Identifying shifts in maternity den phenology and habitat characteristics of polar bears (*Ursus maritimus*) in Baffin Bay and Kane Basin

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Abstract

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The phenology and habitat selection of polar bear (*Ursus maritimus*) maternity dens may change over time in response to shifting environmental conditions. This study compared satellite telemetry data on 40 adult females from the Baffin Bay subpopulation collected from 2009–2015, and 16 adult females from the Kane Basin subpopulation collected from 2012–2015 to previously published data on maternity and shelter dens from 1991–1997 in order to look for shifts in maternity den site characteristics and phenology. Sea ice has decreased markedly in the two study regions since the early 1990s. Our specific objectives were to: 1) identify den entry and exit dates using temperature and location data from satellite radio collars; 2) compute denning duration and compare the results to historical data from the 1990s; and 3) characterize and compare maternal den site habitat attributes between the two time periods. Comparison of the Baffin Bay maternity dens (1990s $n = 8$ dens; 2000s $n = 16$ dens) from the two periods revealed that mean denning duration shortened in the 2000s by an average of 27 days ($\bar{x} = 167.1$ days, SD = 27.6 days) compared to the 1990s ($\bar{x} = 194.1$ days, SD = 21 days). Delayed den entry in the fall was the primary reason for the shorter denning durations observed in the later decade (1990s median entry date = 28 August; 2000s median entry date = 3 October). Maternity dens in Baffin Bay differed significantly in elevation and slope ($p = 0.003$), with bears in the 2000s using denning areas at higher elevation and steeper slopes than in the 1990s. No significant difference in den phenology or habitat characteristics was found among the Kane Basin subpopulation. These results suggest significant changes in maternity den phenology and denning habitat selection in Baffin Bay over the past two decades. Shifts in the timing of melting sea ice and the absence of suitable snow conditions may explain the observed changes. This study offers a successful example of the use of satellite telemetry in detecting shifts in phenology and habitat selection for species that occupy remote habitats.

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Introduction

Changes in the distribution and behavior of organisms can signal shifts in the environment, sometimes before those shifts are directly observed and adequately measured (Gleason 1917; Rubenstein 1992). The relationship between animal behavior and habitat stems from abiotic and biotic factors that dictate the organism's habitat choice (Gleason 1917; Martin 2001). These factors include preferred thermal ranges, home range size, breeding requirements, and dietary needs among other traits (Grinell 1917; Andrewartha and Birch 1954). Whether the species is a generalist or a specialist will also influence the degree to which the organism is able to utilize different habitats (Knowlton and Graham 2010). Phenological traits characterize the timing of important life history events and are intimately associated with seasonal cues such as temperature swings and photoperiod (Andrewartha and Birch 1954; Badeck et al. 2004), making these traits particularly vulnerable to variation in their triggers. Habitat use and population distribution are similarly governed by abiotic factors such as temperature and precipitation (Gleason 1917; Andrewartha and Birch 1954; Martin 2001; Bale et al. 2002), as well as biotic factors such as reproductive habitat needs (e.g. obligate ground-nesting birds, etc.; Grinell 1917), territorial behavior (Klopfer 1962), and competition (MacArthur 1972). The tie between phenology, habitat use, and the environment make these behavioral traits important indicators of environmental change.

Shifts in phenology and distribution are amongst the most readily observable biological responses to habitat modifications brought on by climate change (Sparks and Menzel 2002; Walther et al. 2002; Parmesan and Yohe 2003; Thackeray et al. 2010). There is mounting evidence that warmer mean temperatures are leading to earlier spring phenologies (Parmesan and Yohe 2003; Root et al. 2003). In the Northern Hemisphere, long term monitoring studies using observational data have shown that plants are sprouting their first leaves and flower buds earlier in the year (Wolfe et al. 2005; Schwartz et al. 2006), earlier egg-laying has been observed for some bird species (Crick et al. 1997; Brown et al. 1999; Charmantier et al. 2008), and amphibians are spawning earlier (Beebee 1994; Forchhammer et al. 1998). In the Colorado Rocky Mountains, warmer spring temperatures have led to the earlier emergence of yellow-bellied marmots (*Marmota flaviventris*) from their winter hibernation, as well as the earlier arrival of American robins (*Turdus migratorius*) to their breeding sites (Inouye et al. 2000). Range expansion and contraction due to changes in climate are also expected to occur and have been documented for some terrestrial and freshwater species (Ford 1982; Kullman 1983; Graham and Grimm 1990; Valiela and Bowen 2003; Parmesan 2006; Chen et al. 2011; Field et al. 2014). Increased temperatures cause species to shift their ranges to higher latitudes and altitudes, generally moving away from the equator (Peters 1992; Parmesan and Yohe 2003; Root et al. 2003; Parmesan 2006; Parry et al. 2007). The ecological impact of climate change is expected to be most pronounced at high latitudes (Root et al. 2003), including the Arctic where annual mean temperatures are rapidly increasing (IPCC 2013), species' physiological constraints limit their ability to expand their range (Parmesan 2006; Williams et al. 2010), and ice-adapted organisms are facing extensive habitat loss (Laidre et al. 2008; Wassmann et al. 2011).

Global mean surface temperatures have increased by 0.2°C per decade and this rate has increased tenfold in some areas of the Arctic (Hansen et al. 2006). Warmer temperatures are causing a myriad of environmental changes for both terrestrial and aquatic ecosystems in the Arctic. These shifts include more variable and less predictable weather (Krupnik and Jolly 2002), earlier snowmelt (Stone et al. 2002; Derksen and Brown 2012), and dramatic changes in the sea ice. Since the 1970s, the extent of the Arctic sea ice has declined by an average of 3.8% per decade and the ice has thinned by 2 m during the winter months (Vaughan 2013). Moreover, the total volume of sea ice has dramatically reduced year-round (IPCC 2014), and break-up is occurring earlier in the year while freeze-up is occurring later in the fall (Laidre et al. 2015a). The retreating snow and sea ice cover has led to a decreased albedo effect in the Arctic, thus amplifying seasonal temperatures, and creating a positive feedback system that is causing the Arctic to warm faster than the global mean (Perovich et al. 2007; Hinzman et al. 2013; IPCC 2014). These changes are having a noticeable effect on the phenology of Arctic organisms. Due to earlier declines in snow cover, the growing season is starting earlier in western Arctic Russia and ending later (Zeng et al. 2013). Arctic ground squirrels closely time their hibernation and emergence with winter snow cover and spring melt, and thus are adjusting the timing of both activities in correspondence with late snowstorms and earlier snow melt (Sheriff et al. 2015). For Arctic marine mammals uniquely adapted to life with the sea ice, changes in the sea ice have led to distribution shifts, declines in body condition, and reduced health of populations (Kovacs et al. 2011). Despite surviving millennia of decadal oscillations of warming and cooling in the Arctic, resident marine mammals are struggling to keep pace with the speed at which their habitats are changing (Harington 2008; Laidre et al. 2008; Moore and Huntington 2008).

The core group of resident Arctic marine mammals includes polar bears (*Ursus maritimus*), walrus (*Odobenus rosmarus*), bearded seals (*Erignathus barbatus*), harp seals (*Pagophilus groenlandicus*), ringed seals (*Phoca hispida*), bowhead whales (*Balaena mysticetus*), belugas (*Delphinapterus leucas),* and narwhals (*Monodon monoceros*) (Harington 2008). Of the core group, polar bears, walrus, bearded seals, and ringed seals are considered to be ice-obligate species, meaning they require ice to hunt, breed, and rest (Moore and Huntington

2008). Due to their dependence on the sea ice and specialized diet, polar bears are particularly sensitive to changes in the sea ice (Laidre et al. 2008).

