2014-03-01

Post-Den Emergence Behavior and Den Detection of Polar Bears (*Ursus maritimus*) in Northern Alaska and the Southern Beaufort Sea

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Post-Den Emergence Behavior and Den Detection of Polar Bears (*Ursus maritimus*)

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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March 2014

ABSTRACT

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Pregnant polar bears *(Ursus maritimus)* construct maternal dens out of snow in the autumn where they give birth to and raise altricial young. In recent years, there has been a decrease in polar sea ice extent and thickness, which has led to changes in denning behavior. One such change in the southern Beaufort Sea (SBS) is that polar bears are selecting maternal den sites on land, rather than on unstable sea ice. This change, coupled with expanding petroleum exploration along Alaska's North Slope, heightens the likelihood of bear-human interactions at maternal den sites. The purpose of this research was to 1) describe polar bears' post-den emergence behavior, establishing a benchmark for comparison to identify behavioral changes associated with climate change and disturbance, and 2) explore factors influencing the efficacy of a currently used den detection method, forward-looking infrared (FLIR). Maternal den sites were observed along Alaska's North Slope from March to April of 2009 and 2010. The mean length of stay at den sites post-emergence was 11.3 ± 7.5 d. The mean date of den emergence was 14 March; abandonment 26 March. Adult females were generally inactive (58.4% out-of-den time) with standing being the most prevalent activity (49.9%). Cubs were generally active (76.7%), playing more than any other activity (45.3%). Bears spent the majority of their time in the den (97.3% for adult females and 99% for cubs) with short bouts of intermittent activity ($\bar{x}$ = 7 min 42 s). We documented the death of one member of a triplet polar bear litter at its den site. All three cubs showed low activity levels relative to other cubs observed, and one died within one week of den emergence. Necropsy confirmed that the dead cub had a low body weight and was malnourished. Capture later confirmed that the two surviving cubs were also undersized. Triplet litters are often smaller and suffer higher mortality rates than singletons and twins. This cub was not only a triplet but also born following 2 y of record minimum sea ice extent, both of which may have played a role in this cub's death. Concurrent with the den emergence portion of this work, we conducted a separate study to identify limitations and optimal conditions for locating dens using FLIR. We took handheld FLIR images of three artificial dens under varied conditions. We tested variables hypothesized to influence detectability with linear models using a zero-inflated negative binomial distribution. Solar radiation, wind speed, and den wall thickness reduced the likelihood of detecting dens. The negative effect of wind speed on detectability increased with increasing distance. To maximize the efficacy of hand-held FLIR, den surveys should be conducted when solar radiation is <16 w/m^2 (night) and when wind speed is <10 km/h (6 mph). Adherence to these guidelines will maximize the protection FLIR can afford to denning bears.

Keywords: Alaska, Beaufort Sea, climate change, cub mortality, FLIR, maternity den, North Slope, polar bear, *Ursus maritimus*

ACKNOWLEDGEMENTS

I would like to first thank my advisor, Dr. Tom Smith for his patience, guidance, friendship, and wisdom. His foresight and wealth of experience have taught me valuable life lessons I will always carry with me. Dr. Steve Petersen and Dr. Kevin Bunnell have been wonderful committee members, always providing support and sound advice. Robert and Carolyn Buchanan as well as the entire Polar Bears International family have become dear friends and supporters, and I sincerely appreciate their generosity of time and resources. BJ Kirschhoffer and Jay Olson made the arctic winters and long days enjoyable, and I appreciate their friendship. Thanks to Randy Larsen for helping me understand statistics and statistical software. I thank S. C. Amstrup for invaluable assistance in writing documents as well as A. Derocher, T. DeBruyn, A. Fischbach, and K. Rode for their initial reviews. I thank W. J. Streever, D. Sanzone, and Tatyana Venegas of BP for their support and assistance. N. Hermon of Alaska Clean Seas and K. Thomas-Ford and D. Heebner of BP Environmental provided valuable assistance at the BP Milne Point facility. W. Dawley, B. Collver, and T. Cummings were helpful at the BP PBOC facility. I also thank B. Cardon, R. Minatra, J. Allen, D. Kruger, J. Michaels, and Fire Chiefs Ski and Vic, plus a number of mechanics and other personnel at both the PBOC and Milne facilities for their support and assistance in keeping our project on track and gear operational. Thanks to Michael Lilly and David Shahon who donated their time and expertise to the project. Tom Smith, Randy Larsen, BJ Kirschhoffer, and Cheryl Rosa are co-authors on one or more manuscripts, and their hard work is much appreciated. Funding for this work was provided, in part by Brigham Young University, the U.S. Fish and Wildlife Service, the National Fish and Wildlife Foundation, the U.S. Geological Survey, British Petroleum, the Columbus Zoo, and Polar Bears International.

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Chapter 1

Post-Den Emergence Behavior of

Polar Bears in Northern Alaska

Abstract

In recent years, there has been a decrease in polar sea ice extent and thickness, which will lead to changes in polar bear behavior, particularly denning behavior. One such change already apparent in the southern Beaufort Sea (SBS) is that polar bears are increasingly selecting maternal den sites on land, rather than on unstable sea ice. This shift, coupled with expanding petroleum exploration along Alaska's North Slope heightens the likelihood of bear-human interactions, especially at maternal den sites. The purpose of this study was to describe polar bears' post-den emergence behavior, establishing a standard for comparison with which to identify disturbance events and long-term changes in denning behavior associated with climate change. Maternal den sites were observed along Alaska's North Slope from March to April of 2009 and 2010. Six adult females and 12 cubs were observed at 6 den sites. The mean length of stay at den sites post-emergence was 11.3 ± 7.5 d. The mean date of den emergence was 14 March; abandonment 26 March. Adult females were generally inactive (58.4% out-of-den time), with standing being the most prevalent activity (49.9%). Cubs were generally active (76.7%), playing more than any other activity (45.3%). Bears spent the majority of their time in the den (97.3% for adult females and 99% for cubs), with short bouts of intermittent activity ($\bar{x}$ = 7 min 42 s). Potential disturbance avoidance options, other than total cessation of industrial activity, exist. Future research should test these options and attempt to identify changes in denning behaviors resulting from climate change and their potential long-term effects on the SBS polar bear population.

Introduction

In recent years, there has been a dramatic decrease in polar sea ice extent and thickness (Comiso et al. 2008) which will lead to shifts in trophic interactions involving polar bears through reduced availability and abundance of their main prey: seals. Consequently, polar bear populations are likely to exhibit changes in patterns of activity and behavior (Derocher et al. 2004). One such change that is already apparent in the southern Beaufort Sea (SBS) area is that polar bears are selecting maternal den sites on land, rather than denning on unstable sea ice (Amstrup and Gardner 1994, Fischbach et al. 2007). This shift to terrestrial denning, coupled with expanding petroleum exploration along Alaska's North Slope, heightens the likelihood of bear-human interactions, particularly at maternal den sites.

Den site disturbance can result in displacement, exposure to the elements and subsequent death, predation, family dissolution and cub abandonment (Amstrup 1993, Amstrup and Gardner 1994, Linnell et al. 2000, Smith et al. 2007), and may have greater negative effects on survival and reproduction than at any other time of year (Linnell et al. 2000). Consequently, conservative regulatory measures have been placed on industry (i.e cessation of all activity within a 1.6 km buffer around known polar bear dens), violations of which could result in fines and costly delays in production. However, without baseline knowledge of the activity patterns of polar bears at maternal den sites, it is impossible to determine when activity patterns have been altered in response to human activity, or to tell if an activity has been disruptive. Furthermore, behavioral data will enable the identification of subtle changes in denning behavior associated with climate change.

The purpose of this study is to 1) document the timing of den breakout and abandonment, 2) identify temporal activity patterns of polar bears at maternal den sites, and 3) estimate the activity budgets of polar bears at den sites. By doing this we hope to establish a behavioral standard for comparison in order to identify abnormal, disturbed, or changing polar bear behaviors.

Study Area

We conducted this research along the coastal plain of northern Alaska (North Slope), with the main area of focus extending from Milne Point (70.51°N, 149.46°W) eastward to the mouth of the Shaviovik River (70.19°N, 147.30°W; Figure 1.1). In the southern Beaufort Sea, terrestrial polar bear dens occur primarily along the cut banks of barrier islands and the nearby coastal plain, although some bears have been documented denning as far inland as 50 km (Durner et al. 2003). This region lacks the steep topography associated with polar bear denning sites on Wrangel Island, Russia (Uspenski and Kistchinski 1972), Herald Island, Russia (Ovsyanikov 1998), and Svalbard, Norway (Larsen 1985). Consequently, dens are restricted to coastal islands, riverbank bluffs, and landforms capable of holding sufficient snow for den construction (Durner et al. 2003).

Methods

Detection of Den Site Locations

For the purposes of this study we define "den site" as the den cavity, entrance, and area immediately surrounding the entrance (≤ 50 m). Prior to den breakout in late February-March, den sites may be indistinguishable from the surrounding terrain. Although Durner et al.'s (2006) polar bear den habitat selection model significantly delimits the search area, locating dens prior to breakout is challenging. We relied on three methods to locate dens for observation: 1) radio-telemetry, 2) aircraft-based forward-looking infrared (FLIR) imagery (FLIR Systems, Boston, MA), and 3) hand-held FLIR.

Locating Dens with Radio-Telemetry

Scientists from the United States Geological Survey (USGS) Alaska Science Center in Anchorage, Alaska have radio-tagged polar bears in the Southern Beaufort Sea population since the early 1980s. To locate radio-tagged bears we used a conventional VHF radio-telemetry receiver and directional Yagi antenna to triangulate precise locations of den locations for camera unit positioning. Occasionally a small mound of snow (termed pushup) coincided with the den entrance tunnel and assisted us with camera placement.

Locating Dens with FLIR

FLIR cameras detect slight temperature changes and depict them visually as differing shades of gray, or colors. Hence, when using a gray scale palette with the FLIR imager, polar bear dens appear in lighter shades of gray than the surrounding snow drifts (darker, colder) in which they exist (Amstrup et al. 2004, York et al. 2004). We used a DeHavilland DHC-6 (Twin Otter) belonging to Shared Services (aircraft operations jointly funded by North Slope oil companies British Petroleum and Conoco-Phillips) equipped with an on-board FLIR unit to survey denning habitat and locate potential polar bear dens. We then used a FLIR ThermaCAM P65 HS (FLIR Systems 2004) hand-held unit from the ground to confirm the likelihood of potential dens.

Polar Bear Den Observation and Analysis

Once polar bear dens were located, we used Sanyo® VCC-HD4000 high definition security cameras with 500 GB hard drives to record bear activity at den sites (Figure 1.2). These programmable cameras were set to record continuously from dawn to dusk to conserve battery power and hard drive space. Cameras were housed in heavily insulated coolers containing two 100 aH, 12V gel cell batteries recharged by windmills in 2009 and solar panels in 2010. These batteries provided power for the video camera system and a 5-watt resistor which heated the enclosure to maintain an operating environment of approximately 20°C. We visited each camera weekly to check enclosure temperature and system operational status. Each visit required about 10 min and was accessed by snow machines. Camera units were positioned approximately 125 m from putative den entrances.

Each frame of video has an associated date/time stamp so that the precise timing of bear activity is possible. Using this approach, polar bear activity was continuously sampled (Lehner 1996). Following the field portion of research, video footage sequences were reviewed, and bear activity was encoded into The Observer software (Version 3.0, Noldus Information Systems, 2003). Activity states, events, and the modifiers used to describe polar bear behavior were consistent with definitions used by previous workers (Hansson and Thomassen 1983, Larsen 1985, Ovsyanikov 1998, Smith et al. 2007). The portion of a polar bear's activity budget spent in any particular behavior (e.g., walking, resting, etc.) was totaled and calculated for percentage of total time outside as well as total observation time (total filming time between den breakout and abandonment, excludes hours of darkness or when camera systems were malfunctioning or otherwise not recording). Activities were also categorized as either active (ingesting, vocalizing, nursing, walking, digging, playing, rolling, and running) or inactive (standing, sitting, resting, and carried by mother). Statistical significance was set at $\alpha = 0.05$.

