, analyzed polar bear attacks on people, and found that reported attacks have been extremely rare. From 1870–2014, we documented 73 attacks by wild polar bears, distributed among the 5 polar bear Range States (Canada, Greenland, Norway, Russia, and United States), which resulted in 20 human fatalities and 63 human injuries. We found that nutritionally stressed adult male polar bears were the most likely to pose threats to human safety. Attacks by adult females were rare, and most were attributed to defense of cubs. We judged that bears acted as a predator in most attacks, and that nearly all attacks involved $\leq$2 people. Increased concern for both human and bear safety is warranted in light of predictions of increased numbers of nutritionally stressed bears spending longer amounts of time on land near people because of the loss of their sea ice habitat. Improved conflict investigation is needed to collect accurate and relevant data and communicate accurate bear safety messages and mitigation strategies to the public. With better information, people can take proactive measures in polar bear habitat to ensure their safety and prevent conflicts with polar bears. This work represents an important first step towards improving our understanding of factors influencing human-polar bear conflicts. Continued collection and analysis of range-wide data on interactions and conflicts will help increase human safety and ensure the conservation of polar bears for future generations.

KEY WORDS attacks, climate change, conflicts, conservation, management, PBHIMS, polar bear, predatory, *Ursus maritimus*, wildlife.

Polar bears (*Ursus maritimus*) have evolved to exploit the biologically productive Arctic sea ice niche by using it as a platform to prey upon marine mammals (Amstrup 2003). Before European exploration, this habitat specialization likely kept them separated from most people, and thus helped reduce human-bear conflicts. However, the extent of human-polar bear interactions began to change in the sixteenth century with the advent of widespread maritime exploration. Historical records provide some insight into the nexus between human and bear behavior and help inform current efforts to reduce human-polar bear conflict.

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[1]*E-mail: james_wilder@fws.gov*
[2]*Consultant, Living with Wildlife Specialist, PO Box 386, Tofino, BC V0R 2Z0, Canada.*

Although the Arctic has been inhabited by Indigenous people in relatively low numbers for thousands of years, the first recorded polar bear attack we found dates to 1595 when 2 members of William Barent's second expedition were reportedly killed and eaten by a polar bear in the Russian Arctic (de Veer 1876). The incident occurred on 6 September on an islet near Vaygach Island. Two men were lying in a wind-free depression resting, when:

> "*a great leane white beare came sodainly stealing out, and caught one of them fast by the necke, the beare at the first faling vpon the man, bit his head in sunder.*" The ship's crew rallied, and tried to drive the bear off of the victim: "*hauing charged their peeces and bent their pikes, set vpon her, that still was deuouring the man, but perceiuiug them to come towards her, fiercely and cruelly ran at them, and gat another of them out from the companie, which she tare in peeces, wherewith all the rest ran away* (de Veer 1876:63)."

Eventually the crew was able to again rally, and finally killed the bear as it continued to devour its victims. The vivid account provided by de Veer demonstrates the potential danger of polar bears, and is consistent in many respects with what we have learned from more recent attacks.

Continued European expansion into the Arctic led to increased conflict with, and exploitation of, polar bears (Conway et al. 1904). For example, a commercial expedition to Svalbard in 1610 reported killing 27 polar bears and catching 5 cubs (Lønø 1970). Commercial polar bear hunting continued through the centuries. In the early decades of the twentieth century, hundreds of bears were harvested on Svalbard annually. In 1924 alone, at least 901 polar bears were harvested on Svalbard (Lønø 1970). The widespread use of fossil fuels further accelerated human access to remote areas of the Arctic, resulting in significant hunting pressure on polar bears throughout their range after World War II. As a result, by the 1960s, the most significant threat facing polar bears was over-hunting, and populations in some areas were considered to be substantially reduced (Larsen 1975).

To address these and other conservation concerns, in 1973 the 5 polar bear countries (Canada, Denmark [on behalf of Greenland], Norway, the former Soviet Union, and the United States) signed the Agreement on the Conservation of Polar Bears (1973 Agreement). The 1973 Agreement requires the 5 signatory countries (the Range States) to restrict the taking of polar bears and manage polar bear subpopulations in accordance with sound conservation practices based on the best available scientific data (DeMaster and Stirling 1981, Prestrud and Sterling 1994, Larsen and Stirling 2009). It also allows harvest by local people using traditional methods in the exercise of their traditional rights and in accordance with the laws of that Party (1973 Agreement). Subsequent to 1973, measures implemented by the Range States, such as increased research and monitoring, cooperative harvest management programs, and establishment of protected areas, were presumed to have either stabilized, or led to the recovery of, subpopulations that had experienced excessive unregulated harvest (Amstrup et al. 1986, Prestrud and Sterling 1994). Today, polar bears are legally harvested by Indigenous peoples in Alaska, Canada, and Greenland, and harvest levels in most subpopulations are well managed and occur at a rate that does not have a negative effect on population viability (Obbard et al. 2010, Regehr et al. 2015).