For most of the year, polar bears occupy annual sea ice habitats over continental shelves throughout the Arctic where their primary prey species, ringed seals, are found (Hunter et al. 2010; Stirling and Derocher 2012). The sea ice serves as a hunting platform from which polar bears can stalk their prey, as well as a migration corridor that facilitates movement within their home range (Stirling 2009). Without the sea ice, polar bears cannot hunt and must take refuge on multiyear ice (older, thicker ice) or on land where they fast until the sea ice returns in the fall. Widespread loss of sea ice habitats is expected to negatively impact individual survival, and there are multiple effects of sea ice decline that have been documented in subpopulations in the southern extent of the polar bear range. These effects include declines in body condition in Western Hudson Bay, Southern Beaufort Sea, and Baffin Bay (Rode et al. 2010, 2012, 2014); decreased survival among juvenile, subadult, and senescent bears in Western Hudson Bay and Southern Beaufort Sea (Regehr et al. 2007, 2010; Bromaghin et al. 2015); shifts in habitat use from annual ice to areas with lower ice concentrations and/or multiyear ice in East Greenland (Laidre et al. 2015b); and increased use of terrestrial habitats in the Chukchi Sea and Southern Beaufort Sea (Fischbach et al. 2007; Schliebe et al. 2008; Rode et al. 2015).

Although the negative impacts of climate change on polar bears are well known, the impact of climate change on their reproductive behavior, specifically maternity den habitat selection and phenology, is poorly understood. Like other bear species, polar bears give birth in maternity dens during the winter months. Female polar bears reproduce every three years and mate during the spring season (DeMaster and Stirling 1981; Ramsay and Stirling 1988). In autumn, the pregnant females build dens where they will give birth to two to three altricial cubs between December and January (Blix and Lentfer 1979; Ramsay and Stirling 1988; Wiig 1998; Ferguson et al. 2000). Polar bear maternity dens are an important adaptation to living in the Arctic. Since cubs are born blind, practically hairless, and weighing < 0.5 kg, they need the warmth and protection of the den to properly build up the fat layers necessary to tolerate the cold temperatures of their environment (Blix and Lentfer 1979). Maternity dens also allow the mother to conserve energy since she has not eaten since leaving the sea ice the previous spring (Ramsay and Stirling 1988; Atkinson and Ramsay 1995). After they emerge from the den, the cubs will remain with their mother for two to three years before embarking on their own (Ramsay and Stirling 1988).

With the exception of Western Hudson Bay where earthen dens are used, most females use snowdrifts to build dens that are at least 0.8 m tall, 1.6 m deep, and 1.4 m wide, with a roof around 0.7 m thick (Liston et al. 2016). Factors that contribute to a female's selection of a den include: availability of denning substrate, condition of sea ice prior to denning, distance to coast, fidelity to denning areas, and anthropogenic influences (Harington 1968; Belikov 1980; Lentfer and Hensel 1980; Stirling and Andriashek 1992). Most maternity denning occurs on land (Amstrup 2003) and females closely time their emergence from the den to coincide with the spring seal pupping season which takes place from mid-March through April (Smith and Stirling 1975).

While only pregnant females over-winter in dens, other bears may take shelter in dens during periods of extreme temperatures, to escape inclement weather, or to conserve energy when food is unavailable (Harington 1968; Jonkel et al. 1972; Schweinsburg 1979; Derocher and Stirling 1990; Ramsay et al. 1991; Messier et al. 1994). Bears typically occupy shelter dens for a short period of time (> 14 days to < 4 months) whereas mother polar bears will remain in maternity dens for > 5 months (Messier et al. 1994).

With the sea ice retreating earlier and forming later in the year, it is not yet clear whether females are changing when they enter and/or exit their dens in response to the changes in sea ice availability. The extension of the ice-free period has been to shown to negatively affect the mass of potentially pregnant females, and consequently, breeding rates and cub survival have declined in some areas (Stirling and Parkinson 2006; Regehr et al. 2010). The body fat of a pregnant female determines her ability to successfully reproduce, and her mass is directly correlated with the mass of her cubs at emergence (Derocher and Stirling 1996; Derocher and Stirling 1998). Therefore it is vital that females time their emergence from the dens to coincide with birthing dates of seals. Seal pups are relatively easy to capture, readily facilitating the replenishment of the female's fat reserves and feeding of her cubs. Additionally, Derocher et al. (2004) hypothesized that as the sea ice melts faster, bears will have to travel farther distances to access preferred habitat, burning through energy resources in the process. For pregnant females, this means traveling greater distances to reach their preferred denning habitat. In the southern Beaufort Sea region, more polar bears are now denning on land than previously observed likely due to decreased access to and quality of the pack ice as a denning surface (Fischbach et al. 2007). Similarly, maternity den distribution along the coast of western Hudson Bay has shifted northwards (Ramsay and Stirling 1990). While changes in den distribution have been observed in other regions, changes in den phenology and habitat characteristics for other subpopulations have yet to be quantified.

Polar bears have a circumpolar distribution with a world population of 20,000–25,000 individuals, divided into 19 distinct subpopulations based on telemetry and mark-recapture data

(Obbard et al. 2010; Fig. 1). Since the subpopulations share similar ice habitats, Amstrup et al. (2008) grouped them together into four "ecoregions" based on current and forecasted sea ice melt and movement patterns, they include: the divergent ice, convergent ice, seasonal ice, and archipelago ecoregions (Fig. 1). The largest ecoregion, the divergent ice ecoregion, spans across the Russian portion of the polar bear range and includes the Southern Beaufort, Chukchi, Laptev, Kara, and Barents Seas subpopulations. Sea ice in the divergent ecoregion consists of annual ice that forms every winter and is advected towards the Arctic Basin, or transported south through Fram Strait. Retreating sea ice from the divergent ecoregion and other regions supplies the second ecoregion, the convergent ice ecoregion, with sea ice habitats for the polar bears of the Northern Beaufort Sea and East Greenland subpopulations. The seasonal ice ecoregion on the other hand, consists of only annual ice which completely melts in the summer, forcing bears from the Foxe Basin, Davis Strait, and Baffin Bay subpopulations onto land. In the archipelago ecoregion, annual and multiyear sea ice clings to the land and persists throughout the year, offering year-round access to sea ice for bears in Kane Basin, Norwegian Bay, Viscount-Melville Sound, Lancaster Sound, M'Clintock Channel, and the Gulf of Boothia.

Given current greenhouse gas emission levels and the rate of sea ice melt, Amstrup et al. (2008) listed the seasonal and divergent ice ecoregions as the most sensitive to climate change. Without mitigation of emissions, these regions could become inhospitable to polar bears by 2050 while populations in the archipelago and convergent ecoregions could become reduced (Amstrup et al. 2008, 2010). Of the 19 polar bear subpopulations, one is increasing, five appear to be stable, four are decreasing, and nine have insufficient information to inform a trend (Laidre et al. 2015a). The four declining subpopulations include the Southern Beaufort Sea (divergent ecoregion), Western Hudson Bay (seasonal ecoregion), Baffin Bay (seasonal ecoregion), and

Kane Basin (archipelago ecoregion). Polar bears from the Southern Beaufort Sea and Western Hudson Bay subpopulations are well-studied, whereas the connection between habitat changes and polar bear reproduction in Baffin Bay and Kane Basin is poorly understood.