For the purposes of this study the term "den breakout" refers to the first time bears fully emerged from dens, a definition that excludes nose and head pokes from being classified as den breakout events. Occasional nose and head pokes may reopen the entrance tunnel to recharge the chamber with fresh air, or perhaps allow the mother to sample weather conditions.

Results

In 2009 and 2010, six dens were active for a mean length of 11.3 ± 7.5 d (Table 1.1). All bears were outside dens a combined total of 21 h 23 min (cubs were always accompanied by their mothers). Adult female polar bears were outside dens a total of 12 h 46 min (2.7% of post-emergence observation time), and cubs accompanied by mothers were observed outside dens for a total of 8 h 37 min (1.0% of total post-emergence observation time).

Timing of Denning Events

The mean date of den emergence for all bears studied was 14 March. The mean date of den abandonment was 26 March (Table 1.1, Figure 1.3). Polar bear families remained at den sites from 3-23 d following initial emergence, or breakout, from their dens.

Temporal Activity Patterns

Following den breakout, family groups remained largely in the den (adult females = 97.3%; cubs = 99.0%; Table 1.2). Adult females typically exhibited long periods of inactivity (i.e., not exiting the den; $\bar{x} = 1.9$ d), followed by bouts of activity, during which they would exit and enter the den one to several times. During these activity sequences, the mean length of stay in dens for adult females between emergent, active periods was 1.14 h ($n = 76$) and was significantly longer than the mean time spent outside dens, 0.13 h ($n = 101$, $p < 0.001$). The mean length of stay in dens for cubs between emergent, active periods was 1.31 h ($n = 25$), and was significantly longer than the mean time spent outside dens, 0.21 h ($n = 46$, $p < 0.01$). Adult females and cubs exhibited different patterns of activity with regard to the frequency and order of appearance when exiting dens. We observed adult females exiting dens a total of 101 times, 2.2 times more often than cubs (46 times).

Activity Budgets

Standing was the most prevalent adult female activity (49.9%), followed by rolling in the snow (17.7%), walking (13.6%), sitting (5.5%), nursing (4.8%), resting (3.0%), ingesting (2.6%), digging in the snow (1.9%), running (0.9%), playing (0.1%), and vocalizing (<0.1%), (Table 1.2). Due to the camera's fixed field of view, 39.8% of the time adult females were outside the den, they were unobservable, having wandered out of view. Of the time bears were within the field of view, adult female polar bears were active 41.6% of time (inactive 58.4%). Cubs were engaged in playing more than any other activity (45.3%), followed by nursing (16.4%), walking (13.1%), sitting (12.0%), standing (9.8%), running (1.5%), resting (0.5%), and rolling in the snow (0.4%; Table 1.2). Cubs were not observed ingesting, digging, or vocalizing. Cubs were rarely observed being carried by their mother (1.0%). Cubs were active 76.7% of the observable time while out of the den (inactive 23.3%). Cubs were unobservable 43.4% of the time while out of den due to having moved out of the camera's view, or by being obscured by the mother.

Prior to exiting the den, bears often poked their noses and heads out, presumably sampling the weather and surroundings. Bears were rarely active during the twilight. Of the 101 instances adult bears were observed out of den, bears were active in low light conditions (civil twilight) on only four occasions, three of which were in the morning. Hours of darkness were not filmed or not visible for analysis.

Discussion

As the arctic climate continues to change, a cascade of impacts will likely be manifested in several changes of polar bear denning behavior. In the SBS, polar bears show fidelity to denning areas mostly on land and barrier islands a short distance from the coast (Smith et al. 2007). Reaching these denning areas requires that sea ice freeze early enough in the fall for pregnant polar bears to travel to denning areas in time to excavate a den (October-December) prior to parturition (January). Likewise, polar bear maternal groups are dependent on ice to travel to hunting areas in the spring. Sea ice freezing later in the fall and thawing earlier in the spring will likely shorten the denning and post-den emergence periods and possibly cause bears to abandon dens in the spring before cubs have developed the necessary motor skills and body size to survive. Higher cub mortality rates would result (Derocher et al. 2004). Furthermore, the apparent shift to terrestrial denning reported by Amstrup and Gardner (1994) and Fischbach et al. (2007) increases the likelihood of bear-human interactions at the den site. This study provides greater understanding of current post den emergence behavior of polar bears, and will therefore assist in identifying future changes in denning and post den emergence behavior that may result as the arctic climate warms. Furthermore, it provides industry and management a baseline for comparison to identify den site disturbance and abnormal bear behavior.

Polar bears at maternal den sites exit the den infrequently and for relatively short periods of time ($\bar{x}$ = 7 min 42 s), and total time spent at the den between breakout and abandonment is generally less than two weeks. Consequently, we feel mitigation measures could be taken to avoid disturbance without a total cessation of industrial activity. For example, bear activity at the den site could be monitored, thus allowing some activity to occur (e.g. road traffic at a reasonable distance) while bears are in the den. As bears emerge, activity could be stopped temporarily until bears re-enter the den. Furthermore, our data show that out-of-den activity is very rare in twilight hours, and while we were unable to capture footage at night, we feel that bears do not emerge from the den during hours of darkness. N. Ovsyanikov (pers. communication) stated that in many years of observing denned polar bears on Herald Island, Russia, he had never observed nighttime activity. Therefore, conducting operations at night could be another mitigation measure to minimize potential and prevent costly delays for industry. Future research should focus on the efficacy of avoidance measures, as well as denning behavior. Doing so will provide protection for polar bears at maternal den sites and document future changes in denning activity for the SBS polar bear population.

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Table 1.1. Location, dates, and observational data for 6 polar bear maternal den sites observed in Mar/Apr (2009-2010), Northern Alaska.

Year	Location	Den Breakout	Den Abandonment	Number of Days at Den[a]	Number of Cubs at Den	Adult Total Time Out of Den (h)	Cub Total Time Out of Den (h)[b]	Number of Adult Observation Sessions	Number of Cub Observation Sessions[c]
2009	Bodfish	3/14	4/6	23	1	0.11	0.02	5	1
2009	Badami Ice Road	3/28	4/1	4	2	1.16	0.92	14	12
2009	Pingok	3/10	3/20	10	3	4.57	1.63	57	6
2009	Sag River	3/10	3/22	12	1	6.38	5.98	13	22
2009	South Foggy	3/14	3/30	16	2	0.39	0	10	0
2010	Howe Island	3/9	3/12	3	3	0.15	0.07	2	5
	Totals			68	12	12.76	8.62	101	46
	Average	3/14	3/26	11	2	2.13	0.72	16.8	7.7

[a] Number of days bears were at den site from breakout to abandonment
[b] When there is more than one cub at a den, the total time out of den for all cubs is shown
[c] When there is more than one cub at a den, the total number of observation sessions for all cubs is shown

Table 1.2. Activity budgets of adult female polar bears and dependent cubs at den sites in March/April 2009-2010, Northern Alaska.

	Total Observation Hours		Percent Total Observation Time		Percent Time Outside		Percent Time Outside Excluding Unobservable	
Activity	Females	Cubs	Females	Cubs	Females	Cubs	Females	Cubs
In den	455.5	822.6	97.3	99				
Active[a]	3.2	3.7	0.7	0.4	25	43.4	41.6	76.7
Inactive[b]	4.5	1.1	1	0.1	35.1	13.2	58.4	23.3
Standing	3.8	0.5	0.8	0.1	30	5.5	49.9	9.8
Sitting	0.4	0.6	0.1	0.1	3.3	6.8	5.5	12
Resting	0.2	<0.1	<0.1	<0.1	1.8	0.3	3	0.5
Carried by Mother	NA	0.1	NA	<0.1	NA	0.6	NA	1
Ingesting	0.2	0	0.4	0	1.6	0	2.6	0
Vocalization	<0.1	0	<0.1	0	<0.1	0	<0.1	0
Nursing	0.4	0.8	0.1	0.1	2.9	9.3	4.8	16.4
Walking	1	0.6	0.2	0.1	8.2	7.4	13.6	13.1
Digging	0.1	0	<0.1	0	1.2	0	1.9	0
Playing	<0.1	2.2	<0.1	0.3	<0.1	25.6	0.1	45.3
Rolling	1.4	<0.1	0.3	<0.1	10.6	0.2	17.7	0.4
Running	0.1	0.1	<0.1	<0.1	0.5	0.9	0.9	1.5
Unobservable	5.1	3.7	1.1	0.4	39.8	43.4		
Totals	468.3	831.2	100	100	100	100	100	100

[a]Active includes Ingesting, vocalizing, nursing, walking, digging, playing, rolling, and running.
[b]Inactive includes standing, sitting, resting, and carried by mother.

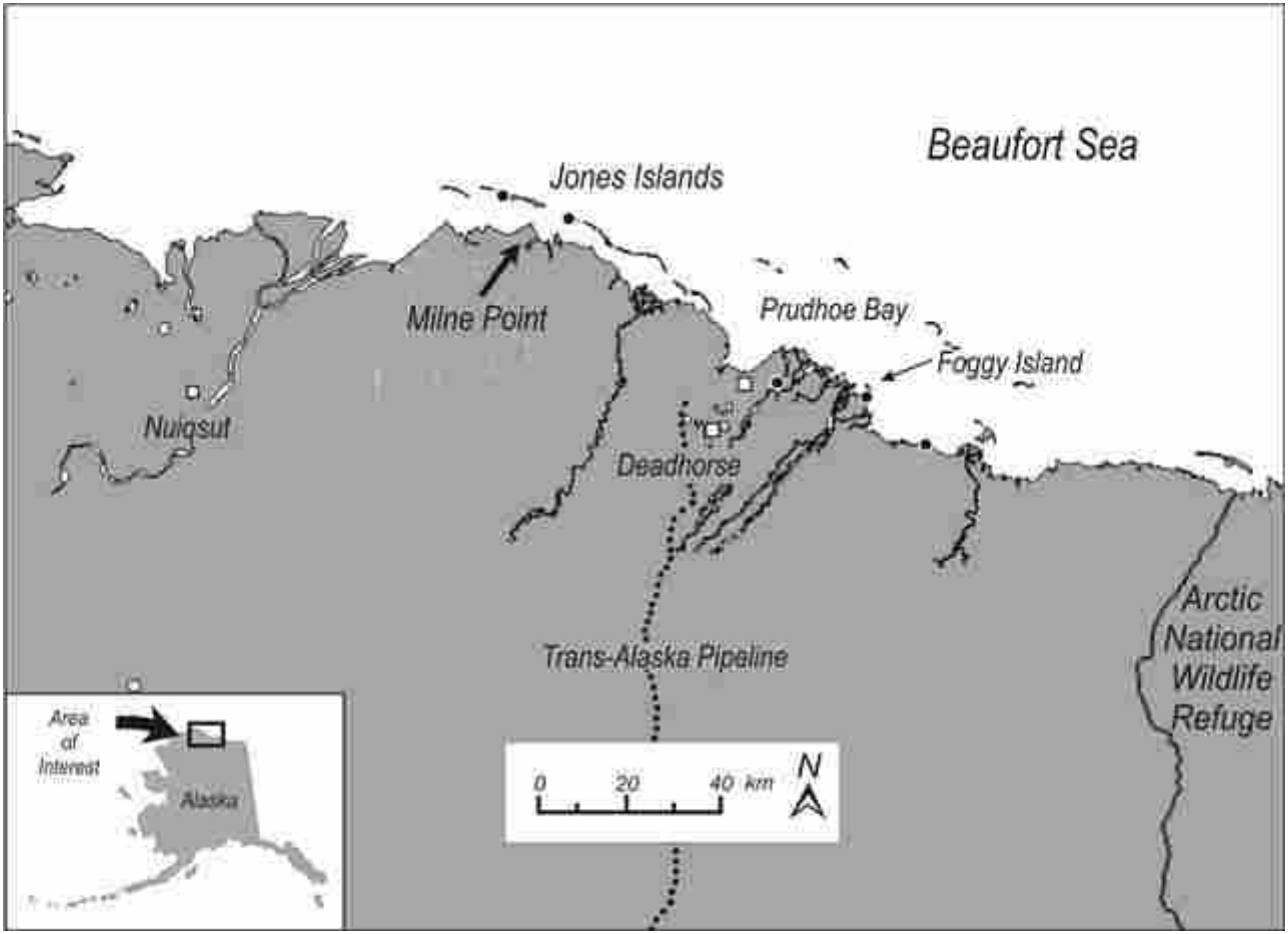

Figure 1.1. Maternal den study area, March/April (2009-2010), North Slope, Alaska.