However, polar bears now face a new and unprecedented threat due to the effects of climate change on their sea ice habitat (Stirling and Derocher 1993, 2012; Derocher et al. 2004; U.S. Fish and Wildlife Service 2008; Atwood et al. 2016*a*). Although the current status of polar bear subpopulations is variable, all polar bears depend on sea ice for fundamental aspects of their life history (Amstrup et al. 2008), including access to their primary prey, ice seals (Stirling 1974). Arctic sea ice extent and thickness have declined over the last 4 decades (Stroeve et al. 2014, Stern and Laidre 2016), leading some to conclude that the Arctic Ocean in summer may be largely ice free (i.e., $<1,000,000\,km^2$) as early as 2020 (Overland and Wang 2013).

In some parts of the polar bear range, diminishing summer sea ice has resulted in the increased use of terrestrial habitat by polar bears (Stirling et al. 1999, Schliebe et al. 2008, Gleason and Rode 2009, Cherry et al. 2013, Rode et al. 2015*b*). Longer ice-free periods (Stern and Laidre 2016) shorten polar bear hunting opportunities during the critical hyperphagic period of late spring and early summer (Ramsay and Stirling 1988), when hunting conditions are most favorable (Stirling and Øritsland 1995), and extend the duration of the on-land period through which polar bears must survive on finite stores of body fat (Cherry et al. 2013). The resultant increased fasting has significant negative effects on polar bear body condition (Stirling et al. 1999, Rode et al. 2010*a*) and the increasing ice-free period has been linked to declines in survival (Stirling and Derocher 1993; Stirling et al. 1999; Regehr et al. 2007, 2010; Bromaghin et al. 2015). Longer periods of fasting and increased nutritional stress (Cherry et al. 2009; Molnár et al. 2010, 2014; Rode et al. 2010*a*; Regehr et al. 2010) have also been attributed to incidents of infanticide, cannibalism, and starvation in some polar bear subpopulations (Lunn and Stenhouse 1985, Derocher and Wiig 1999, Amstrup et al. 2006, Stirling et al. 2008*a*), although Taylor et al. (1985) suggested that cannibalism is not an uncommon phenomenon in polar bear biology. When on shore, some nutritionally stressed bears are highly motivated to obtain food however they can, and appear more willing to risk interacting with humans as a result (e.g., Stirling and Derocher 1993, Derocher et al. 2004, Stirling and Parkinson 2006, Towns et al. 2009). Increased frequency of hungry bears on land due to retreating sea ice, coupled with expanding human activity in the polar bear range, is expected to result in a greater risk of human-polar bear interaction and conflict (Stirling and Derocher 1993, Derocher et al. 2004, Stirling and Parkinson 2006).

To date, polar bear attacks on humans have been rare. When they do occur, they evoke negative public reaction, often to the detriment of polar bear conservation. In some communities, those negative reactions can persist for decades and result in less social tolerance for polar bears and increased defense kills (Löe and Röskaft 2004, Voorhees et al. 2014). Recurrent conflicts not only undermine the well-being of people and wildlife (Madhusudan 2003), they also negatively affect local support for conservation (Naughton-Treves et al. 2003). Therefore, the effective management of human-bear conflict is an essential precondition for the coexistence of bears and people across the Arctic (Madden 2004).

A primary management goal of the Range States is to ensure the safe coexistence of polar bears and people. In 2009, the Range States recognized the need to develop comprehensive strategies to minimize human-bear conflicts resulting from expanding human activities in the Arctic and a continued increase of nutritionally stressed bears on land due to reductions in sea ice (Directorate for Nature Management 2009). However, one of the difficulties in understanding and managing human-polar bear conflicts is that they are often poorly documented, particularly at the circumpolar level (Vongraven et al. 2012). Although considerable attention has been focused on understanding black (*U. americanus*) and grizzly (*U. arctos*) bear-human conflicts (Herrero 2002), there have been few attempts to systematically collect, analyze, and interpret available information on human-polar bear conflicts across their range (but see Fleck and Herrero 1988, Stenhouse et al. 1988, Gjertz and Scheie 1998, Dyck 2006, Towns et al. 2009). As a result, the public is left with misconceptions and misinformation regarding polar bears and their behavior, most of it driven by sensational media coverage. For example, it is commonly asserted that polar bears are the most aggressive of bears and polar bears are the only large predator that will actively hunt people (e.g., The Daily Mail 2008). An important factor that fuels such common folklore is that only a small fraction of the interactions between polar bears and people are reported; the exceptions are attacks that lead to human injuries or death.

To address these knowledge gaps and public misperceptions, the Range States tasked the United States and Norway with leading an effort, in collaboration with other polar bear experts and managers, to develop a system to collect and analyze data on human-polar bear conflicts (Directorate for Nature Management 2009). The result was the Polar Bear-Human Information Management System (PBHIMS), a database designed to document, quantify, and help evaluate human-bear interactions and other information relevant to bear management. We analyzed data entered into PBHIMS to characterize the occurrence of polar bear attacks on humans. We used this information to suggest methods to minimize the risk of future polar bear attacks to promote both human safety and polar bear conservation. We also identified data needed to best inform future management of conflicts. Although the PBHIMS includes other types of data that can be used to mitigate conflicts, we initially focused on attacks because they are the most extreme and undesirable encounters between humans and polar bears.

STUDY AREA

Our study area comprised the range of the polar bear, including the frozen seas and coastal areas of Arctic Canada, Greenland, Norway, Russia, and the United States.