The Baffin Bay subpopulation was last estimated at 2,074 ± 226 individuals in the 1990s (Taylor et al. 2005) and is contained within the borders created by the North Water Polynya to the north; the coast of West Greenland to the east; Baffin Island, Nunavut, Canada, to the west; and Cape Dyer, Baffin Island, to the south (Taylor et al. 2001; Fig. 2). The Kane Basin subpopulation was last estimated at 164 ± 35 individuals in the 1990s (Taylor et al. 2008), and is contained within the boundary set by the North Water Polynya to the south; Greenland to the east; and Ellesmere Island, Canada, to the west and north (Taylor et al. 2001; Fig. 2). The two subpopulations are not only close in proximity, but are genetically similar. A study by Paetkau et al. (1999) revealed that polar bears in Baffin Bay and Kane Basin are closely related due to the absence of significant microsatellite genetic variation between the two subpopulations. There was however a significant difference between bears in Baffin Bay and those in Davis Strait to the south. Studying the Baffin Bay and Kane Basin subpopulations provides the opportunity to examine how climate change may be affecting the reproductive behavior of two closely related subpopulations that occupy different ecoregions.

The present study utilized satellite telemetry data collected on the Baffin Bay and Kane Basin subpopulations from 1991–1997 and 2009–2015 in order to characterize any shifts in polar bear denning behavior. Our specific objective was to quantify shifts in maternity den phenology and habitat characteristics over space (latitudinal zones) and time. In addition to this main objective, we performed an exploratory investigation into potential differences in habitat characteristics of shelter dens between the two time periods, and constructed a map of potential maternity den habitat on Baffin Island using our results. We hypothesized that in comparison to the 1990s data, pregnant females in the 2000s would leave their dens earlier over time in correlation to the earlier break-up of sea ice. It was also expected that characteristics of maternity and shelter dens would remain the same over time, in accordance to the results of previous studies (Messier et al. 1994; Ferguson et al. 2000).

Methods

Study Area

The study area spanned $2.58x10^6$ km^2 from 65ºN to 82°N and from 50°W to 110°W, including Baffin Bay to the south and Kane Basin to the north (Fig. 2). Baffin Bay is a deep-water bay framed by Greenland to the east and Baffin Island to the west. The bay is characterized by a seasonal ice cycle where the sea ice almost completely disappears by late summer and begins to refreeze starting in October, followed by a period of complete coverage from December to April (Tang et al. 2004). In the spring, warm water flowing northward in the West Greenland Current causes the sea ice to melt along the western edge of Greenland (Tang et al. 2004) in a counterclockwise pattern, with the last ice melting along the coast of Baffin Island (Ferguson et al. 1997). The height of the coastal mountains on the islands surrounding Baffin Bay, including Baffin Island, has a strong effect on the precipitation patterns in the region with peak precipitation occurring in October (Seidel 1987). Due to its high-elevation mountainous terrain (> 2000 m; Ferguson et al. 1997), the eastern coast of Baffin Island receives more precipitation in the form of snow than surrounding islands (Andrews and Barry 1972; Crowe 1976; Maxwell 1980). Baffin Bay itself, however, receives very little precipitation (0.1 m per year; Appenzeller et al. 1998).

Kane Basin lies to the north of Baffin Bay between Ellesmere Island and Greenland. Smith Sound and the North Water polynya border the region to the south, and the Kennedy Channel borders the region to the north (Fig 2). Sea ice patterns in Kane Basin are heavily influenced by the North Water Polynya, an area of persistent open water maintained by strong prevailing winds moving southwards from Smith Sound (Dumont et al. 2009). In some years, an ice bridge forms across Smith Sound, preventing the transport of sea ice from the north (Tang et al. 2004). The sea ice in Kane Basin can persist well into June in years when an ice bridge forms. Without an ice bridge, sea ice is transported south and open water stretches into north Kane Basin during the summer months. Sea ice coverage in Kane Basin and North Water polynya varies widely from year to year (Heide-Jørgensen et al. 2013), though landfast ice can be commonly found along the coastal areas surrounding the North Water polynya (Shokr and Sinha 2015). The coasts of the islands bordering Kane Basin, including Ellesmere, Coburg, and Devon Islands (Fig. 2), receive relatively heavy precipitation in the winter (> 0.3 m annually; Ingram et al. 2002).

Data Collection

Satellite telemetry data were collected on 40 adult females from the Baffin Bay subpopulation from 2009 to 2015, and from 16 adult females from the Kane Basin subpopulation from 2012 to 2015. Baffin Bay bears were captured in the Melville Bay area of northwest Greenland between April and May of 2009–2013. Kane Basin bears were tagged off the eastern coast of Ellesmere Island between April and May of 2012–2013. All bears were darted and immobilized using methods established by Stirling et al. (1989), and equipped with Telonics TAW-4610H satellite telemetry collars (Telonics, Mesa, AZ). The collars were programmed to transmit during a 6-hour period each day on 4-day intervals. The Argos Data Collection and

Location System (Toulouse, France) received all transmissions from the tags and assigned a location quality score (LQ) based on the radius of error which is calculated using the number and strength of messages received by the satellites. Positions with an LQ of 1, 2, and 3 are within 500–1500 m, 250–500 m, and < 250 m of the true position of the animal respectively (Argos User Manual 2016). A LQ of zero has no presumed accuracy, and LQ scores of A, B, and Z are considered to be of poor quality. For this study, only positions with LQ scores of 1–3 were used.

The Argos files for each month were filtered by a speed-distance-angle filter from the "Argosfilter" package developed by Freitas et al. (2008) in the statistical software program R.3.0.2 (R Core Team 2013). The filter calculates the distance between two successive positions and determines whether this distance exceeds the maximum sustainable velocity for a polar bear, which we set as 10 km per hour. Any points inconsistent with the plausible upper limit of travel speed were viewed as erroneous and removed from the database.

Data collected on polar bear dens in the Baffin Bay and Kane Basin regions from 1991–1997 were originally published by Ferguson et al. (1997), and included 29 dens from Baffin Bay and nine from Kane Basin. The 1990s data were provided in the form of one position per day.

Determining Den Locations

Solitary females or females with two year-old cubs were considered candidates for denning the following winter after capture (Wiig 1998). All of the satellite collars provided temperature and motion data along with position coordinates. Temperature was measured by a thermistor within the collar (Fischbach et al. 2007). Although the reading from the collars is influenced by the animal's body temperature, the temperature reported by the collar is a general representation of the ambient temperature of the surrounding habitat (Harris et al. 1990). Temperature data were extracted from transmitters using the Telonics Data Converter software

(Version 2.21; Telonics, Mesa, AZ). Position and temperature data for bears identified as denning candidates were examined from July to June of the following year. Only one best quality position and one temperature reading were used for each day. The designated position for each day was selected by choosing the first position with the best LQ score. The temperature reading for each day was selected by first removing any temperature points ≥ 40ºC or ≤ –40ºC which were considered outliers (Tchernova 2010), and calculating the average. Three variables signal that a female is in a den: high temperature readings compared to ambient air temperature (10–40°C warmer), constant position on land, and decreased quality and frequency of transmissions (Amstrup and Garner 1994; Messier et al. 1994; Wiig 1998; Fischbach et al. 2007). Temperature data were available for all Baffin Bay bears, however only four of the Kane Basin bears provided useable temperature data.