Figure 1.2. Camera system used for recording polar bear activity at den sites, March/April (2009-2010), North Slope, Alaska.

Chapter 2

Polar Bear (*Ursus maritimus*) Cub Mortality at a Den Site in Northern Alaska

Abstract

In March 2009, we documented the death of one member of a triplet polar bear (*Ursus maritimus*) litter at its den site in the southern Beaufort Sea (SBS) of Alaska. We used a self-contained video camera unit to document activity between den emergence and departure. All three cubs showed low activity levels relative to other cubs observed, and one died within one week of den emergence. Necropsy confirmed that the dead cub had a low body weight and was malnourished. Capture later confirmed that the two surviving cubs were also undersized. Polar bear cub survival is influenced by many factors including litter size and sea ice conditions. Triplet litters are often smaller and suffer higher mortality rates than singletons and twins. This cub was not only a triplet but also born following 2 y of record minimum sea ice extent, both of which may have played a role in this cub's death.

Introduction

Reported rates of polar bear cub-of-the year mortality range from approximately 20—60 percent (Stirling 1988; Amstrup and Durner 1995). Most cub deaths are unobserved in the wild and are of unknown cause. Reported causes of mortality in polar bear cubs include disease, starvation, intra/interspecific predation, and accidents (Amstrup et al. 2006; Clarkson and Irish 1991; Blix and Lentfer 1979; Kenny and Bickel 2005; Richardson and Andriashek 2006). Natural cub mortalities at or near the den site (<10km) have rarely been observed; we are aware of only one other instance (A. Derocher, University of Alberta, personal communication), and it involved a member of a triplet litter. Here, we report the death of a polar bear cub in another triplet litter.

Triplet litters are uncommon in polar bears (Uspenski and Kistchinski 1972; Taylor et al. 1987). Although triplets formerly comprised approximately 10% of litters in the Western Hudson Bay (WHB) population (Ramsay and Stirling 1982), they are less commonly observed today (I. Stirling, Canadian Wildlife Service, personal communication). In arctic populations such as the SBS, triplets comprise only 1-3% of all litters (Stirling 1988).

Often in triplet litters there are two normal sized cubs and a “runt”. In the WHB the mean mass of spring cubs (late February to late March) in triplet litters varied from 11.9 ± 0.4 kg for the largest cub, to 9.0 ± 0.4 kg for the middle cub, down to 5.6 ± 0.2 kg for the smallest (Derocher and Stirling 1998). When triplets were observed during the spring in Ontario, one cub was noticeably smaller and frequently trailed the group (Kolenosky and Prevett 1983). Triplet data in the SBS are limited but two triplet litters have been captured by the US Geological Survey (USGS) and were similar in weights to those of the WHB. One SBS triplet litter captured on 11 April 2005 had cubs weighing 5.0, 9.0, and 9.7 kg and another on 1 April 1992 produced weights of 5.0, 9.0, and 10.0 kg (USGS, unpublished data). Furthermore, the mean mass of individual cubs in spring is greatest for singletons and least for triplets (Ramsay and Stirling 1986). Derocher and Stirling (1996) reported similar weights in twin and triplet litters but noted that cub survival in triplet litters varied according to cub size, larger cubs out-surviving those smaller. Reporting mortality events is important, particularly given the heightened concern for polar bears in the face of a changing climate (Amstrup et al. 2008).

Methods

From 5 March to 7 April 2009 we conducted a polar bear den emergence study in the SBS using self-contained digital camera systems which were serviced on a weekly basis (Smith et al. 2007). On 17 March we performed routine camera maintenance at a den site located on the south shore of Pingok Island, northwest of Prudhoe Bay, AK (Figure 2.1). While scanning the den site with binoculars from 140 m, we observed a polar bear cub lying motionless near the entrance (~11 m). There was no sign of predation or scavenging, but the cub could not be retrieved until the radio-collared adult female abandoned the site. On 25 March, after telemetry confirmed the maternal group had left, we approached the den and noted the dead cub lying somewhat closer to the entrance than when first observed. We photographed the cub and measured the location of its carcass as well as its initial location in relation to the den entrance (Figure 2.2). The cub was placed in a plastic bag and kept frozen until a necropsy was performed.

Standard necropsy procedures were followed to determine cause of death. Body measurements and photographs were taken. The esophagus was tied off at the level of the lower esophageal sphincter and the colon at the level of the rectum, and the gastrointestinal tract was removed and sampled. The liver was sampled, along with spleen, kidney, adrenals, and tissues from the urogenital tract. Muscle tissue was sampled from the latissimus dorsi. The pelt and the skull were returned to US Fish and Wildlife Service as requested (no brain tissues were taken).

Histopathological analysis of a suite of representative tissues was conducted by both a wildlife pathologist and a wildlife veterinarian.

On 27 April the mother of the litter was captured by injecting Telazol® with projectile syringe fired from a helicopter (Stirling et al. 1989). The two surviving cubs were manually restrained until they could be injected by hand. Once immobilized, standard weights, measures, and condition assessments were recorded for all three bears (Rode et al. 2010).

Results

Video footage revealed that the adult female first emerged alone from her den on 10 March. Following emergence on 14 March, she reached back into the den and carried each cub out by the scruff of the neck. These cubs appeared undersized and exhibited little movement, unlike cubs at other dens we have observed (n = 25 dens). The adult carried each cub approximately 10 m from the den entrance. Then, after several min, she carried each back to the den and placed it inside. Although the adult was observed making many out-of-den appearances without her cubs, this 14 March observation was only one of three instances in which one or more live cubs was observed out of the den.

On 17 March we observed one cub lying motionless near the den entrance and presumed it dead. We returned to the site on 18 March to perform camera maintenance and noticed that the cub was no longer visible. Because the camera had malfunctioned from 17 March to 18 March we had no video record of what had happened to the cub. However, shortly after the camera resumed operation on 18 March, it recorded the adult polar bear emerging from the den with the dead cub in her teeth and placing it on the ground adjacent to the den opening. The adult female left the den on 22 March with the two surviving cubs and headed north. When we returned to the site on 25 March to recover camera gear, we saw the dead cub lying on its side with legs outstretched, 2.3 m from the den entrance. Gross necropsy and histopathological analysis indicated that the cub was normal, other than a low body weight (3.9 kg), and that it died of malnourishment. There was no indication of recent feeding activity (empty stomach/gastrointestinal tract) at time of death.

The USGS polar bear research crew recaptured the 10-year-old adult female and two surviving cubs on 27 April. The adult weighed 179.0 kg, normal for recent female weights (2001-2009) with cubs-of-the-year in late April ($\bar{x}$ =168.5 kg ± 18.5 kg, n = 20; USGS unpublished data). The male cub weighed 10.9 kg and the female 8.6 kg. The adult was originally captured as a cub on 26 April 1999. She was recaptured as a 197.0 kg adult traveling with a courting male in April 2006, at which time she was fitted with a radio collar. That fall she denned on Pingok Island. She was not recaptured the following year, but her reproductive attempt was apparently unsuccessful because she was recaptured again on 28 April 2008 traveling without cubs and accompanied by a courting male. At that time she weighed 208 kg. She denned on Pingok Island 2008, the location at which we made these observations the following March. This family group was observed on 15 May and again on 14 October 2009. On 31 October the adult female was observed again, this time with only one cub.

Discussion

All three cubs in this litter exhibited signs of underdevelopment relative to other cubs we have observed. Following den breakout, cubs spend the majority of their time in active behaviors including walking, digging, playing, rolling, and running (86.6%; Smith et al. 2013). The cubs in this litter were active only 17.2 % of the time, or one-fifth that of normal cubs. Carrying cubs by the nape of the neck suggests that they were in a weakened state (Alt 1984; Erickson and

Martin 1960). Furthermore, based on cub weights of those captured in the SBS during this same time period (27 April ±3 d; $\bar{x}$ =14.0 kg ± 3.9 kg, n = 103; S. Amstrup, USGS, unpublished data), both surviving cubs were small.

This litter's low weight and subsequent mortality may be attributable to a number of factors, including late implantation and the subsequent delayed birth, or to a lack of maternal resources to provide for three cubs. The previous summer's minimal sea ice extent may have been a contributing factor as it has been shown to influence both cub size and survival (Rode et al. 2010). Due to the remote location of this den, it is unlikely that disturbance from industrial or seismic activities played a role in this death. The absence of food in the cub's stomach during necropsy suggests that the cub died due to a lack of access to maternal resources.

Lactation places high energetic demands on females (Gittleman and Thompson 1988; Ramsay and Dunbrack 1986). Singleton cubs can be as much as 30% larger than cubs in twin litters (Ramsay and Stirling 1988), presumably because single cubs, unlike those in larger litters, have exclusive access to their mother's milk. Because the surviving cubs were unusually small a month after den departure we suspect that the mother did not have adequate resources to successfully rear three cubs. Even though we do not know exactly why this cub died, we feel it is important to document events such as these in order to better understand keys to polar bear survival in a changing climate.

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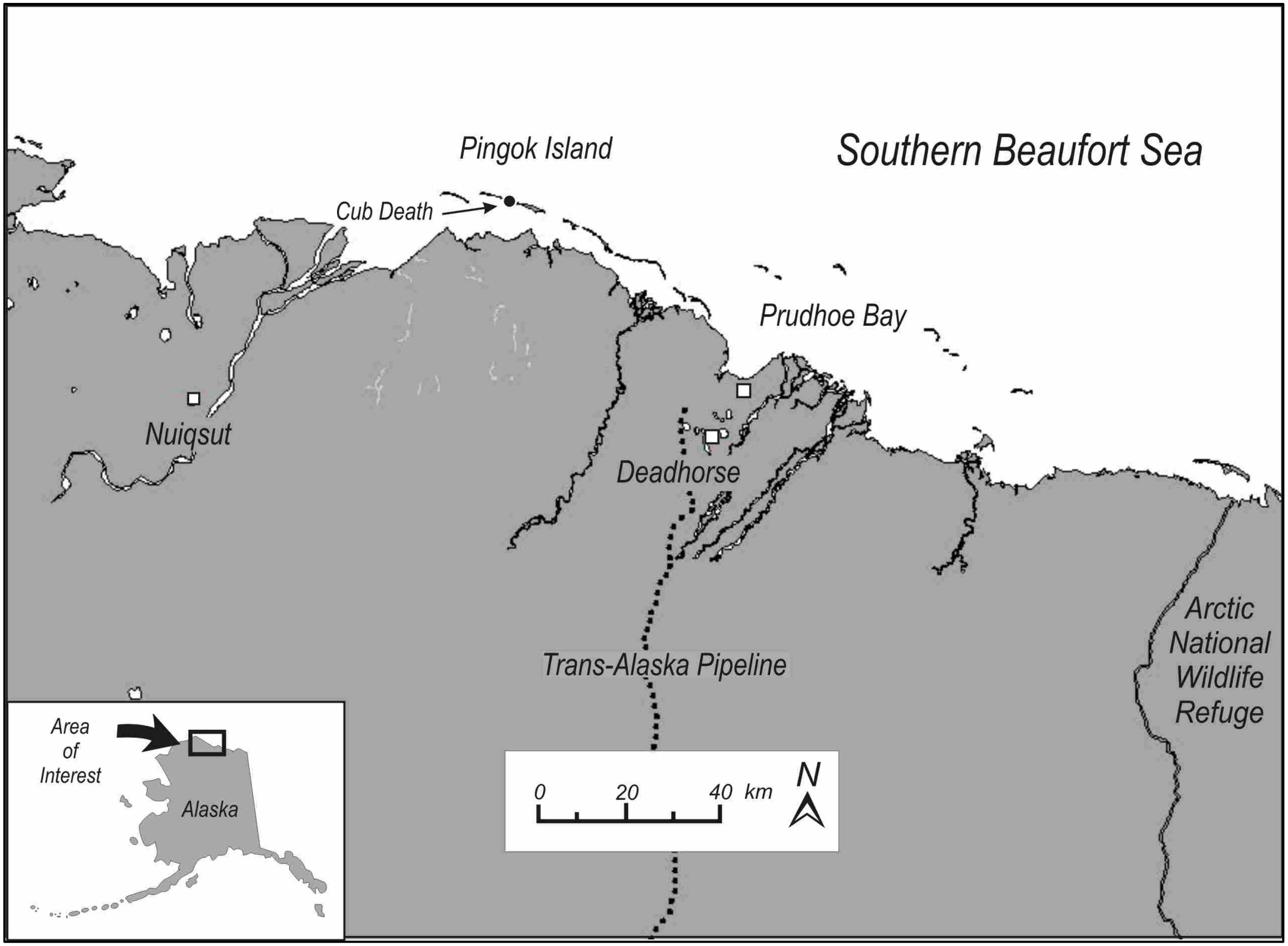