METHODS

We compiled information on human-polar bear conflicts from government records, published literature, biologists' field notes, and news media for entry into PBHIMS. We included some data that were previously reported (Gjertz and Persen 1987, Fleck and Herrero 1988, Gjertz et al. 1993, Gjertz and Scheie 1998), and augmented those data with additional information, where available. To the extent possible, we formulated data categories and variables of interest in PBHIMS to be consistent with relevant literature on human-bear conflicts (Fleck and Herrero 1988, Stenhouse et al. 1988, Smith et al. 2008, Hopkins et al. 2010).

We limited this analysis to incidents in which polar bears attacked people. A bear attack refers to intentional contact by a bear resulting in human injury (Smith et al. 2005, Hopkins et al. 2010). A predatory attack is one in which a bear preyed upon, or attempted to prey upon, people (Herrero and Higgins 2003, Hopkins et al. 2010). We considered wounds to the head or neck and consumption of human flesh to be indicative of a predatory attack. We also used behavioral components such as stalking and rushing the victim (Herrero and Higgins 2003), absence of vocalizing and stress behaviors by the attacking bear (Fleck and Herrero 1988, Herrero et al. 2011), and prolonged attacks despite sustained attempts by onlookers to drive the bear off, to support the identification of predatory events. The completeness of the information reported here varied by period, data source, and region. We acknowledge that this is not a complete dataset, and additional attacks likely occurred that we are unaware of because of incomplete reporting.

We classified independent bears from 3 to 4 years of age as subadults, and bears older than 4 years as adults. When information on bear body condition was available, we assigned a condition score from 1 (skinny) to 5 (obese) using the body condition index developed for polar bears (Stirling et al. 2008*b*). When possible, we assigned a probable cause to each attack after considering the totality of information available. Probable cause is the main factor that initially brought bears and humans into conflict.

A food-conditioned bear is one that has learned to associate people (or the smell of people), human activities, or human-use areas, with anthropogenic food (Hopkins et al. 2010). We followed Stenhouse et al. (1988) and defined location types where human-bear conflict occurred as follows: 1) towns (communities of $\geq$50 people living long-term in permanent buildings), 2) industry (permanent camps such as mines, well sites, and exploration camps), 3) research (associated with scientific expeditions and research activities), and 4) field areas (associated with camps and people camping or traveling across the land). We defined encounter group size as the number of people that initially encountered the bear(s). This may be different than the total number of people in the group. For example, in an incident where the lead 2 hikers in a group of 5 strung out over several hundred yards of a trail encounter a bear, the total group size is 5, but the encounter group size is 2.

We summarized polar bears attacks on humans from 1870 to 2014. Because reported attacks in recent decades were more accessible than were older records, we used records since 1960 to investigate trends in attacks by decade. We report spatial, temporal, and demographic characteristics of attacks, and notable aspects of bear and human behavior that may have influenced causation and outcome. We used a linear regression to determine if there was a trend in the number of attacks per decade from 1960–2014. We used chi-square tests to determine if a relationship existed between sex and age class of polar bears involved in attacks, and if the incidence of attacks varied relative to the number of people encountered by bears. Polar bear harvest is typically male-biased, with upwards of 60–70% of the annual harvest consisting of males (Derocher et al. 1997). However, there is no harvest in Norway and Russia, so we used what we believe to be a conservative ratio of 60 females:40 males for the expected sex class proportions in chi-square tests. Age class composition of harvest varies between populations and years but is close to a ratio of 50:50 for subadults to adults (Lee and Taylor 1994), which we used for the expected age class proportions. We accepted statistical significance at $\alpha = 0.05$. Details for some variables of interest were not always available for each incident analyzed. In those cases, we report the number of incidents for which we had adequate data.

RESULTS

We analyzed 73 confirmed attacks in which 20 people were killed and 63 were injured by wild polar bears. Of the attacks, 38 occurred in Canada, 4 in Greenland, 10 in Norway, 15 in Russia, and 6 in the United States. Seven other probable fatalities and 5 injuries occurred in Russia and Norway during this same period but are not included in our analyses because we could not confirm them (i.e., those attacks were referenced in other literature, but the details could not be confirmed or there were no witnesses to the incidents to confirm that they were actually attacks, even though all evidence indicated that as the most likely explanation).

Probable Cause of Attacks

Based on the criteria described in our methods, we judged that the bear involved acted as a predator in 59% (37 of 63) of attacks on people (Fig. 1). Sixty-four percent (7 of 11) of attacks by females with cubs resulted from defense of cubs; 2 of these occurred at den sites. Where probable cause could be determined, 100% (5 of 5) of attacks by single females were predatory in nature, 4 of which were by subadults and 1 by an adult (Table 1). Only 1 attack could be attributed to a bear defending a carcass. In 38% (14 of 37) of attacks, anthropogenic attractants were present. There was no indication that natural attractants (e.g., whale carcass) were present in any polar bear attacks on people.