Since transmissions were received on a 4-day duty cycle, the position data were particularly coarse since points found within the denning period did not closely center on a single den position, but rather consisted of a splatter of points within a small area. Most previous den studies do not describe exact methods for determining the den location. For their study, Andersen et al. (2012) used the first best quality position after emergence as the den position. However, since the collars for this study transmitted once every four days, an instrumented bear could have travelled a great distance away from the actual den site before providing a high-quality position. Instead, we devised a new method to determine the den sites for this study. First, the data for all adult females were examined for sustained high temperatures (greater than 0°C), decreased transmission quality and frequency, and a stationary position on land during the denning period (September through March). Since females give birth in December/January, they should be in their dens from December through February. Therefore we created a subset of the position data for each denning candidate during this time period and mapped the points in ArcMap v.10.1 (Environmental Systems Research Institute, Inc. [ESRI], Redlands, CA 2012). Individual point shapefiles were created from the identified subset for the three location quality categories: LQ 1, LQ 2, and LQ 3. A buffer was then drawn around each point with radii equivalent to the maximum error estimate for each LQ score (points with LQ 1 had a buffer of 1500 m, LQ 2: 500 m, LQ 3: 250 m). The mean center of the intersection of these buffers was then determined as the den position. The method provides a probable location for the den site based on the error estimate of the satellite telemetry positions during the denning period and is independent of the number of positions as well any spatial outliers. Note that not all of the dens were determined using this method, some bears had sparse location data within the denning period and thus the den positions had to be determined using variants of the buffer method.

Den Phenology Analyses

Length of denning was used to distinguish maternity dens from shelter dens. Shelter dens are typically occupied for a short period of time (> 14 days to < 4 months) whereas females will typically remain in maternity dens for > 5 months (Messier et al. 1994). Though shelter dens were included in the den habitat characteristics analyses, they were excluded from the phenology analyses since analyzing shelter den phenology was beyond the scope of this study. In addition to denning duration, den entry and exit dates were compared with the 1990s data (Ferguson et al. 2000). The exit date for each den was established as the median date between the female's last transmission from the den and the first movement outside the den, indicated by a significant drop in temperature and movement away from the den site. Most of the entry dates for the 2000s dens were determined by creating a 1 km buffer around each den site and taking the median date between the last date outside of the buffer and the first date inside the buffer. The entry date was then verified by comparing the autumn temperature data for each denning bear with temperature readings from a non-denning bear that same year to check for a difference of more than 10°C. The dates when the temperature readings diverged by $\geq$ 10°C were then compared to the entry dates determined by the position data (for notes on how the entry and exit dates were determined for each bear, see Appendix I). Both the den entry and exit dates were measured as day-of-year (DOY; Day #1 is 1 January), which we then used to calculate the denning duration in number of days (Messier et al. 1994; Wiig 1998; Ferguson et al. 2000).

To test for differences between the entry/exit dates between the 1990s and 2000s datasets, as well as duration spent in the dens without assuming normality, we applied two-sample Mann-Whitney U tests to the maternity den temporal data from the two subpopulations. Additionally we tested for a correlation between den entry date and latitude since Ferguson et al. (2000) found a significant correlation by using a Spearman's rank correlation test (r_s). However the Spearman's rank test is inappropriate for ties in the data, so we used a Kendall's tau test instead to compare the den entry/exit dates and duration with latitude within the two subpopulations. An alpha value of 0.05 was used for all statistical analyses.

First Date on Land

In addition to analyzing den phenology, the date of entry onto land was determined for each bear. First date on land (FDOL) was defined as the date that the bear first came onto land without returning to the sea ice until freeze-up the following fall (Cherry et al. 2013). For the pregnant bears, the first date on land was the date after which the bear did not return to the sea ice until she emerged in the spring. First dates on land for sheltering bears were also calculated, but not analyzed (See Appendix Tables II-IV).

Den Habitat Characteristics Analyses

All den positions were imported into ArcMap and overlaid with a digital elevation model (DEM) of the study area. The DEM consisted of a mosaic of tiles from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (ASTER GDEM; Version 2), a product of Japan's Ministry of Economy, Trade, and Industry (METI) and the United States National Aeronautics and Space Administration (NASA). The ASTER GDEM had an overall horizontal resolution of ~17 m at the 95% confidence interval with a vertical resolution of 75 m. The DEM was produced at a 22.625 x 22.625 m resolution with elevations positioned in the WGS 1984 datum and projected in a North Pole Stereographic projection with a central meridian of –55°W. The elevation, aspect, and slope of each den site were extracted from the DEM while straight-line distance to the nearest shoreline was measured using a vector shapefile of Canada's coastline (US Defense Mapping Agency). Elevation was calculated as the elevation of the cell containing the den site and was measured in meters. Aspect gives the compass direction (in degrees) the cell faces, while slope measures the rate of maximum change of elevation in degrees. Following the same procedure as Ferguson et al. (2000), the dens were sorted into three zones based on latitude: south (< 70°N), central (70–75°N), and north (> 75°N). Two-sample Mann-Whitney U tests were applied to the results to compare the habitat characteristics of both maternity and shelter dens between the 1990s and 2000s datasets, as well as within latitude zones and subpopulations.

In addition to the univariate analyses, a principal component analysis (PCA) using a correlation matrix was performed on the habitat data of the maternity dens in order to determine which variables drive any dissimilarity among the den sites. In the data matrix for the PCA, each den site was listed with its elevation, aspect, slope, and distance to coast. A second matrix organized the den sites into two groups, sample period (1990s or 2000s), and latitude zone (south, central, and north). Prior to the analyses, the environmental variables in each dataset were $\log_{10}$-transformed to control for skewed data (Kenkel 2006). After computing the PCA, a Monte Carlo randomized approach was used to test the significance of the eigenvalues ($\alpha = 0.05$). All analyses were performed using the statistical software R version 3.0.2 along with the "vegan" package (Oksanen et al. 2013) and the "Biostats" R package (McGarigal 2015).

In order to test for differences in environmental descriptors between the two groups, a permutational multivariate analysis of variance (perMANOVA) was performed on the maternity den matrix. PerMANOVA tests for group differences by applying an analysis of variance (ANOVA) to a distance matrix, and comparing variance within groups to the variance between groups. For the distance matrices, Euclidean distances were calculated for each $\log_{10}$-transformed and column-standardized matrix of raw data. This approach is a powerful tool for determining group similarity as it can partition variation among the different variables using any distance metric (Anderson 2001). The resulting *Pseudo-F* test statistic is the ratio of the among-group sum of squares to the within-group sum of squares. A permutation test was used to evaluate the significance of the *Pseudo-F* statistic as compared to a null hypothesis of no difference between groups.

Results from a perMANOVA only indicate the presence of differences between groups. Dissimilarity between groups could arise from differences in spread (variance), position in multivariate space, or some combination of the two. To determine the source(s) of dissimilarity, we applied a supplementary test of multivariate homogeneity of group dispersion (DISPER; Anderson 2006). DISPER involves computation of the distance of each group member to the group's centroid and applies an ANOVA to the distances with a null hypothesis of no difference in variation among groups.

Den Habitat Map for Baffin Island

Using the ranges (minimum–maximum) of elevation, aspect, slope, and distance from the coast, as identified for den sites found on Baffin Island from 1991–1997 and 2009–2015, a map of suitable denning habitat was created for the island using methods similar to those of Durner et al. (2013). Durner et al. used a high-resolution DEM obtained from Interferometric Synthetic Aperture Radar (IfSAR) data along with polar bear den habitat data to create a map of denning habitat in the National Petroleum Reserve on the North Slope of Alaska, USA. For this study, we used the ASTER DEM and created new rasters for elevation, aspect, and slope using the Raster Calculator tool. All cells with values that fell within the ranges for elevation/aspect/slope were coded with a '1' and the rest with a '0.' This created three binary rasters, one each for elevation, aspect, and slope. The Raster Calculator tool was then used to find the cells coded by a '1' in all three rasters. This step created a new binary raster where the cells that fit all three habitat criteria were coded with a '1.'