Figure 2.1. Location of dead polar bear cub, March 2009, Pingok Island, Alaska.

Figure 2.2. Dead polar bear cub found at den site, March 2009, Pingok Island, Alaska.

Chapter 3

Factors Influencing the Efficacy of Hand-Held Forward-Looking Infrared in Polar Bear Den Detection

Abstract

Female polar bears construct maternal dens in snowdrifts in autumn. Forward-looking infrared (FLIR) has been used to locate dens to prevent disruption of denning by human activities, but with mixed results. To identify limitations and optimal conditions for locating dens, we took handheld FLIR images of three artificial dens under varied conditions. We tested variables hypothesized to influence detectability with linear models using the zero-inflated negative binomial distribution. Solar radiation, wind speed, and den wall thickness reduced the likelihood of detecting dens. The negative effect of wind speed on detectability increased with increasing distance. To maximize the efficacy of ground-based FLIR, den surveys should be conducted when solar radiation is <16 w/m^2 (night) and when wind speed is <10 km/h (6 mph). Adherence to these guidelines will maximize the protection FLIR can afford to denning bears.

Introduction

Pregnant polar bears in the southern Beaufort Sea and adjoining coastal areas excavate dens in October through December (USGS, Alaska Science Center, unpublished data). Cubs are born in mid-winter and remain at the den until leaving in March-April (Blix and Lentfer 1979, Amstrup 1993, Amstrup and Gardner 1994, Smith et al. 2007). Disturbance at den sites may have greater negative effects on survival and reproduction than at any other time of year (Linnell et al. 2000). Disturbance may result in displacement, exposure to the elements and predation, family dissolution, cub abandonment and subsequent death. Consequently, the ability to identify den sites is key to limiting negative influences from disturbance.

Expanding petroleum exploration along Alaska's North Slope area, coupled with a shift to terrestrial dens (Amstrup and Gardner 1994, Fischbach et al. 2007), heightens the likelihood of bear-human interactions. Furthermore, industry can be required to limit or cease activities in the vicinity of known dens or fined as a result of den disturbance by the US Fish and Wildlife Service, the regulatory agency tasked with managing polar bears. Consequently, much work has been done to identify and map suitable denning habitat in order to avoid potential conflicts with, and mitigate disturbance of, polar bears (Amstrup 1993, Durner et al. 2001, Durner et al. 2003, Blank 2012,). Denning habitat occurs in areas such as riverbanks and coastal bluffs, where drifting snow accumulates (Amstrup 1993, Amstrup and Gardner 1994, Durner et al. 2001, Durner et al. 2003). Forward-looking Infrared (FLIR) has been used to survey denning habitat and locate dens prior to constructing ice roads and other production efforts (Amstrup et al. 2004).

FLIR imagers can be mounted on vehicles (e.g., aircraft, trucks, or track vehicles), or can be handheld; these platforms have proven to be useful for identifying and locating polar bear dens. FLIR imagers are capable of detecting the very slight temperature differences (changes as small as 0.01° C) on the surface of a snow bank resulting from denned polar bears (Amstrup et al. 2004). Temperature differences are shown in the imager's display as varying shades of color, with lighter colors representing warmer temperatures. In the FLIR imager, polar bear dens generally appear as light-colored "hot spots" with soft edges that gradate into the surrounding darker, colder terrain (see Figure 2 in Amstrup et al. 2004). To optimize den detectability with hand-held FLIR, it is important to identify factors that influence the image quality. Although atmospheric conditions (i.e., relative humidity, temperature, dew point, precipitation, and wind) have been known to influence the effectiveness of aerial FLIR when used for den detection, critical thresholds for detection were not identified (Amstrup et al. 2004). The purpose of this study was to model variables that influence the ability of hand-held FLIR to detect dens and identify optimal conditions for conducting polar bear den surveys with hand-held FLIR.

Study Area

The study area was located west of Prudhoe Bay, Alaska in the Prudhoe Bay oil field. This area is comprised largely of BP (British Petroleum) lease lands that have been developed for oil exploration and production, including scattered gravel pads and industrial facilities linked by 4800 km of pipeline and roads. Our study took place approximately 1.6 km south of the BP Milne Point processing facility (70. 4587°N 149.4414°W; Figure 3.1). For the construction of artificial dens for this study, we selected a snowdrift approximately 60 m long and 4 m high. Artificial dens were excavated ~20 m from an unheated power source which provided electricity for den heaters.

Methods

Sampling

In February 2010, we excavated three artificial polar bear dens with initial snow wall thicknesses of 25, 50, and 75 cm in a south-facing snowdrift. To construct these dens, we excavated from the top of the drift down 2 m using snow shovels and snow saws. Initial dimensions of each den were approximately 1 x 1 x 2 m (Figure 2). Dens were excavated 3 m apart (from edge to edge). We placed a 200-watt, ceramic heater in each den, simulating the heat generated by a denning polar bear (Watts 1983). We used measuring sticks to monitor changes in den wall thickness throughout the sampling period as snow depth changed due to wind and snowfall. Each measuring stick had a stopper on the end inside the den that we pulled tight against the inner wall after the dens had melted to a stable size and before any sampling began. For the duration of the study, den chamber access shafts were sealed with plywood lids over which snow was back-filled for insulation. After turning heaters on, we allowed den temperatures to stabilize for two weeks (a conservative time frame based on previous trials we performed) prior to sampling. We began sampling den heat loss with FLIR on 11 March 2010. After the study was concluded we opened the dens and ensured that the stoppers were still against the inner wall and that wall thickness measurements were accurate.

Using a FLIR ThermaCAM™ P65HS thermal imager (FLIR Systems, Boston, MA) with a 72 mm IR lens, we sampled one or more times daily (mean = 3). Sampling was scheduled at stratified intervals with consideration of solar time, the time relative to the sun's positioning in the sky; thus accounting for variation in solar radiation (Figure 3). During each sample period we recorded images from 3 distances: 60 m, the minimum distance the US Fish and Wildlife Service allows handheld FLIR surveys for polar bear dens to take place (USFWS 2013), 100 m, and 200

m. A laser rangefinder was used to determine distance. To ensure accurate thermal readings, we entered required parameters into the imager settings, including air temperature, relative humidity, distance, emissivity, and reflected temperature, before each sampling period. Excluding these parameters does not affect the visual appearance of the image that is saved to the imager but does affect the accuracy of specific pixel temperatures used in later analysis. Air temperature and relative humidity were determined using a Kestrel® 3000 weather meter (Nielsen-Kellerman, Birmingham, MI). Emissivity, a measure of a substance's ability to release the thermal energy, was set to 0.85 for snow as specified by the manufacturer of the FLIR device (FLIR Systems 2006). Reflected temperature was calculated according to FLIR manual instructions by facing the FLIR imager in the opposite direction of the snowdrift, setting the emissivity to 1, adjusting to near focus, saving an image, and using the box function to calculate an average temperature. In addition to air temperature and relative humidity we recorded wind speed and temperature/dew point spread with the same weather meter placed at the 100 m sampling location at the same height as the FLIR imager. Presence/absence of precipitation was noted, and solar radiation data were provided by a research weather station at BP's F-Pad facility, 11 km from the study site, after the hand-held sensor we were using had failed. Solar sensors at the weather station were oriented horizontally, not consistent with the frontal slope of the artificial dens, but still gave consistent and reliable readings relative to solar radiation received at den sites. Resting the imager on posts marking each sample distance, we recorded images at each distance. Den wall thickness was recorded by walking along the top of the snowdrift and peering over the side of the drift to view measuring sticks protruding from each den. These measurements were taken directly after the conclusion of each sampling event to ensure that the thermal properties of the dens were not disturbed before or during sampling. We never walked on or otherwise disturbed the surface of the drift being sampled.

After data collection, we downloaded images and assigned each a detectability score. We first determined whether or not a hot spot was detectable to the human eye in each sample image. If it was not, it was automatically given a detectability score of zero. If a hot spot was visible, we calculated a detectability score using FLIR Quick Report® (FLIR Systems, Boston, MA), a software package used to organize and analyze thermal images taken with FLIR cameras. The software features an area tool that highlights an area of interest and exports temperature data for each pixel. We created a rectangle that encompassed a typical hot spot at each distance (26 x 41 pixels for 60 m, 21 x 28 for 100 m, 12 x 16 for 200 m). This rectangle was centered over each hot spot and pixel temperatures were exported for the next step of analysis. The mean background temperature of the surrounding snowdrift was determined in the same manner. To determine a detectability score for each hot spot we subtracted the mean background temperature of the snowdrift from the temperature of each pixel within the hot spot to calculate the total ΔT for all the pixels within the hot spot, thus generating a sum total temperature above background for each den image (i.e., detectability score).

Statistical Analysis

We were unable to identify the den's hot spot (detectability score of zero) in many images. As a result, we used linear models with the zero-inflated negative binomial distribution for the error structure in our modeling. Advances with linear models that use zero-inflated distributions (e.g., zero-inflated negative binomial or zero-inflated poisson distribution) provide a solution to count data with excess zeroes (Lambert 1992, Welsh et al. 1996). With these models, one can evaluate the influence of explanatory variables on both the count response and probability of a zero count.

Zero-inflated models estimate a point mass at zero in addition to standard distributional estimates and have been successfully used with ecological data in a variety of settings (Welsh et al. 1996, Martin et al. 2005, Arab et al. 2008). These methods reduce bias in parameter estimates associated with large numbers of zeroes.

To assess the influence of factors on detectability, we used an information-theoretic approach, Akaike's Information Criterion adjusted for small sample size (AICc), to rank models (Akaike 1973, Burnham and Anderson 2002). We constructed 40 total models (Table 1) by including permutations of the six variables of interest (solar radiation, wind speed, den wall thickness, relative humidity, temperature/dew point spread, and presence/absence of precipitation), while excluding models with more than three variables (the maximum allowable number of parameters) as well as one model with a convergence error. We then averaged over all models for each den using the MuMin package (Barton 2013) and glmmADMB package (Skaug et al. 2006, Fournier et al. 2012) in Program R (Version 2.10.0, www.r-project.org, accessed 26 October 2009) to evaluate the direction and strength of associations between explanatory variables and den detectability. We also used the pscl (Zeileis et al. 2008, Jackman 2012), calibrate (Graffelman 2012), and MASS (Venables and Ripley 2002) packages in program R to perform analyses. This modeling was performed with only the 100 m data. Images taken from 60 and 200 m were used to analyze the effects of each variable as distance increased.