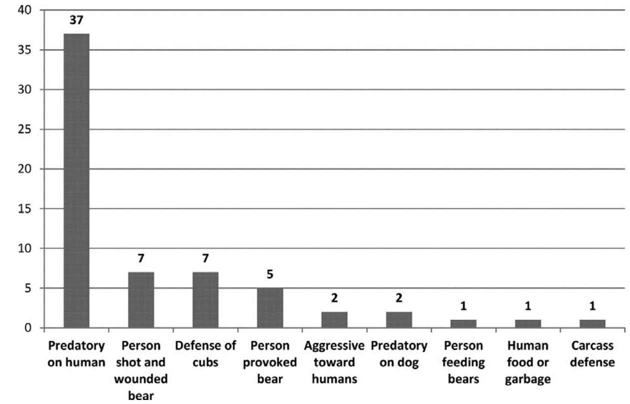

Figure 1. Probable cause of polar bear attacks on humans in Canada, Greenland, Norway, Russia, and the United States, 1870–2014. The predatory on human category includes predatory attacks on people in tents and buildings (9) and predatory investigations (2).

Demographic Characteristics and Body Condition of Attacking Bears

For attacks in which sex of the bear was known ($n = 45$; Table 1), the observed percentages of male (62%) and female (38%) polar bears involved differed from hypothesized percentages ($\chi^2_1 = 9.26$, $P = 0.002$). Ninety-one percent (11 of 12; Table 1) of attacks by adult females involved those with cubs (cubs of the year, yearlings, or 2-year-olds; $\chi^2_1 = 8.33$, $P = 0.004$). Incidence of attacks also varied by age class ($\chi^2_2 = 12.33$, $P = 0.002$), with adults involved in 52% ($n = 28$), subadults in 35% ($n = 19$), and independent 2-year-olds and yearlings in 13% ($n = 7$) of attacks in which age class was known. Fifty-four percent (7 of 13) of attacks in towns were by subadult and yearling polar bears.

The incidence of predatory attacks ($n = 25$) differed among sex classes ($\chi^2_1 = 10.67$, $P = 0.001$). Seventy-two percent (18 of 25) of predatory attacks involved male bears, 20% (5 of 25) involved single female bears, and 8% (2 of 25) were committed by females with cubs (Table 1). Incidence of predatory attacks also varied between age classes ($\chi^2_2 = 5.87$, $P = 0.05$) with 42% (13 of 31) committed by adults, 45% (14 of 31) committed by subadults, and 13% (4 of 31) by independent yearlings or 2-year-olds. Where reported, polar bears vocalized before attacking in only 13% (4 of 30) of attacks.

Sixty-one percent (19 of 31) of bears that attacked humans were in below-average body condition, meaning they were skinny or thin (Figs. 2 and 3). Only 6% (2 of 31) were considered fat (Fig. 3); none were considered obese. Sixty-five percent (13 of 20) of bears involved in predatory attacks on people were in below-average body condition; none were in above-average body condition. Fifty-six percent (5 of 9) of the bears that attacked people in towns were in below-average body condition; none were in above-average body condition.

Sixty-four percent (7 of 11) of bears involved in fatal attacks on humans were in below-average body condition; none were in above-average body condition. We judged that the bear involved acted as a predator in 88% (14 of 16) of fatal attacks.

Table 1. Attacks by independent polar bears on humans in Canada, Greenland, Norway, Russia, and the United States by bear demographic class, 1870–2014, for all attacks and for predatory attacks.

	Sex class				
Age class	**Male**	**Female**	**Female with cubs**	**Unknown**	**Total**
All attacks					
Adult	14	1	11	2	28
Sub-adult	8	4	NA[a]	7	19
Two-year old	1	1	NA	0	2
Yearling	3	0	NA	2	5
Cub	0	0	NA	0	0
Unknown	2	0	NA	17	19
Total	28	6	11	28	73
Predatory attacks					
Adult	9	1	2	1	13
Sub-adult	5	4	NA	5	14
Two-year old	1	0	NA	0	1
Yearling	2	0	NA	1	3
Cub	0	0	NA	0	0
Unknown	1	0	NA	5	6
Total	18	5	2	12	37

[a] Not applicable.

Where reported, 100% (10 of 10) of the people killed by polar bears received major wounds to the head and neck. In 83% (10 of 12) of fatal incidents, the bear consumed part of the human; in 1 clearly predatory incident the bear was killed before feeding on the human. Only single bears were involved in fatal attacks on people: 93% (13 of 14) were committed by males, 7% (1 of 14) by females, 64% (9 of 14) by adults, 21% (3 of 14) by subadults, and 14% (2 of 14) by yearlings.

Spatial and Temporal Patterns of Attacks

Between 1960 and 2009, 47 attacks by polar bears on people were reported, ranging between 7 and 12 per decade, though we note that the partial decade of 2010–2014 had the most number of attacks ($n = 15$). There was no trend in the number of attacks by decade from 1960–2014 ($r^2 = 0.21$, $\beta = 0.08$, $P = 0.36$; Fig. 4). Between 1870 and 2014, attacks occurred in every month, with 68% (44 of 65) occurring between July and December. Since 2000, 88% (22 of 25) of attacks have occurred between July and December.

The majority of attacks (53%, 35 of 66) occurred in association with field camps and people traveling across the landscape; 27% (18 of 66) occurred in towns; 8% (5 of 66) occurred in association with research activities; and 6% (4 of 66) occurred at industrial sites. Eleven percent (7 of 63) of attacks were on people in their tent. Two attacks involved a

A

B

Figure 2. Representative body condition of polar bears: skinny (A) and average (B). Photos by D. Hedman, Daniel J. Cox Natural Exposures.