We clipped the binary raster using a polygon buffer drawn around Baffin Island that fit within the minimum–maximum distance to coast in order to reduce the habitat raster to the island's extent. This step was achieved by creating two buffers to the right of a line shapefile of Baffin Island, including Brodeur Peninsula (Fig. 2). The first buffer was the maximum distance to the coast, the second the minimum. We then erased the minimum distance buffer from the maximum distance buffer using the 'Erase' tool to create a polygon that fit our range. Using the 'Clip' tool in ArcMap, we clipped the habitat raster with the distance to coast polygon.

The newly clipped habitat raster was reclassified using the ‘Reclassify’ tool and all the ‘0’ cells were reclassified as ‘NoData’ in order to eliminate cells that did not meet the habitat criteria. We then simplified our raster using the ‘Boundary Clean’ and ‘Region Group’ tools (selecting for eight neighbors), and converted the raster to a polygon in order to calculate the area. The procedure was conducted for the 1990s and 2000s dens using the habitat results for the two time periods, respectively.

Results

Baffin Bay Subpopulation

We found 21 dens among the Baffin Bay subpopulation between 2009 and 2015, including 16 maternity dens (Fig. 3) and five shelter dens (Fig. 4). Ferguson et al. (1997) found 29 dens from the Baffin Bay subpopulation between 1991 and 1997 with eight maternity dens and 21 shelter dens (Table 1). All but one of the dens from the Baffin Bay subpopulation were located on land (one 1990s shelter den was located on landfast ice inside a fjord near the shore of Baffin Island), and the majority were found on Baffin Island (n = 38). The exceptions were four dens located on Bylot Island, two dens on Coburg Island, one den on Devon Island, one den on Prince Wales Island, and two dens in the Melville Bay region of northwest Greenland (maternity dens: Fig. 3; shelter dens: Fig. 4). The maternity den on Greenland was included in the phenology analyses but not the habitat characteristics analysis. The lowest latitude for the 1990s dens was 66.353°N, and for the 2000s dens 67.477°N.

There were a few interesting cases to note from the Baffin Bay subpopulation. One bear built a den in 2012 that was 1.25 km away from her previous denning site from 2009 on a peninsula close to Eglinton Fjord, Baffin Island (Fig. 5). This was the only case where a bear exhibited fidelity to a denning area among the bears that built a maternity den twice in our dataset ($n = 3$). The other females denned in areas far from previous den sites. Also, a different female built two maternity dens in consecutive years (2011 and 2012), indicating that she either lost her cubs in the intervening spring, or her pregnancy failed.

Kane Basin Subpopulation

For the Kane Basin subpopulation, nine dens were found from 2012 to 2015, consisting of three maternity dens (Fig. 3) and six shelter dens (Fig. 4). Ferguson et al. (1997) found nine dens total with three maternity dens and six shelter dens from 1992–1995 (Table 1). Almost all of the dens were on land with the exception of one 1990s shelter den that was located on landfast ice nine kilometers from the shore of Ellesmere Island. Most of the dens were located on Ellesmere Island except for three dens on Devon Island (Figs. 3 and 4). None of the females from the Kane Basin subpopulation denned on Greenland. The minimum latitude for the 1990s dens was 77.942°N, and for the 2000s dens 77.039°N.

All Dens

In both Baffin Bay and Kane Basin, the majority of the dens were found on a north-facing slope ($n = 21$) and were located within 21 km of the coast (Tables 2 and 3). All of the maternity dens were located further inland than shelter dens, averaging 8.5 km from the coast in comparison to 6 km among shelter dens. On average, the maternity dens were also located at higher elevations (524.2 m) in comparison to shelter dens (395.7 m) (t-test p-value = 0.086). The majority of the dens were located in the central latitudinal zone (70–75° N, $n = 28$), with an almost equal number of dens in the northern (> 75° N, $n = 21$) and southern latitudinal zones (< 70° N, $n = 19$), though it should be noted that all dens from Kane Basin were in the north latitudinal zone (Tables 4 through 6). One bear denned a little less than 35 km away from Qikiqtarjuaq, however most bears denned far from human settlements ($\bar{x} = 143.1$ km).

Den Phenology Comparison

In the Baffin Bay subpopulation, female polar bears in the 2000s on average spent less time in their dens ($\bar{x}$ = 167.1 days, SD = 27.6 days) than in the 1990s ($\bar{x}$ = 194.1 days, SD = 21 days; Table 7). The Mann-Whitney U test found a significant difference in den duration between the two time periods with a p-value of 0.017 (Fig. 6). Timing of entry in the dens differed significantly among the two periods ($p = 0.018$), however no significant difference was found among exit dates ($p = 0.399$; Fig. 7). The median entry date for dens in the 2000s dataset (3 October) was more than a full month later than the median date of entry for dens in the 1990s (28 August). Therefore, differences in entry dates accounted for the observed difference in duration among the two time periods. There was no significant correlation between latitude and den entry ($\tau = 0.135$, $p = 0.383$) and exit dates ($\tau = 0.194$, $p = 0.212$) for the Baffin Bay maternity dens, and the negative correlation of den duration with latitude was not significant ($\tau = -0.167$, $p = 0.278$).

For the Kane Basin subpopulation, there was no significant difference in denning duration ($p = 1$) (Table 8; Fig. 8), or among the entry dates ($p = 0.6$) and exit dates ($p = 1$) (Fig. 9). There was no significant correlation between latitude and Kane Basin maternity den entry dates ($\tau = 0.138$, $p = 0.848$), or duration ($\tau = 0.2$, $p = 0.707$). However the positive correlation between den exit dates and latitude exit dates was almost significant ($\tau = 0.733$, $p = 0.06$).

First Date on Land

The first dates on land (FDOL) were analyzed for all pregnant bears. For most of the 1990s dens, the date of the first position on land was after the listed den entry date, therefore the first date on land was also the first date in the den ($n = 7$; Appendix Tables II and IV). In the 2000s dataset, some of the FDOLs had to be determined using poorer quality positions (LQ of 0, A, B, and Z) due to gaps in the best quality positions (*n* = 5). In these cases, the latitude of the bears' arrival was determined to be the latitude of the best quality position of the group, or a calculated mean center of the points. Most of the bears came onto land and then slowly made their way to the den area, averaging 11 days in the 1990s and 55 days in the 2000s between the FDOL and den entry date (Appendix Tables II-IV). Two bears from the Baffin Bay subpopulation returned to the sea ice before entering their den in the 2000s dataset, and thus had two FDOLs: the first date they came onto land (in the late summer/early fall), and the first date on land before they entered their dens (Appendix Table II).