As sampling distance changed, variation in detectability coefficients largely became a function of the number of pixels within the standardized area tool rectangle used for each distance instead of actual trends. As a result, it became necessary to exclude distance as a variable of interest in our modeling approach and analyze it separately. The same models and methods were used for this analysis (Table 1) but only included den images that contained hot spots visible to the human eye (*n*=102), so we did not include a zero-inflated portion in this modeling approach. Forty-one models were included in this analysis. As distance increased between an artificial den and the FLIR imager, atmospheric effects also increased. To account for this in our analysis, we compared declines in actual detectability score to expected score declines that would occur without atmospheric effects. Because an image taken at 200 m contains only 30% of the number of pixels that are contained in a 60 m image (60/200), the detectability score at 200 m would be 30% of the 60 m score. To determine the relative influence of atmospheric conditions, we calculated the percentage of actual score decline compared to the predicted score decline without atmospheric influence by dividing the actual score decline (200 m score/60 m score) by the predicted score decline (0.30). Therefore a lower percentage would theoretically signify a greater effect of atmospheric conditions on the detectability of the hot spot. We averaged over all models and assessed each variable for significance (α=.05). We also analyzed the effect of den wall thickness on detectability by regressing detectability scores and den wall thickness to estimate thresholds of detection.

Results

Over a period of 19 d we conducted 52 sampling sessions. All three dens were measured during each sampling period. Detectability scores ranged from 0 to 927, although 33% of sample images yielded a detectability score of zero. The resulting frequency histograms of detectability scores were typical of those associated with zero-inflated data (Figure 4). Solar radiation ranged from 0 – 320.3 w/m^2, wind speed ranged from 2.4—32.5 km/hr, precipitation was present during 19 sampling events, relative humidity ranged from 68.8—86.2%, den wall thickness ranged from 30—80 cm, and temperature/dew point spread ranged from 0.5—9.3°C during the period we sampled.

After reopening dens at the conclusion of the study, we found that all three dens had melted out to similar volume approximations (mean ± S.D.=3.32 ± 0.14 m^3; height x width x length) due to heater effects and were within the range of natural den chambers previously reported in the southern Beaufort Sea and eastern Canada (Harington 1968, Durner et al. 2003). Additionally we noted that a 2.5 cm thick ice lens formed on the inner surfaces of each chamber, as occurs in actual polar bear dens (Harrington 1968, Durner et al. 2003).

The best-fit model for detectability was the same for each den and included solar radiation, wind speed, and presence/absence of precipitation (Table 1). Wind speed was negatively correlated ($p < .01$) with detectability. Solar radiation was negatively correlated with detectability in den 1 ($p < .01$), but not in dens 2 and 3. Den wall thickness was negatively correlated with detectability in den 3 ($p < .05$), but not significant in dens 1 and 2. Temperature/dew point spread and relative humidity was positively correlated with detectability; yet only temperature/dew point spread was significant ($p < .05$) and only in den 1. In the zero-inflated portion of this model wind speed, solar radiation, den wall thickness, and temperature/dew point spread were positively correlated with the probability of a zero score. However, the only significant variables were solar radiation ($p < .01$) in all three dens and den wall thickness ($p < .05$) in dens 1 and 3. Thickness was strongly correlated with detectability in den 2 ($p < .1$). Humidity and the presence of precipitation were negatively correlated with the probability of obtaining a zero score, neither of which was significant.

After averaging the coefficients of all three den analyses, we found that solar radiation, wind speed, and den wall thickness were significant factors (Table 2). Solar radiation negatively affected detectability scores for the count portion of the models (Figure 5), with a 1 w/m^2 increase in solar radiation decreasing detection by a factor of 0.998 ($p < .05$). In the zero-inflated portion of the models, solar radiation was positively associated with obtaining a zero score, with a 1 w/m^2 increase in solar radiation increasing the odds of a den receiving a zero score (not detected) by a factor of 1.027 ($p < .01$). Wind speed negatively affected detectability in the count portion of the model (Figure 6) with a 1 km/hr increase in wind speed decreasing den detection by a factor of 0.954 ($p < .01$). Den wall thickness had a positive correlation with the probability of a zero score. A 1 cm increase in den wall thickness increased the odds of a den receiving a zero score (not detected) by a factor of 1.485 ($p < .05$). We found the mean point of den wall thickness at which dens became undetectable to be 90 cm.

For the distance portion of the analysis, the best-fit model included wind speed and precipitation. Wind speed was the only variable that was significant (Figure 7). It was negatively correlated with detectability and was included in all 16 supported models (Table 1; >99% weight). A 1 km/hr increase in wind speed increased the spread between predicted and actual detectability by a factor of 0.404 ($p < .01$).

Discussion

Amstrup et al. (2004) identified solar radiation, airborne moisture, and temperature/dew point spread as important factors in polar bear den detection using aircraft-based FLIR. Our findings are similar with regard to both solar radiation and temperature/dew point spread, although we did not use airborne moisture as a metric. Rather, we used precipitation (falling or suspended moisture) as one metric and wind speed, which accounts for blowing snow, as another. We did not find precipitation alone to be significant in any of our models. It should be noted, however, that only light precipitation occurred during our sampling sessions, which likely limited our ability to evaluate its influence. Poor FLIR performance has been observed during moderate snowfall while attempting to detect actual polar bear dens (Smith et al. 2007). Therefore, precipitation and its intensity should also be considered (Amstrup et al. 2004).

Solar radiation and wind speed were the most important factors influencing artificial polar bear den detection using FLIR (Figures 8-10). Of den images that were not detectable (n = 47), 94% had solar radiation >100 w/m^2. Conversely, only 39% of detectable den images (n = 109) had solar radiation > 0 w/m^2. Regardless of all other variables, 96% of all dens sampled at night (n = 69) were detectable at some level. Den detectability scores were 2.7 times higher in hours of darkness than when sunlight was present. Because of convection, as well as blowing ground snow (i.e., wind driven snow close to the ground), wind had a negative effect on den detectability in general, and also as horizontal distance to the den increased. However, detectability as vertical distance increases may not be impacted by wind as much as it is with horizontal increases. Imagers on the ground are subject to compounding ground snow particles as distance increases, whereas an aircraft-based imager may only be subject to the blowing snow directly over the den. Even if this is the case, convection and the constantly moving particles will still have a negative effect on detection, and we recommend that windy conditions be avoided altogether, regardless of the imaging platform.

Ice lenses forming on the inner surfaces of natural polar bear dens has been reported (Harington, 1968, Durner et al. 2003), but polar bears will usually scrape at the walls and ceilings with their claws, leaving little if any ice. Because the artificial dens being sampled had ice lenses form on the inner surfaces, heat dissipation may have been somewhat different than in natural dens. In spite of this concern, we feel our artificial dens simulated real dens adequately to provide useful detection methods. Specific thresholds may need further testing.

Snow depth above the chamber of a polar bear den can vary greatly (mean ± S.D. = 72 ± 87 cm) and has been measured up to 400 cm (Durner et al. 2003). The resulting confidence intervals suggest that 15% of dens have wall thicknesses greater than 90 cm and would likely go undetected with hand-held FLIR. During the course of this study, den wall thickness fluctuated as much as 16 cm with changing wind, and a single windstorm before the study began added 4 horizontal meters and 2 vertical meters of snow to our sample snowdrift, resulting in a reconstruction of artificial dens. We recommend conducting FLIR surveys as early as possible in the denning period when snow depth over dens is expected to be at winter minimums (Uspenski and Kitchinski 1972).

In order to reach maximum detectability (top 10% for each den at 100 m), we recommend that managers tasked with locating polar bear dens using hand-held FLIR do so between dusk and dawn when the wind is < 10 km/hr (6 mph). The mean solar radiation for the top 10% of detectability scores was 16 w/m^2, with all but one top score occurring at night. If surveys must be conducted during daylight hours, time periods near dawn or dusk with heavy cloud cover should be sought in order to minimize the effects of solar radiation. Although all of our measurements were collected on the ground, they largely corroborate past work (Amstrup et al. 2004), and our observations with aerial FLIR. Our findings here likely apply to aerial FLIR as well. We feel that by following these recommendations, polar bear den detection will be optimized, thus avoiding potentially negative impacts associated with the interactions of denning polar bears and industry.

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Table 3.1. Supported models (AICc weight > 0.01) for detectability (count) and distance analyses. Artificial den FLIR sampling at Milne Point, Alaska, March 2010.

Model	Variables[a]	AIC_c[b]	ΔAIC_c[c]	W_i[d]
		Detectability (Count)		
26	PRECIPITATION+SOLAR+WIND	468.65	0	0.74
28	SOLAR+THICKNESS+WIND	471.14	2.49	0.21
16	PRECIPITATION+SOLAR	475.37	6.72	0.03
32	PRECIPITATION+SOLAR+SPREAD	476.81	8.16	0.01
		Distance		
9	PRECIPITATION+WIND	794.8	0	0.15
1	WIND	794.86	0.06	0.15
10	HUMIDITY+WIND	795.59	0.79	0.1
8	SOLAR+WIND	796.42	1.61	0.07
23	PRECIPITATION+SPREAD+WIND	796.42	1.62	0.07
29	HUMIDITY+PRECIPITATION+WIND	796.61	1.8	0.06
11	THICKNESS+WIND	796.81	2.01	0.06
30	PRECIPITATION+THICKNESS+WIND	796.85	2.04	0.06
7	SPREAD+WIND	796.97	2.16	0.05
26	PRECIPITATION+SOLAR+WIND	796.98	2.17	0.05
24	HUMIDITY+SPREAD+WIND	797.55	2.75	0.04
31	HUMIDITY+THICKNESS+WIND	797.62	2.82	0.04
27	HUMIDITY+SOLAR+WIND	797.75	2.94	0.04
22	SOLAR+SPREAD+WIND	798.35	3.55	0.03
28	SOLAR+THICKNESS+WIND	798.42	3.61	0.03
25	SPREAD+THICKNESS+WIND	798.95	4.15	0.02

[a]SOLAR=solar radiation, WIND=wind speed, PRECIPITATION-presence/absence of precipitation, HUMIDITY=relative humidity, SPREAD=temperature/dew point spread, THICKNESS=den wall thickness.
[b]Akaike's Information Criterion adjusted for small sample size.
[c]Change in AICc value compared to top model.
[d]AICc weight.

Table 3.2. Model-averaged coefficients with associated P values from FLIR sampling of artificial polar bear dens at Milne Point, Alaska, March 2010.