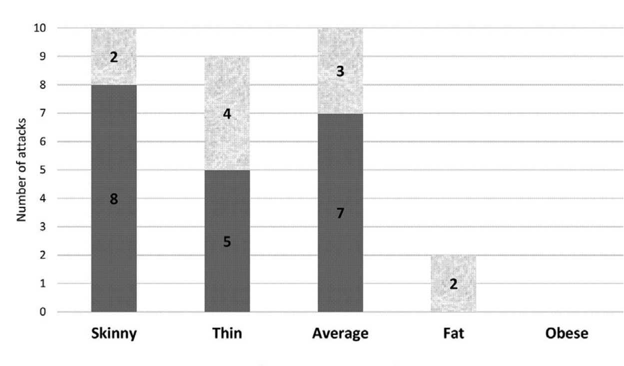

Figure 3. Body condition of polar bears that attacked humans in Canada, Greenland, Norway, Russia, and the United States, 1870–2014.

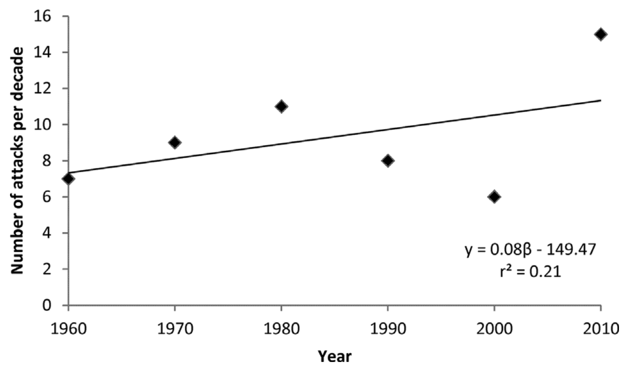

Figure 4. Number of polar bear attacks on humans by decade (e.g., 1960–1969) from 1960–2014.

bear attacking a person inside a building. Sixty percent (9 of 15) of attacks in towns were predatory.

Human Behavior

The incidence of attacks varied with the number of people a bear encountered ($\chi^2_2 = 19.34$, $P < 0.001$). Encounter group size was available for 56 attacks, 61% (34) of which involved 1 person, 27% (15) involved 2 people, and 12% (7) involved 3 or more people (i.e., 2 attacks involved 5 people and 2 involved $\geq$8 people). The encounter group size was known in 16 fatal attacks; 75% (12) involved 1 person, 19% (3) involved 2 people, and 6% (1) involved 5 people.

In 59% (30 of 51) of attacks, the person's behavior contributed to the attack (e.g., the person shot and wounded the bear or its cub, got too close or provoked the bear, fed the bear, slept on the ice, ran from the bear, was unarmed, carried inadequate firearms, or was inexperienced with the firearms carried). In 38% (24 of 63) of attacks, firearms were used to end the attack. In 84% (31 of 37) of nonfatal attacks, either the victim or a nearby bystander had firearms in their possession. In 57% (8 of 14) of fatal attacks, no firearms were in possession. In 25% (9 of 36) of attacks where a firearm was in possession, victims and bystanders mishandled firearms because of inexperience or the stress of the incident (sometimes multiple times by multiple people). In all cases this contributed to further human injury or death.

In 56% (29 of 52) of attacks, the person was surprised and had no chance to deter the bear before the attack. Thirty-nine percent (11 of 28) of attacks in which the person was aware of the bear before the attack were predatory in nature. In 7 attacks, multiple attempts to scare the bear off before the attack were unsuccessful. Bear spray was in possession of the person in only 1 of 36 polar bear attacks since 1986 (when bear spray became available in some regions). However, the spray was not used in that incident because the victim was attacked, reportedly without warning, and dragged from his tent in the middle of the night.

In 51% (32 of 63) of attacks, other people who witnessed or were involved in the attack were able to save victims by driving off or killing the attacking bear. Victims successfully fought off or killed the attacking bear in only 9% (6 of 63) of attacks. In the attacks in which the bear did not kill a person, fatalities and further injuries were prevented by killing the bear ($n = 22$), by the bear ending the attack on its own ($n = 9$), and by hitting the bear in the head with a tool ($n = 2$); single observations of wounding the bear with a firearm, using a helicopter, poking the bear in the eye with a thumb, firing flares at the bear, running into a building, using a cellphone light, stabbing the bear, scaring the bear away with snowmachines, throwing stones and shouting, a dog chasing the bear away, and shooting at the bear were recorded.

DISCUSSION

This research offers the first comprehensive assessment of polar bear attacks on people, the frequency of which has historically been low. For example, between 1960 and 1998, black and grizzly bears caused 42 serious or fatal human injuries in Alberta, Canada (Herrero and Higgins 2003). Herrero et al. (2011) documented 63 fatal attacks by black bears from 1900 to 2009 throughout North America. Conversely, over the 145-year period we investigated, we found records of only 73 confirmed polar bear attacks that resulted in 20 human fatalities and 63 human injuries. We acknowledge that we likely have not discovered or had access to information on all the attacks that occurred during the period investigated, and some attacks occurred that were likely never recorded. Regardless, under historical sea ice conditions and human population levels in the Arctic, the odds of being killed or injured by a polar bear were low.