Two-sample Mann-Whitney U tests were applied to five data matrices: all pregnant bears with the first FDOL, all pregnant bears with the second FDOL for the two Baffin Bay bears, Baffin Bay pregnant bears with the first FDOL, Baffin Bay pregnant bears with the second FDOL, and Kane Basin pregnant bears with their FDOLs. The Mann-Whitney U test generated significant *p*-values for the matrices with all pregnant bears and Baffin Bay pregnant bears (first and second FDOL), but not for the Kane Basin bears (see Table 9 for *p*-values). Therefore the dates of entry onto land in the 2000s significantly differed from the 1990s for all pregnant females, and this difference was most likely driven by a difference among the Baffin Bay subpopulation given that the result for Kane Basin was insignificant. The median first date on land among the Baffin Bay maternity denning bears was 7 August in the 2000s (SD = 9.1 days) compared to 25 August in the 1990s (SD = 19 days) (Fig. 10). Among the Kane Basin bears, the median first date on land for the three pregnant females in the 1990s was 18 September (SD = 31 days) whereas the median date for the 2000s was 23 August (SD = 20.8 days; Fig. 11). Small sample size and large variation among the Kane Basin FDOLs could explain why the difference between the two time periods was not significant despite the median FDOLs being 27 days apart.

A Kendall's tau test was also applied to the five FDOL matrices to identify any correlation between FDOL, latitude and elevation. The test did not detect a significant correlation between latitude and first date on land for any of the matrices (see Table 9). There was a significant correlation between elevation and the FDOL for the all pregnant females matrix with first FDOL ($\tau = -0.27$, $p = 0.04$), and the matrix with the second FDOL ($\tau = -0.372$, $p = 0.005$; Table 9).

Den Habitat Characteristics Analyses

For the comparison of habitat characteristics within subpopulations, the elevation and slope significantly differed between the 1990s and 2000s maternity dens for the Baffin Bay subpopulation only ($p = 0.003$; Table 10). There were more dens at mid to high elevations and steeper slopes in the 2000s data than in the 1990s (Fig.12). The average elevation and slope among the 2000s Baffin Bay maternity dens (elevation: $\bar{x} = 707$ m, SD = 284.9 m; slope: $\bar{x} = 23.1°$, SD = 7.4°) was double that of the 1990s dens (elevation: $\bar{x} = 351.3$ m, SD = 194.5 m; slope: $\bar{x} = 11.9°$, SD = 6.4°; Table 2). Although most dens were found at southern-facing aspects in the 2000s data and most dens were found at northern-facing aspects in the 1990s (Fig. 12), no significant difference was detected between the two time periods ($p = 0.392$). Females in both subpopulations maintained similar distance to coast between the two time periods (Figs. 12 and 13). Habitat characteristics among the Kane Basin maternity dens did not significantly differ (Fig. 13; Table 10), and there were no significant differences among the habitat characteristics of shelter dens for either subpopulation (Table 10).

The Mann-Whitney U test comparing habitat characteristics between the 1990s and 2000s within the latitudinal zones only produced significant results for the central zone (70–75°N latitude). Both the elevation and slope of maternity dens in the central zone significantly differed between the two time periods (elevation: $p = 0.004$, slope: $p = 0.019$; Table 11). Maternity dens in this region were found at much higher elevations in the 2000s ($\bar{x} = 659.3$ m, SD = 89.1 m) than in the 1990s ($\bar{x} = 326.2$ m, SD = 209.2 m), with much steeper slopes (2000s: $\bar{x} = 25.1°$, SD = 6°; 1990s: $\bar{x} = 11.2°$, SD = 8.3°). For the shelter dens only the elevation significantly differed among 1990s and 2000s dens in the central zone ($p = 0.006$; Table 11), with an average elevation for the 2000s dens of 618.7 m (SD = 114.3 m) compared to 223.4 m for the 1990s (SD = 175.7 m).

Due to the small sample size for Kane Basin, we were restricted to performing a principal component analysis (PCA) on the Baffin Bay maternity dens only. The PCA ordination analysis on the Baffin Bay maternity dens matrix produced two principal components (PC) that together explained 65.69% of the variation (Table 12). The first component, PC 1, explained 37.31% of the variation and had strong loadings from elevation and slope (loadings > 0.6 or < –0.6 were considered significant; Table 12). PC 2 explained almost a third of the variation at 28.38% and was strongly loaded by aspect. We tested the statistical significance of the first four eigenvalues by applying a Monte Carlo randomization test and found both PC 1 ($p = 0.455$) and PC 2 ($p = 0.4$) to be insignificant. The perMANOVA analysis detected a significant difference between the habitat variables of the year groups ($p = 0.003$), but not the latitudinal zone group ($p = 0.775$).

To check the results of the comparison between year groups for the Baffin Bay maternity dens dataset, the year groups were visualized in ordination space using a PCA biplot, with dispersion ellipses drawn around the year groups using the ordiellipse function from the "vegan" package (Fig. 14). The ellipses are drawn around the standard deviations of the point scores, and the directions of their principal axes are defined by the weighted correlations (Oksanen et al. 2013). In the biplot, most of the 2000s maternity dens are positioned to the left of the plot whereas the 1990s dens are on the right. Since elevation and slope had the highest loadings for PC 1, the dens in the left half of the biplot have higher elevation and slope than those to the right. Another important observation to note is that the ellipses hardly overlap for the two time periods. This reinforces our earlier results showing a significant difference in habitat characteristics between the 1990s and the 2000s. The DISPER test on group dispersion did not indicate a significant difference in the variances among the year or zone groups. Therefore the observed difference between the year groups cannot be attributed to variance alone.

Den Habitat Map for Baffin Island

A total of 13 maternity dens from the 2000s dataset and seven from the 1990s dataset were found on Baffin Island (Fig. 15). The polygon generated from the results for the 1990s and 2000s habitat ranges combined covered 35.9% of the area of Baffin Island (555,223 km^2 including Brodeur Peninsula). The total area for the 1990s den habitat was 80,380.2 km^2 while the total area for the 2000s den habitat was 119,191.4 km^2, a difference of 38,811.2 km^2. The disparity between the two areas was due to a larger range for slope and elevation among the 2000s Baffin Island dens in comparison to the 1990s dens. All human settlements on Baffin Island with the exception of Cape Dorset are located within 10 km of potential maternity den areas (Fig. 15). The habitat map could have been refined further if we had snow depth data at the time of den entry. However there were no terrestrial snow depth datasets available that matched the spatial and temporal resolution of our data. Also, the potential den habitat extends beyond the boundaries of the Baffin Bay subpopulation. Therefore the map is not restricted to Baffin Bay bears only, but rather illustrates the areas that meet the minimum elevation, slope, aspect, and distance to coast requirements set by the results from the subpopulation.

Discussion

The purpose of this study was to determine whether the phenology and habitat characteristics of polar bear maternity dens have shifted since the 1990s in Baffin Bay and Kane Basin. The results show that both the phenology and habitat characteristics of maternity dens in Baffin Bay have changed, but we did not detect any shifts in Kane Basin largely due to small sample sizes. In Baffin Bay, den duration was significantly shorter in the 2000s than in the 1990s due to females entering their dens later in the fall. Additionally, when compared to maternity dens in Baffin Bay in the 1990s those in the 2000s were found at higher elevations and steeper slopes, while aspect and distance to coast remained consistent. Females also came onto land significantly earlier in the year in the 2000s than they did in the 1990s, whereas there was no significant difference detected between the two time periods for Kane Basin females. As for the shelter dens, there were no significant differences in habitat characteristics for either of the subpopulations.