	Estimate	Std. Error	z	P
Count				
Intercept	6.54	0.57	17.54	< 2e-16
Wind	-0.05	0.01	3.98	<0.01
Solar	-1.86E-03	0.00	2.10	<0.05
PRY[a]	-0.16	0.19	0.77	0.47
Spread	0.09	0.05	1.78	0.08
Humidity	0.85	2.82	0.30	0.76
Thickness	-0.04	0.03	1.30	0.30
Zero-Inflation				
Intercept	-6.61	9.27	0.97	0.37
Wind	0.04	0.12	0.37	0.71
Solar	0.03	0.01	3.08	<0.01
PRY	-22.61	5045.00	4.33E-03	1.00
Spread	0.01	0.49	0.22	0.83
Humidity	-22.28	21.07	1.01	0.35
Thickness	0.36	0.17	2.03	<0.05

[a]PRY=presence of precipitation

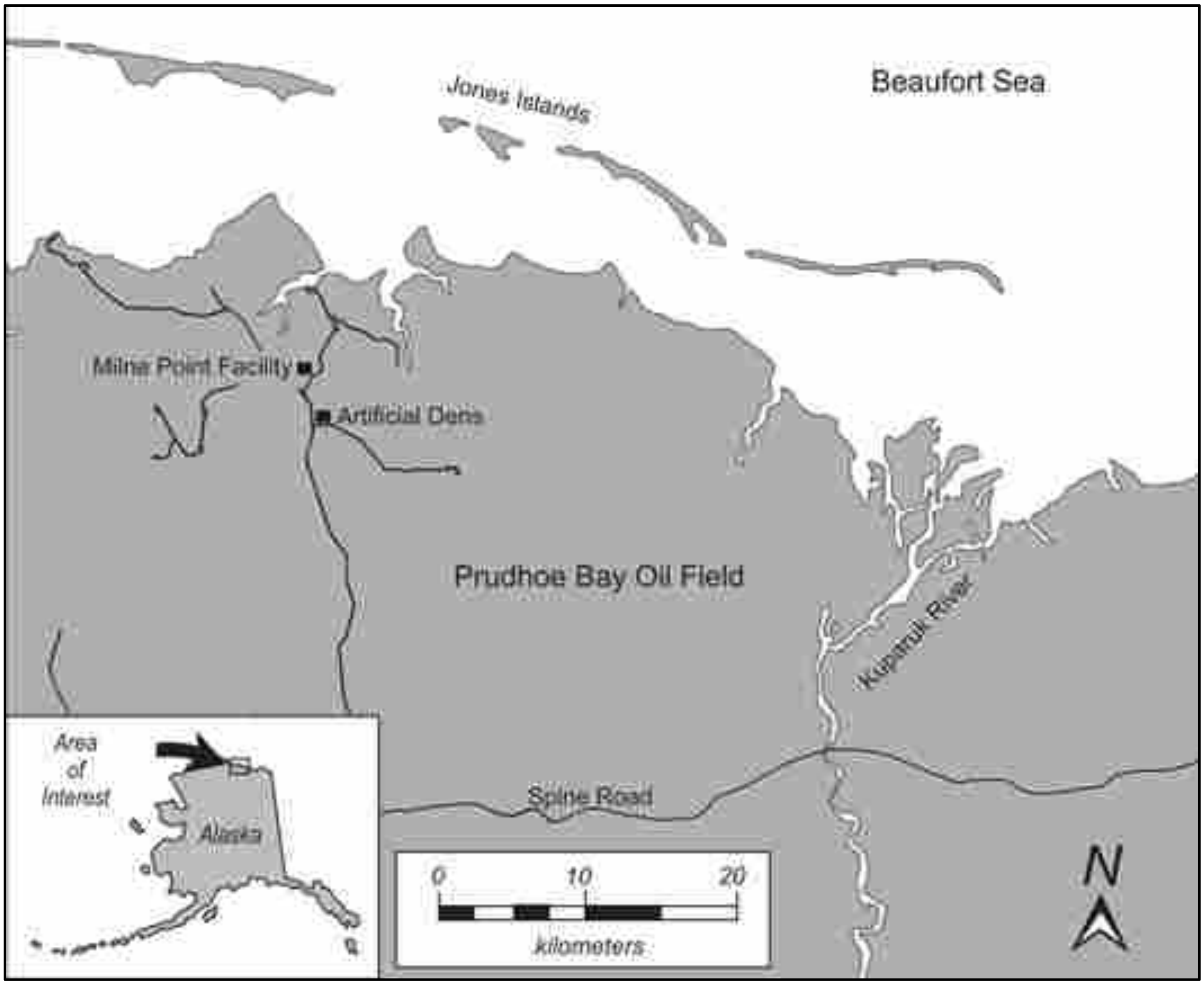

Figure 3.1. Study area south of Milne Point, Alaska where artificial den FLIR sampling took place, March 2010.

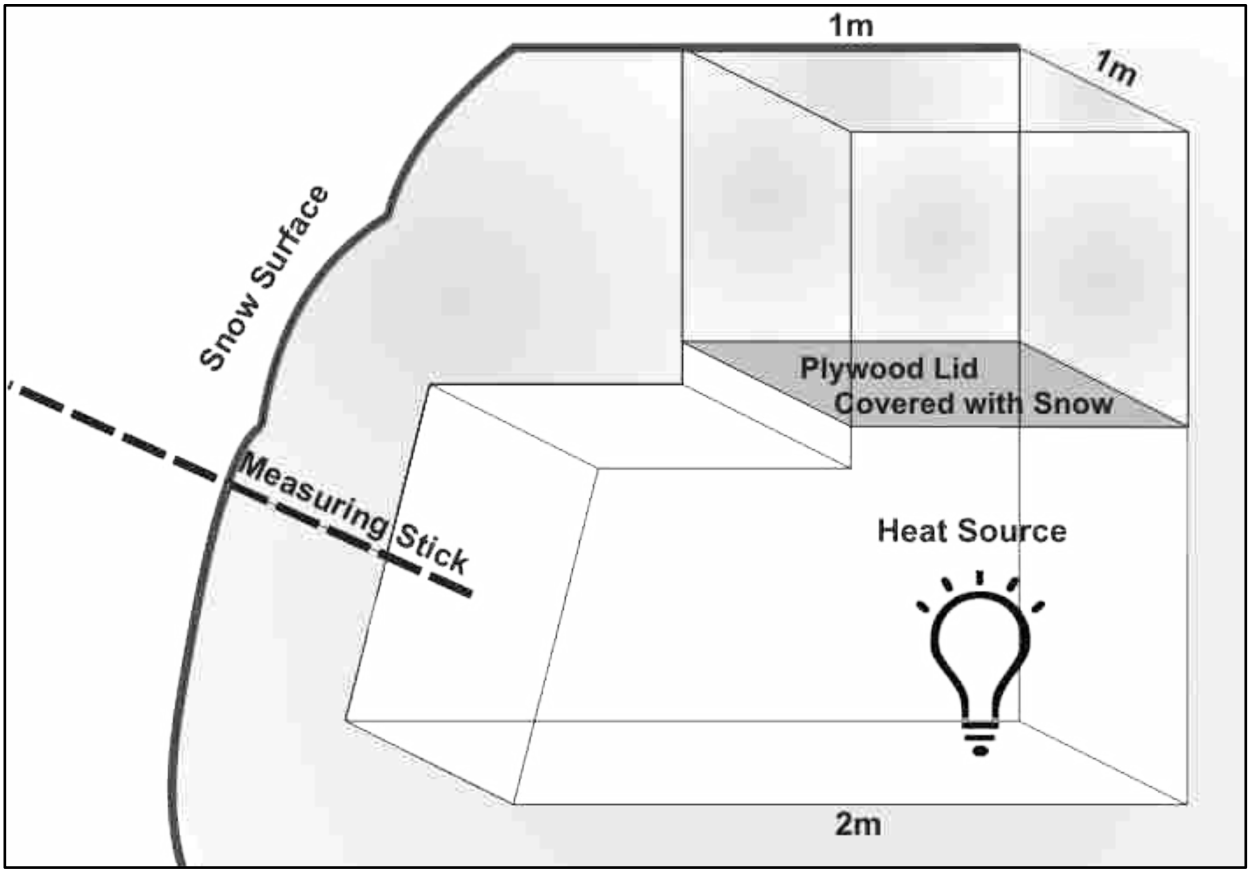

Figure 3.2. Schematic of artificial snow den structure used to test the efficacy of hand-held FLIR for detecting polar bear maternal dens, Milne Point, Alaska, March 2010.

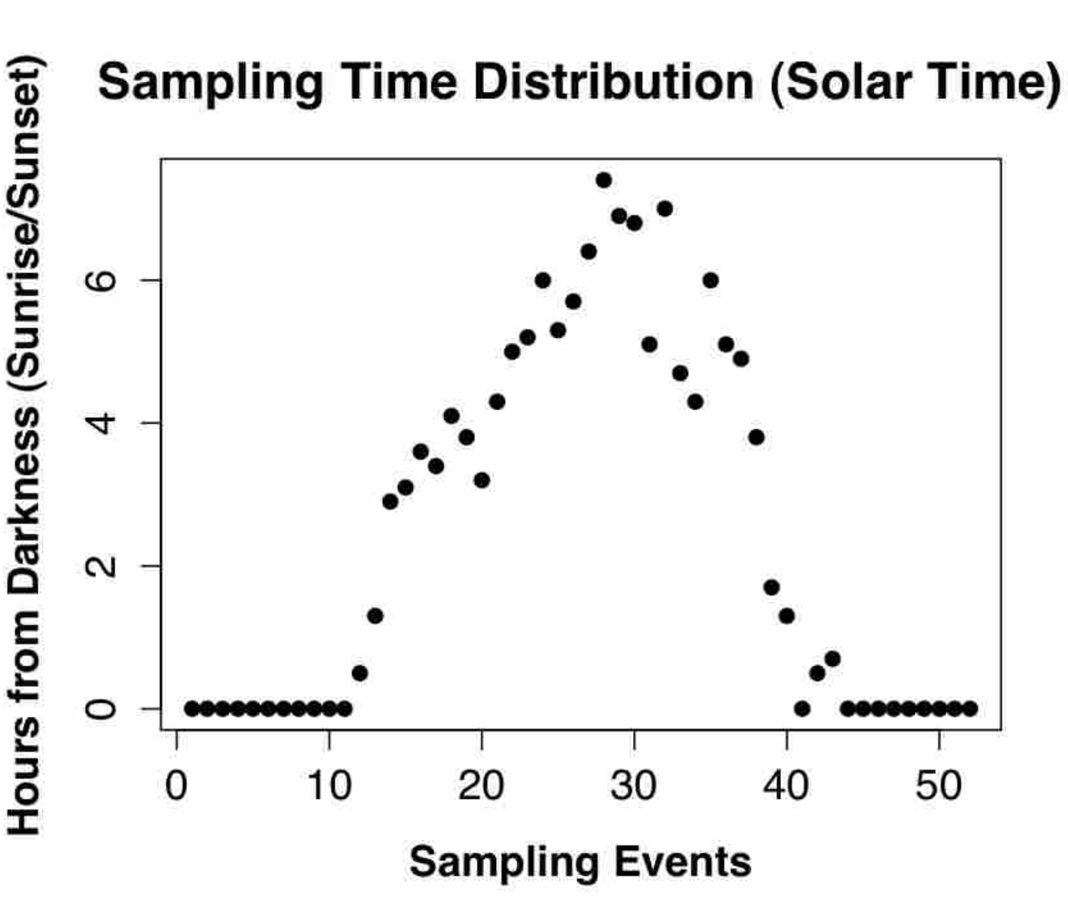

Figure 3.3. Sampling time distribution in relation to solar time used in FLIR sampling of artificial dens. Milne Point, Alaska, March 2010.