Although the risk of a polar bear attacking a person remains low, it does exist, particularly when bears are nutritionally stressed and in poor body condition, which was characteristic of bears involved in the majority of attacks we analyzed. It is reasonable to postulate that polar bears (which are obligate carnivores) in poor body condition represent a greater threat to people than polar bears in above-average body condition. Indeed, those living near polar bears commonly report that bears in poor nutritional body condition are much more dangerous and aggressive than bears in good condition (Voorhees et al. 2014). This is supported by data presented here, which indicates that the body condition of polar bears is a significant factor contributing to their attacking people.

Further, historical conditions are increasingly rare as the availability of sea ice is dramatically and rapidly changing throughout the polar bear range (Stroeve et al. 2014, Stern and Laidre 2016). These changes will likely influence how polar bears interact with people. For example, the greatest number of polar bear attacks occurred in the partial decade of 2010–2014, which was characterized by historically low summer sea ice extent and long ice-free periods (i.e., the period of time when $\geq$15% concentration sea ice is absent; Stroeve et al. 2014) that have been linked to increased land use in a number of subpopulations (Rode et al. 2015*b*, Atwood et al. 2016*b*).

Given projected further declines in summer sea ice extent and lengthening of the open-water period, polar bears will likely become increasingly reliant on land during summer (Atwood et al. 2016*a*). The interplay between the amount of time spent onshore, fat reserves accumulated prior to arrival, and available terrestrial food will determine where over-summering is possible (Douglas and Atwood 2017). The presence of anthropogenic food attractants is likely to draw the increasing number of nutritionally stressed land-based bears into close proximity to human activities, escalating the risk of conflict and the potential for lethal outcomes.

We suggest the range-wide adoption of comprehensive protocols for conflict investigation and that thorough investigations and analyses be completed for all polar bear attacks and aggressive bears that are killed. Furthermore, rigorous analyses of spatio-temporal patterns of human-polar bear interactions are warranted to identify risk factors and geographic hot spots for conflict. For the safety of people and conservation of polar bears, it is essential that managers craft both site-specific and range-wide management strategies through a data-driven assessment of human-polar bear conflicts, and tailor bear safety recommendations to specific user groups throughout the polar bear's range.

To gain a more comprehensive understanding of human-polar bear interactions and place them in proper perspective, it is necessary to also analyze incidents that do not result in human injury or death (Herrero 2002). For example, we do not have records of all the times that bears were successfully deterred, and more importantly, how. This limits our ability to determine what factors can prevent human-polar bear incidents from escalating to more dangerous levels. Where government agencies have the authority (e.g., when issuing permits), they should consider requiring that permittees report the details of all human-polar bear interactions to the appropriate authorities.

To help accomplish these objectives, polar bear managers should continue to populate and refine the PBHIMS with conflict data, and other data of interest. These include observations of natural bear mortalities (e.g., drowning, starvation, cannibalism), taking of alternative prey, and unusual movements, which could all be indicators of local or regional changes in the ecology and the welfare of polar bears (Vongraven et al. 2012). The long-term value of the PBHIMS database is that it standardizes how such observations are recorded, which will be important to estimating whether the rate of occurrence of such events changes over time.

Characteristics of Attacking Bears

Male bears were responsible for the majority of predatory attacks on people, and have been implicated in most serious and aggressive polar bear-human interactions throughout Canada and Norway (Lunn and Stirling 1985, Fleck and Herrero 1988, Stenhouse et al. 1988, Gjertz et al. 1993, Gjertz and Scheie 1998). Rather than being defensive, our data suggest that the intent of a male polar bear during an attack is to kill the person. Our results also indicate that independent immature bears (subadults, 2-year-olds, and yearlings), irrespective of sex, were more prone to be predatory towards humans. Males tend to be more aggressive than females (Tate and Pelton 1983, Ramsay and Stirling 1986, Dyck 2006), and immature bears may be less cautious, more easily habituated to humans, more nutritionally stressed than adults, and more aggressive towards people (Stirling and Latour 1978, McArthur Jope 1983, Dyck 2006, Towns et al. 2009). Furthermore, independent young bears are not yet adept at catching their natural prey (ice seals) and thus more prone to being in below-average body condition than are older, more experienced animals (Lunn and Stirling 1985, Towns et al. 2009). In addition, immature bears, with their smaller absolute fat stores, are likely to be among the first affected by prolonged fasting periods (Cherry et al. 2013, Pilfold et al. 2016). Nutritional stress associated with the lengthening ice-free season has been linked to increases in conflicts involving subadult bears in the western Hudson Bay region (Stirling and Parkinson 2006, Towns et al. 2009).

Fleck and Herrero (1988) reported that, in contrast to male polar bears, females with offspring that attacked people were not exhibiting predatory behavior but rather were defending their cubs. Our results differ in that we found that some attacks by female polar bears with offspring were predatory. However, we do not know of any reports of a female polar bear with cubs killing a person.