For the Baffin Bay subpopulation, the data did not support our hypothesis that earlier sea ice break-up dates would result in earlier emergence from the dens. Rather, females entered their dens later in the year in the 2000s than they did the 1990s, shortening the total time spent in their dens. This change could have resulted from females returning to the sea ice after the ice-free period to hunt and build-up their fat reserves before denning. Previous studies have documented pregnant females hunting out on the sea ice as late as December (Koettlitz 1898; Harington 1962), as well as bears leaving their dens to return to the coast to hunt (Harington 1964) possibly due to insufficient fat reserves. In Baffin Bay, the sea ice melted an average of 7 days/decade earlier in the spring and formed an average 5.2 days/decade later in the fall from 1979 to 2013, thus effectively lengthening the ice-free period in the region (Laidre et al. 2015a). With less time to hunt out on the sea ice, bears are coming onto land in poorer condition as evidenced by a decline in girth observed by Rode et al. (2012) among Baffin Bay bears. Polar bears in this region are under intense food stress and consequently pregnant females may try to maximize their time hunting and scavenging rather than immediately establishing a den site once on land.

Alternatively, the sea ice may be melting so quickly that females are forced onto land in less optimal habitat and must travel farther distances to find favorable den sites. In general, female polar bears do not exhibit fidelity to specific sites, though they have been known to return to the area of previous dens (Amstrup and Gardner 1994). One explanation for this behavior is that these areas are located close to where the females successfully caught seals in the past. Thus, a female may select a den site known to have a relatively short route back to desirable hunting grounds once she emerges in the spring (Ramsay and Andriashek 1986; Ramsay and Stirling 1990). By this reasoning, if a female is marooned on land far from familiar or optimal areas, she may choose to travel back to the favorable denning regions even if it means establishing her den later in the year. This hypothesis could also explain why den duration decreased with increasing latitude. Females who denned in the high latitude regions may have been forced onto land farther south by the melting sea ice and had to travel greater distances to reach their desired den area, thus delaying their entry date.

Another possible explanation for the delayed entry dates as well as the observed difference in elevation and slope is that there may be fewer multi-year snowdrifts at lower elevations now than in the past due to warmer annual temperatures. Consequently, females must climb to higher elevations in order to find suitable snow accumulations in which to excavate a den. In some regions, females “build” dens by simply lying in a depression in a previous year’s snowdrift and waiting until enough snow accumulates on top of her before excavating a den

(Jonkel et al. 1972). Due to size of the dens, snowdrifts that are at least 2m deep are required (Liston et al. 2016). Thus, the presence of snowdrifts is most likely an important factor in den selection for Baffin Bay females. Furthermore, snow density also determines the quality of a den site as hard snow can make excavation difficult (Harington 1968). Examining average snow depth and density, as well as the distribution of snowdrifts in denning regions could potentially explain the difference observed in den elevations between the two time periods, and should be explored in future analyses.

Our finding that aspect and distance to coast remained approximately the same between the two time periods is consistent with results from previous studies. The majority of females in the Canadian Arctic Archipelago build their dens within 10 to 16 km of the coast (Harington 1968; Messier et al. 1994; Ferguson et al. 2000), most likely to minimize their travel time back to the sea ice in the spring. There is some variability in the literature on preferable aspects for polar bear dens. In the Canadian Arctic Archipelago, south-facing slopes tend to have better snow due to the transport of precipitation by northerly winds, making these areas excellent denning habitat (Harington et al. 1968; Schweinsburg et al. 1984). They also receive the highest solar radiation, making for a warmer environment for the cubs once they emerge from the den (Van de Velde 1957; Harington 1962). For these reasons, most dens in this area are found on southern-facing slopes (Stirling 2011), which is consistent with our results for the 2000s Baffin Bay maternity dens ($n = 7$) and the majority of the Kane Basin maternity dens for both time periods ($n = 4$). However, north-facing slopes may provide enough shade from the sun to preserve the snowdrifts (Uspenski and Chernyavski 1965), possibly explaining why many of the maternity dens were found on north-facing slopes ($n = 6$).

Shelter dens had a large range of elevation and slope values, consistent with protocols under which females may not select for certain characteristics when creating a shelter den. Rather an individual, for example, may simply find the best available location to take shelter during a storm, or to wait for food to become available. Although it was beyond the scope of this study, it would be interesting to examine the shelter den data to see if females are building more or fewer shelter dens during the different seasons. A rise in the occurrence of shelter dens could indicate amplified environmental stressors, such as higher temperatures or decreased food availability in the summer months, or harsher storms in the winter.

Females in Baffin Bay are spending less time in their dens due to later entry dates, which could signal increased food stress and/or lower quality den habitat. Furthermore, the distribution of maternity dens in this region is shifting to higher elevations and steeper slopes. The increased use of these upper slope habitats for maternity dens most likely explains why we found a larger area of potential den habitat on Baffin Island using the 2000s habitat results than the 1990s results. Adding data on the distribution of snowdrifts at the time of denning to the habitat map could further refine the range of potential den habitat on Baffin Island, and should be included in future versions.

The results from Kane Basin contrast with the results from the Baffin Bay subpopulation in that there were no significant changes in either the phenology or habitat characteristics of maternity dens despite similar declines in sea ice. However, our small sample sizes in Kane Basin requires for more data in order to draw any conclusions.

Conclusion

For this study, our goal was to determine if the phenology and habitat characteristics of maternity dens have shifted in the Baffin Bay and Kane Basin polar bear subpopulations since the 1990s. Using satellite telemetry data collected on adult females from 2009–2015, we developed a procedure for modelling den positions, and for calculating the entry and exit dates using the polar bears' movement and temperature data. Since we had to model the den positions based on satellite telemetry data and estimate the entry/exit dates without the ability to ground truth our methods, the phenology results and den positions for the 2000s dens were approximations. Additionally, the raw movement data for the 1990s females were not available during the actual denning periods of the bears. Instead, the position data for the dates within the denning period consisted of only the coordinates for the den sites determined by Ferguson et al. (1997, 2000). Therefore we were unable to independently determine the 1990s den positions or entry/exit dates using our methods. Despite these main limitations, this study demonstrates the utility of satellite telemetry data as a means of studying shifts in phenology and habitat use among species that occupy remote environments.

The focus of previous biological phenology studies has largely centered on studying the timing of reproduction such as egg-laying among birds and amphibians (Beebee 1994; Crick 1997; Brown et al. 1999), seasonal events such as leaf-opening among plants, and the arrival of migrating birds (Hüppop and Hüppop 2003; Gordo et al. 2005) and butterflies (Roy and Sparks 2000; Forister and Shapiro 2003; Stefanescu et al. 2003). The majority of previous phenological studies required long term monitoring and years of observations in order to make the connection between detected phenology shifts and environmental modifications brought on by climate change. A minimum of 19 to 20 years of data is recommended for studies examining the biological impact of climate change (Rosenzweig et al. 2008; Brown et al. 2015). Though our data spans 24 years and meets the requirement, the detected phenological shift in Baffin Bay cannot be fully attributed to climate change rather than annual variability just yet. Harington

(1968) observed females entering their dens on eastern Baffin Island from the 1st to the 7th of October, considerably later than the range for the 1990s dens published by Ferguson et al. (2000). Therefore entry dates among Baffin Bay bears may vary widely and later den entry dates could be a normal occurrence. Moreover, the results of this study cannot attest to the rate of change due to the fact that we did not continuously monitor the subpopulations between 1991 and 2015. In order to confidently ascribe the shift in den entry dates to climate change, more data over a longer time span are needed and thus we recommend conducting a similar study in the near future.