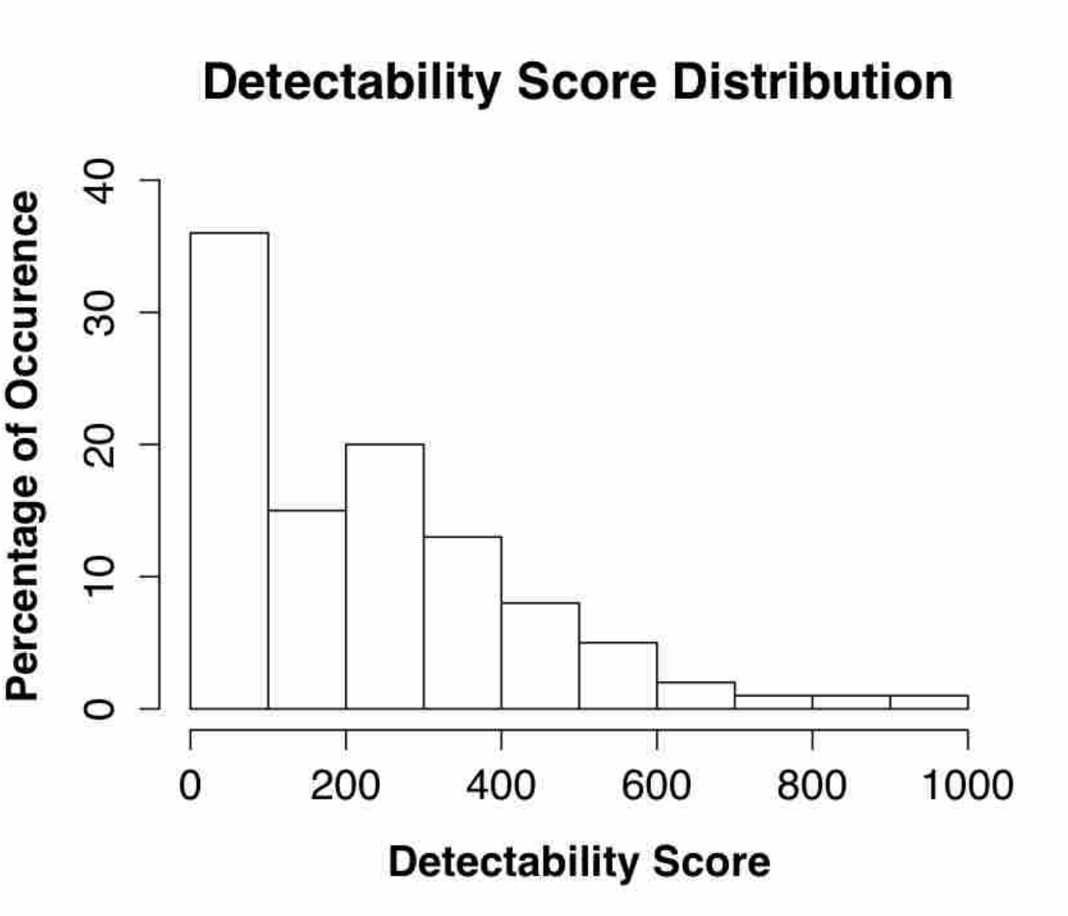

Figure 3.4. Distribution of detectability scores from all samples at 100 m distance, Milne Point, Alaska, March 2010.

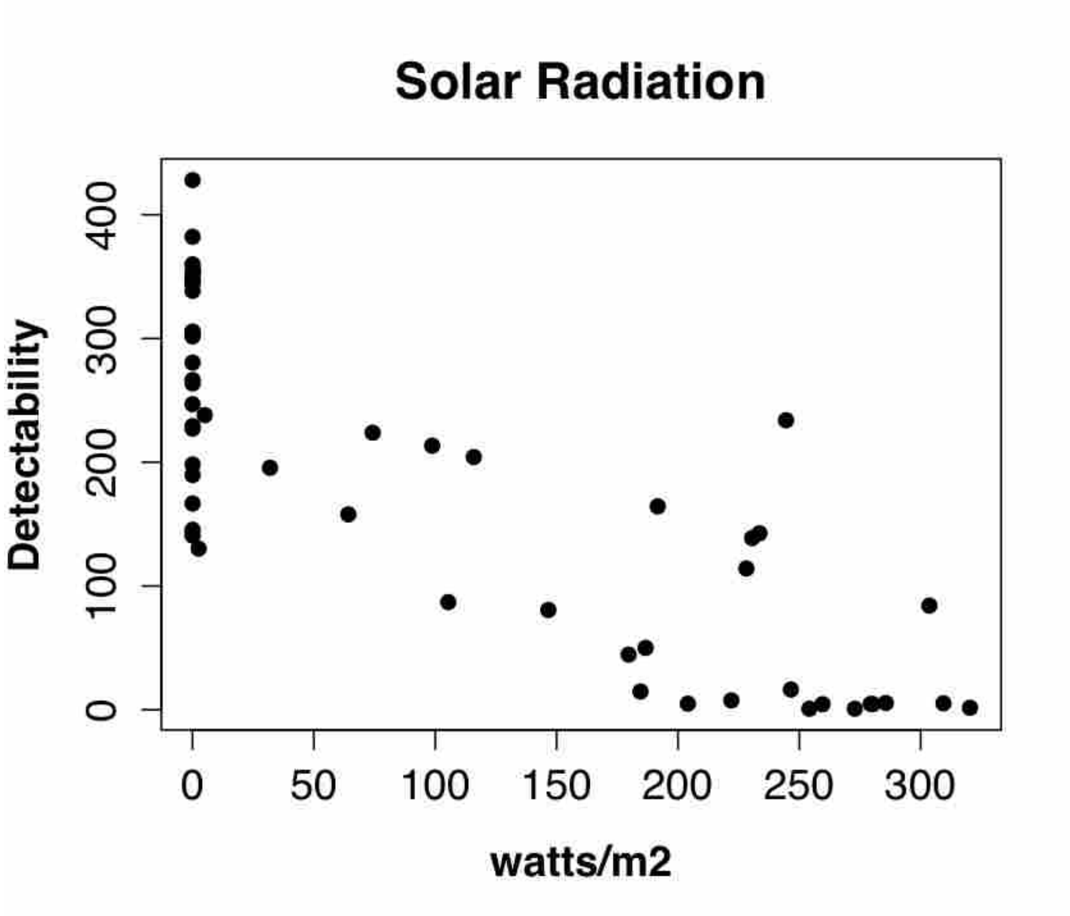

Figure 3.5. Plot showing relationship between solar radiation and den detectability of all samples at 100 m distance, Milne Point, Alaska, March 2010.

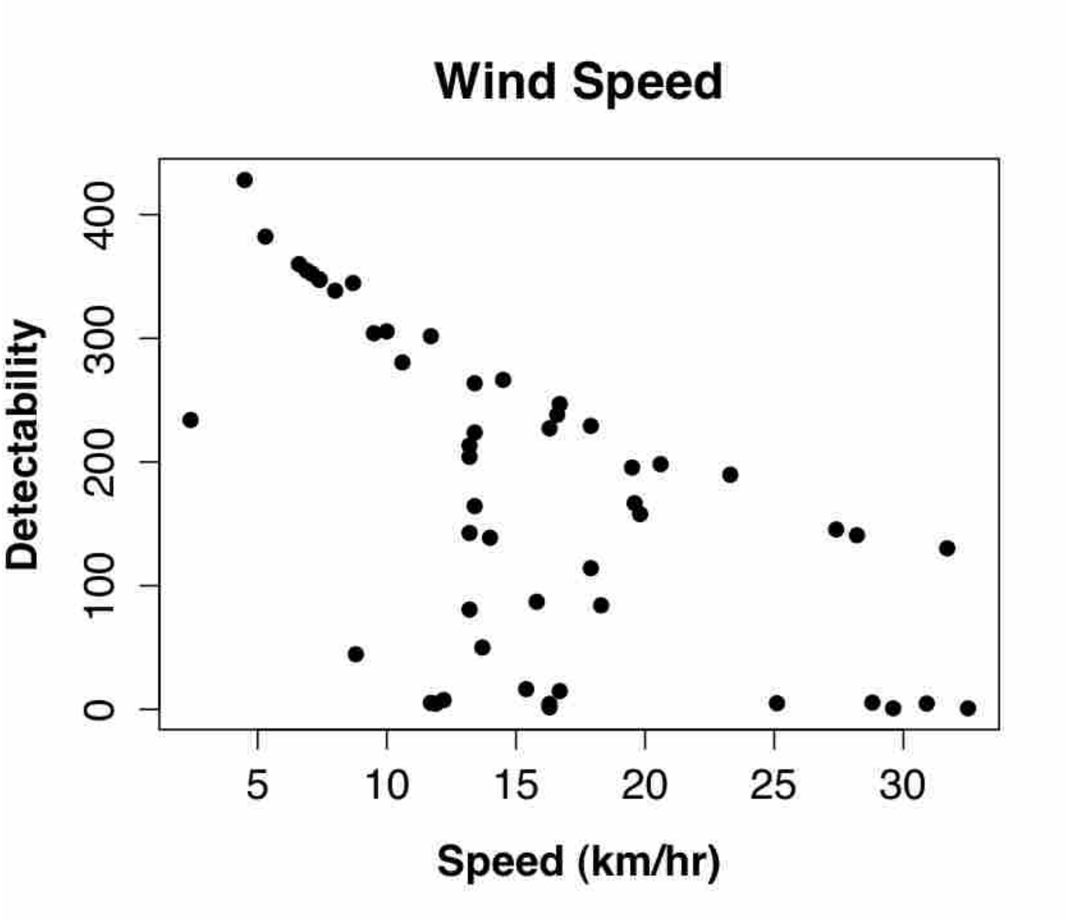

Figure 3.6. Plot showing relationship between wind speed and den detectability of all samples at 100 m distance, Milne Point, Alaska, March 2010.

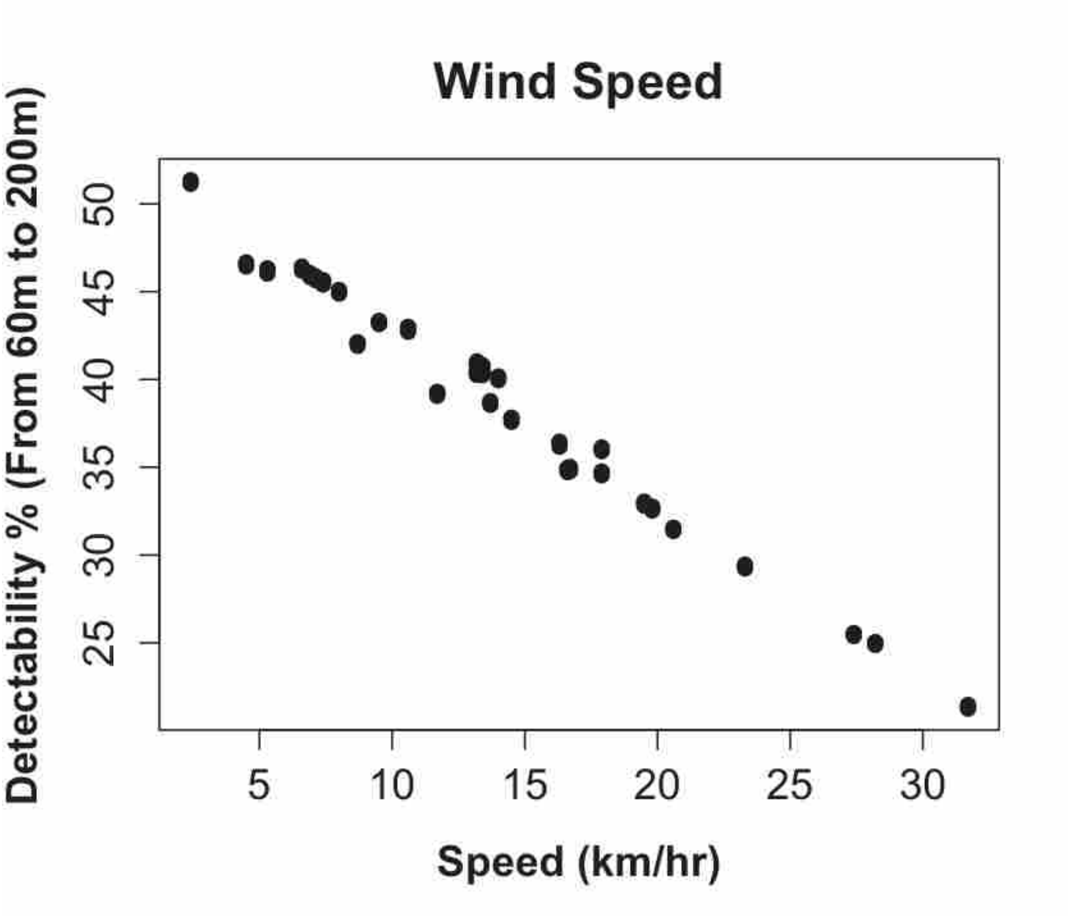

Figure 3.7. Plot showing relationship between wind speed and den detectability as distance increases, Milne Point, Alaska, March 2010.