Seasonality of Attacks

Historically, polar bear attacks have occurred in every month of the year. Inuit in Northern Hudson Bay and northwest Greenland told early explorers that polar bears were generally very hungry in the spring and there were many instances of them breaking into tents and sometimes killing women or children (Perry 1966). However, our data indicate that since 2000, 88% of polar bear attacks on people have occurred between July and December, which includes the period of time when sea ice is at its minimum extent. Towns et al. (2009) found that the date of sea ice freeze-up was the best predictor explaining the annual occurrence of problem bears, which is cause for concern in light of a lengthening open-water season and the consequent effects on polar bear body condition (Stern and Laidre 2016).

Without the sea ice substrate, prey are largely unavailable to polar bears (Stirling and Derocher 1993, Rode et al. 2015*a*); the result is increased fasting, which leads to declines in body condition and survival (Atkinson and Ramsay 1995, Derocher and Stirling 1995, Cherry et al. 2009, Robbins et al. 2012, Derocher et al. 2013). These adverse consequences become increasingly dire as the ice-free period lengthens beyond 4 months (Molnár et al. 2010, 2014; Robbins et al. 2012; Pilfold et al. 2016). By the end of this century, ice-free conditions in the Arctic are likely to persist for 5 to 11 months out of the year (Amstrup et al. 2008). This is well beyond the point (i.e., 5 to 6 months) at which extended fasting will likely lead to increased starvation in polar bears (Molnár et al. 2010, 2014; Robbins et al. 2012; Pilfold et al. 2016). This, combined with the evidence that bears in below-average body condition are more prone to attack people, should be a serious concern for all who live, work, or recreate in polar bear habitat, as well as for the agencies responsible for managing polar bears.

Bear Behavior

As with black bears (Herrero et al. 2011), our data indicate that polar bears acted as predators in most fatal attacks on people. All humans killed by polar bears had major wounds to their head and neck, similar to the method polar bears use to kill ice seals (Stirling 1974). Predatory behavior typically involves silent stalking, direct approaches with no sign of curiosity or hesitation, followed by a fast head down rush (Fleck and Herrero 1988). Polar bears hunting their normal prey (seals) do not vocalize (Herrero and Fleck 1990); neither did the majority of polar bears that attacked people in our analysis. The lack of any warning noises or other directed, investigatory behaviors by the bears that attacked people suggests that they were hunting (Fleck and Herrero 1988). Lack of warning, however, is not always related to predatory intentions. For example, female polar bears will act aggressively to protect their offspring, particularly during sudden encounters.

The Role of Human Behavior in Attacks

Our findings suggest certain human behavior may influence the potential for negative interactions with polar bears. For example, it is likely important to not act like prey. Data in the PBHIMS includes 3 incidents where bears stalked people with predatory intentions but appeared to realize their mistake at the last minute and emitted a puff of air (Stirling 2011) or a hiss (Stefansson 1923) just before aborting their attack. This suggests that, because the bears were hunting something different than their normal prey, they used their sense of smell to give themselves additional information just before attacking (Stirling 2011). Submissive human behavior can cause an interaction with a cautious, curious bear to escalate into something far more dangerous by encouraging the bear's natural predatory instincts. Conversely, there are several cases where predatory polar bear behavior was effectively deterred by people's aggressive action, such as shouting, throwing hot water or wax in the bear's face, rushing the bear with a vehicle, firing flares, using bear spray, or striking the bear with rocks, fists, or sticks.

Furthermore, humans often exacerbate the potential for negative interactions with polar bears by not properly managing aromatic attractants such as garbage, harvested animals, meat caches, and dog yards. In the absence of attractants, polar bears are generally cautious during initial encounters with people and more susceptible to being scared away (Fleck and Herrero 1988). This may help to explain the low number of attacks at industrial sites, which typically implement strict mitigation policies that address attractant management, building security, and hazing and deterrent actions.

When attractants are present, nutritionally stressed or food-conditioned bears can quickly lose their sense of caution around people (Fleck and Herrero 1988, Herrero 2002). Some of these bears can become quite dangerous, and may view humans as prey. We found that the majority of attacks that occurred in towns involved subadult and yearling bears, were predatory in nature, and most of the bears involved were in below-average body condition, meaning they were hungry and likely motivated to procure food however they could, including by preying on people. We also found that anthropogenic attractants were present at 80% of attacks that occurred in towns. These findings support the idea that the combination of anthropogenic attractants and polar bears in poor body condition increases the risk for negative and potentially lethal interactions.

In over half of the attacks we analyzed, other people who witnessed or were involved in the attack were able to save the victim(s) by driving off or killing the attacking bear. Although we documented the use of firearms to successfully end attacks by polar bears, we also found that in 25% of attacks where a firearm was in possession, victims and bystanders mishandled firearms because of inexperience or the stress of the incident.

Many people do not believe that bear spray is effective against polar bears. However, Fleck and Herrero (1988) suggested that bears that have experienced an unpleasant interaction with people are more likely to avoid them in the future. We have records of 16 incidents in which bear spray was used successfully to deter polar bears, including incidents where other deterrents failed. Although bear spray was not used in any attacks reported here, it was used successfully to stop 3 attempted attacks by polar bears. In 3 other incidents in which bears exhibited persistent aggressive behavior, bear spray successfully altered the bear's behavior after other deterrent efforts failed. Importantly, no humans or bears were killed or injured in the 16 incidents in which bear spray was used to deter polar bears. Other researchers have also found bear spray to be an effective deterrent against other bear species (Herrero and Higgins 1998, Smith et al. 2008). Bear spray is currently illegal in Norway and Greenland, and unavailable, though legal, in much of the Canadian and Russian Arctic.

Difference in Attacks by North American Bear Species

The nature of attacks by polar bears appears to differ from attacks by grizzly and black bears. For example, a substantial proportion of fatal attacks by grizzly bears are defensive and carried out by females with young (Herrero 1970; Herrero and Higgins 1999, 2003). We did not find a single case where a female polar bear with cubs had killed a person. However, in one clearly predatory attack, a female with a yearling attacked and dragged off a worker at an exploration camp in Canada's Norwegian Bay in the dark of the Arctic night. The victim was saved from being killed by a co-worker, who, when alerted, tracked down the bear and drove it off the victim with a front-end loader.

We also documented a substantial proportion of attacks by polar bears in towns, which are relatively rare for grizzly and black bears (Herrero and Higgins 2003), although some exceptions exist, such as Anchorage, Alaska, USA (Coltrane and Sinnott 2015). It is unclear why polar bears may be more likely to attack people in and around human settlements. However, increased nutritional stress experienced by some polar bears may compel them to take greater risks by venturing into settlements to seek food (Towns et al. 2009).

Grizzly bears occasionally attack or even kill people in defense of, or to claim, a carcass (Herrero and Higgins 1999, 2003). In contrast to grizzly bears, we found only one polar bear attack that could be attributed to a polar bear's defense of a carcass; in this case a female with 2-year-old cubs apparently defended fermented walrus (*Odobenus rosmarus*) meat (*igunaq*) at a cache site.

Although polar bears are the apex predator in their environment and therefore seem to have little fear of anything save other bears, as obligate carnivores they must maintain their physical capacity to hunt seals; any serious injury they suffer could prove fatal. Unlike grizzly and black bears, which are able to survive on vegetative diets, polar bears must hunt seals to survive (Rode et al. 2010*b*). As a result, polar bears may be more averse to physical confrontations than grizzly bears, contrary to the common assertion that they are the most aggressive of bears (Miller et al. 2015). This is likely because, throughout their evolution, the presence of other large terrestrial Pleistocene predators (such as short-faced bears [*Arctodus* spp.] and several species of large wolves and cats; Matheus 1995, Leonard et al. 2007) selected for aggression in grizzly bears (Herrero 1972, 2002). Conversely, polar bears evolved to exploit a rich marine niche, largely in the absence of competitive influences from the suite of terrestrial Pleistocene predators that influenced grizzly bear evolution.

Another key difference in the nature of attacks between North American ursids is that, unlike grizzly and black bears, most predatory attacks by polar bears have been committed by independent immature bears (subadults, 2-year-olds, and yearlings; Herrero 2002, Herrero and Higgins 2003). Although most fatal attacks by polar bears were caused by adults, the fact that even independent yearlings have killed people is a striking difference from other North American bear species (Herrero and Higgins 2003, Herrero et al. 2011). However, for polar bears the proportion of fatalities to the total number of injured persons, 24% (20 of 83 people injured by a polar bear died), is relatively low. For comparison, Herrero and Higgins (2003) reported a fatality rate for attacks by black and grizzly bears of 42% and 32%, respectively. Furthermore, contrary to popular opinion we found that the proportion of fatal attacks by polar bears that were predatory (88%) was almost identical to that of black bears (87%; Herrero et al. 2011). In other words, to date polar bears have been no more likely to actively hunt and kill people than black bears.

Similar to findings for grizzly bears and black bears, groups of 1 or 2 people are more likely to be attacked by a polar bear than are larger groups (Herrero 2002, Herrero et al. 2011). Numerically larger parties are probably louder, more intimidating, and better able to fight off a bear attack (Herrero et al. 2011). However, in stark contrast to those species, we also found that in rare cases, polar bears were willing to attack groups of 10 or more people. This difference may be explained by some polar bears' willingness to attack large herds of prey (e.g., walrus; Calvert and Stirling 1990). Finally, contrary to grizzly and black bears, bluff charges directed at people have rarely been observed in polar bears (Fleck and Herrero 1988). A charging polar bear should be interpreted as a bear intent on injuring a person.

MANAGEMENT IMPLICATIONS

Key to minimizing the potential for conflict between humans and polar bears is proactive management of attractants, encounter group size, evaluation of the behavior and body condition of bears encountered, and proper use of deterrent tools and techniques, which collectively can mitigate most human-polar bear conflicts. All group members should be knowledgeable and proficient with the firearms and other deterrent tools carried. In anticipation of continued climate change impacts, we suggest that wildlife managers prepare for more human-polar bear encounters throughout their range. Finally, the Polar Bear Range States would be well served to support applied research into effective polar bear warning and deterrent systems, such as use of biologically relevant perimeter alarm systems (Wooldridge and Belton 1980), electric fences (Wooldridge 1983, McMullen 1999), and bear spray. Our findings underscore the need for managers to implement plans to address the stranding of unprecedented numbers of nutritionally stressed bears on coastlines throughout their range in close proximity to human activities (Peacock et al. 2011, Derocher et al. 2013).

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