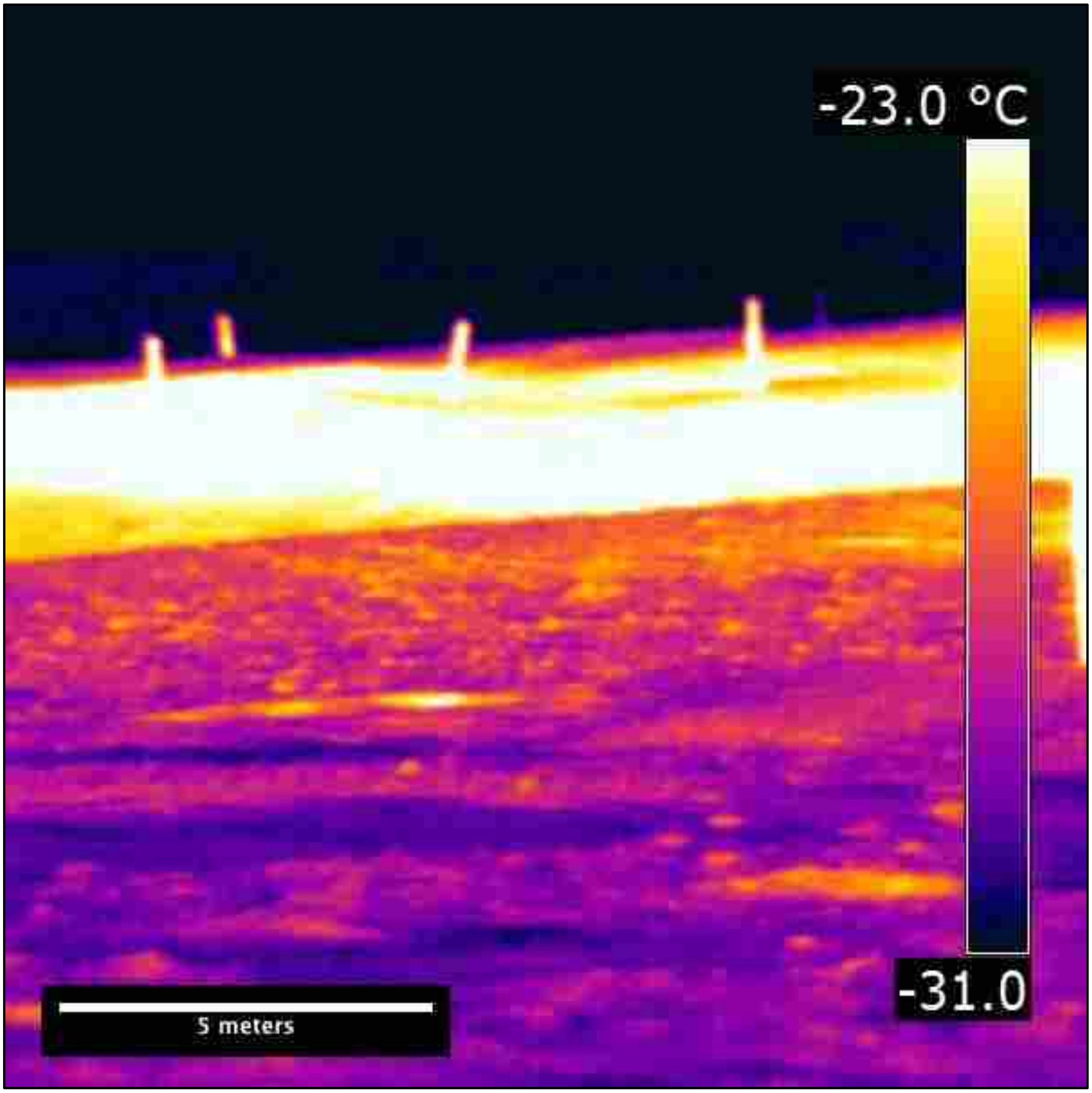

Figure 3.8. Infrared image of artificial dens at 100 m distance showing sunny conditions, Milne Point, Alaska March, 2010.

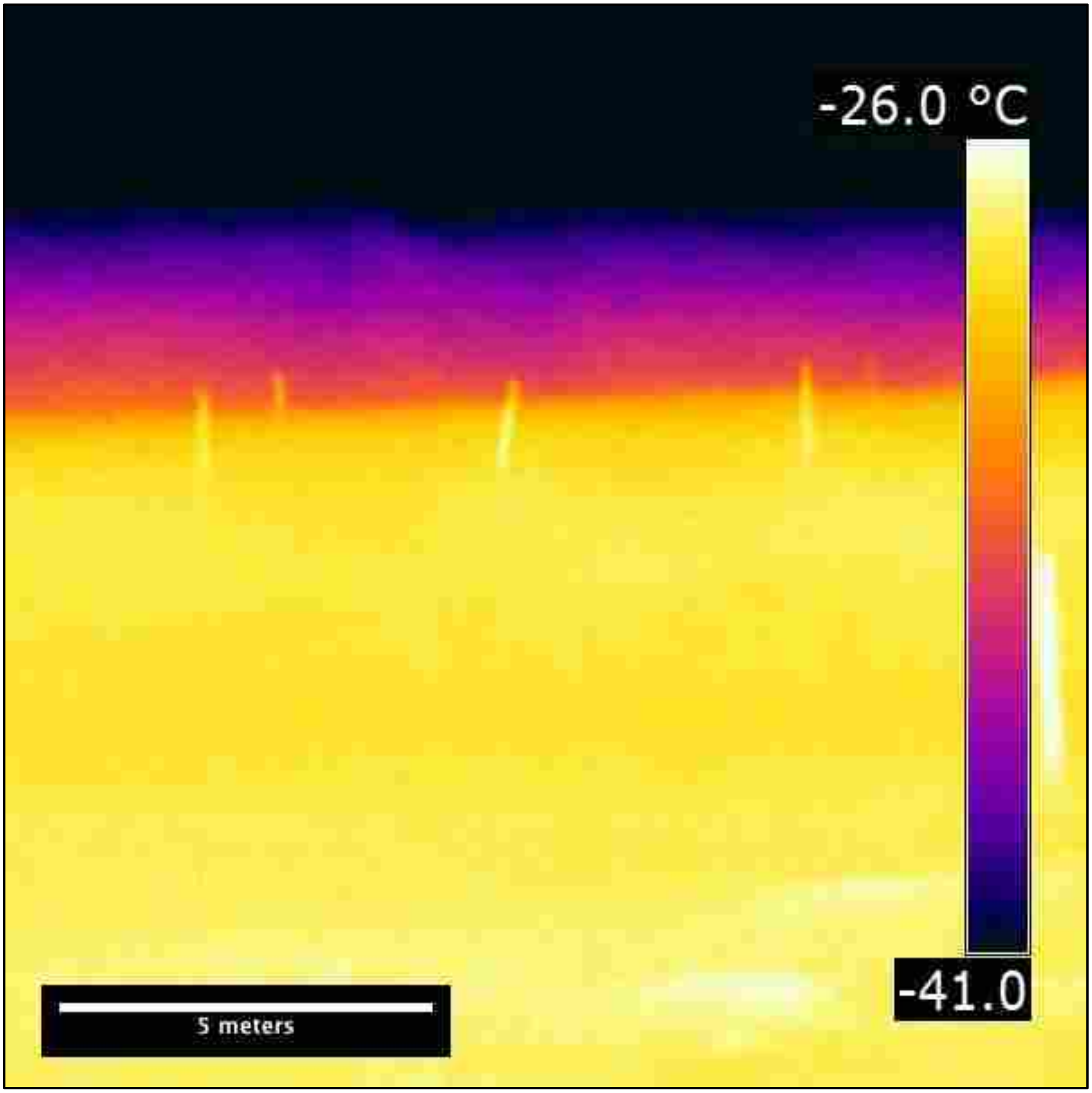

Figure 3.9. Infrared image of artificial dens at 100 m distance showing windy conditions, Milne Point, Alaska, March 2010.

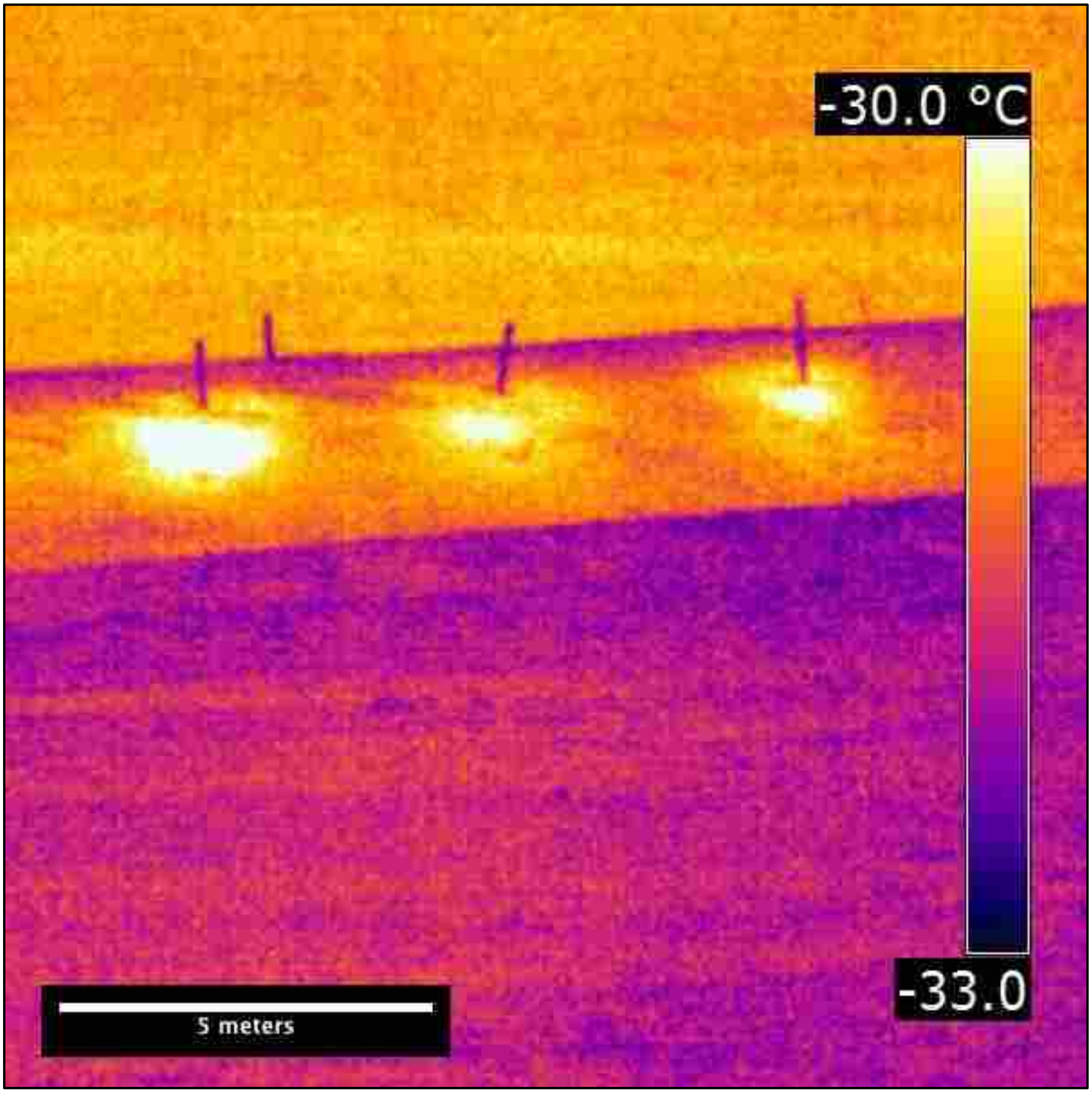

Figure 3.10. Infrared image of artificial dens at 100m distance showing optimal conditions, Milne Point, Alaska, March 2010.