Driven by physiological tolerances and habitat requirements, species also tend to shift their ranges polewards and to higher latitudes in response to rising temperatures (Peters 1992; Parmesan and Yohe 2003; Root et al. 2003; Parmesan 2006; Parry et al. 2007). In their meta-analysis of distribution data for 16 taxonomic groups found in terrestrial and freshwater habitats in Great Britain, Hickling et al. (2006) found that 275 species out of 329 had shifted their range northwards while 227 species had shifted to higher altitudes. Though we did not detect a northwards shift in den distribution, the results for the Baffin Bay subpopulation show that female polar bears extended their denning range to higher elevations. Similar to the phenology results, it may be too early to attribute use of high altitude habitats to declines in habitat quality rather than other biological drivers, such as competition with other females for dens sites. The rapid changes occurring in the Arctic due to climate warming however leave little doubt that a lack of adequate denning substrate in the form of snowbanks may have been a significant factor in the expansion of denning to higher elevations.

Previous studies examining change in polar bear denning behavior over time are few in number and focus on only some of the 19 subpopulations. A study by Laidre et al. (2015b) on

East Greenland females revealed earlier den entry dates in 2007–2010 in comparison to 1993–1998. Messier et al. (1994) similarly found that bears in McClure Strait and Viscount Melville Sound entered their dens earlier in 1989–1992 in comparison to previous studies on polar bears in the High Arctic (Harington 1968; Jonkel et al. 1972; Stirling et al. 1980). In both cases, the bears exited their dens around the same time. Expanding this study to other subpopulations could help determine if our observed changes are unique to the Baffin Bay subpopulation and thus are only a regional effect, or if polar bear maternity den characteristics and phenology are changing throughout their range. More studies are also needed to determine the degree to which maternity den distribution is fluctuating. Previous work examining shifts in den distribution are similarly restricted to a small portion of the Arctic, and mostly examined shifts in den ecology in relation to changes in sea ice (Fischbach et al. 2007; Derocher et al. 2011). The results of this study highlight the need for monitoring changes in snowpack throughout the Arctic and its impact on den distribution, not just the sea ice.

As demonstrated by this study, satellite telemetry can be a powerful tool for studying phenology and habitat use, especially for species that live in hard to access areas. Methods from this study could be applied to examining shifts in the denning behavior of other bear species, or other important phenological events for any organism that can be equipped with a tag or collar and reliably tracked over time. Continuing to monitor the phenology and habitat use of polar bears and other species will play an important role in tracking the biological impact of climate change, and will greatly assist in future conservation efforts.

Literature Cited

Amstrup SC, Gardner C (1994) Polar bear maternity denning in the Beaufort Sea. J Wildl Manage 58:1–10

Amstrup SC (2003) Polar Bear. In: Feldhammer GA, Thompson BC, Chapman JA (eds) Wild mammals of North America, biology, management and conservation, 2nd edn. Johns Hopkins University Press, Baltimore, pp 587–610

Amstrup SC, Marcot BG, Douglas DC (2008) A Bayesian network modeling approach to forecasting the 21st century worldwide status of polar bears. In: DeWeaver ET, Bitz CM, Tremblay L-B (eds) Arctic sea ice decline: observations, projections, mechanisms and implications, Geophys Monogr Ser 190, Am Geophys Union, Washington DC, pp 213–268

Amstrup SC, DeWeaver ET, Douglas DC, Marcot B, Durner GM, Bitz CM, Bailey DA (2010) Greenhouse gas mitigation can reduce sea-ice loss and increase polar bear persistence. Nature 468:955–958

Andersen M, Derocher AE, Wiig Ø, Aars J (2012) Polar bear (*Ursus maritimus*) maternity den distribution in Svalbard, Norway. Polar Biol 35:499–508

Anderson MJ (2001) A new method for non-parametric multivariate analysis of variance. Austral Ecology 26:32–46

Anderson MJ (2006) Distance-based tests for homogeneity of multivariate dispersion. Biometrics 62:245–253

Andrewartha H, Birch C (1954) The distribution and abundance of animals. University of Chicago Press, Chicago

Andrews JT, Barry RG (1972) Present and paleo-climatic influences on the glacierization and deglacierization of Cumberland Peninsula, Baffin Island, N.W.T., Canada. University of Colorado, Institute of Arctic and Alpine Research. Occasional Paper Number 2. Boulder, Colorado

Appenzeller C, Schwander J, Sommer S, Stocker TF (1998) The North Atlantic Oscillation and its imprint on precipitation and ice accumulation in Greenland. Geophys Res Lett 25:1939–1942

Atkinson SN, Ramsay MA (1995) The effect of prolonged fasting on the body composition and reproductive success of female polar bears (*Ursus maritimus*). Funct Ecol 9:559–567

Badeck F-W, Bondeau A, Böttcher K, Doktor D, Lucht W, Schaber J, Sitch S (2004) Responses of spring phenology to climate change. New Phytol 162:295–309

Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer TM, et al (2002) Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biol 8:1–16

Beebee TJC (1994) Amphibian breeding and climate. Nature 374:219–220

Belikov SE (1980) Distribution and structure of dens of female polar bears in Wrangel Island. Ursus 4:117

Blix AS, Lentfer JW (1979) Modes of thermal protection in polar bear cubs—at birth and on emergence from the den. Am J Physiol 236:R67–R74

Bromaghin JF, McDonald TL, Stirling I, Derocher AE, Richardson ES, Regehr EV, Douglas DC, Durner GM, Atwood T, Amstrup SC (2015) Polar bear population dynamics in the southern Beaufort Sea during a period of sea ice decline. Ecol App 25(3):634–651

Brown JL, Shou-Hsien L, Bhagabati N (1999) Long-term trend toward earlier breeding in an American bird: a response to global warming? Proc Natl Acad Sci USA 96:5565–5569

Brown CJ, O’Connor MI, Poloczanska ES, Schoeman DS, Buckley LB, Burrows MT, Duarte CM, Halpern BS, Pandolfi JM, Parmesan C, Richardson AJ (2015) Ecological and methodological drivers of species’ distribution and phenology responses to climate change. Global Change Biol. doi: 10.1111/gcb.13184

Charmantier A, McCleery R, Cole L, Perrins C, Kruuk L, Sheldon B (2008) Adaptive phenotypic plasticity in response to climate change in a wild bird population. Science 320:800–803

Chen I-C, Hill JK, Ohlemüller R, Roy DB, Thomas CD (2011) Rapid range shifts of species associated with high level of climate warming. Science 333(6045):1024–1026

Cherry SG, Derocher AE, Thiemann GW, Lunn NJ (2013) Migration phenology and seasonal fidelity of an Arctic marine predator in relation to sea ice dynamics. J Anim Ecol 82:912–921

CLS (Collecte Localisation Satellites) (2016) Argos user’s manual. http://www.argos-system.org/manual/. Accessed 16 March 2016

Crick HQP, Dudley C, Glue DE, Thomson DL (1997) UK birds are laying eggs earlier. Nature 388:526

Crowe RB (1976) A climate classification of the Northwest Territories for recreation and tourism. Enviornment Canada, Atmospheric Environment Service, Meterological Application Branch. Project Report Number 25. Toromto, Ontario 232 pp

DeMaster DP, Stirling I (1981) *Ursus maritimus.* Mamm Species 145:1–7

Derksen C, Brown R (2012) Spring snow cover extent reductions in the 2008-2012 period exceeding climate model projections. Geophys Res Lett 39(19)

Derocher AE, Stirling I (1990) Distribution of polar bears (*Ursus maritimus*) during the ice-free period in western Hudson Bay. Can J Zoology 68:1395–1403

Derocher AE, Stirling (1996) Aspects of survival in juvenile polar bears. Can J Zool 74:1246–1252

Derocher AE, Stirling (1998) Maternal investment and factors affecting offspring size in polar bears (*Ursus maritimus*). J Zool 245(3):253–260

Derocher AE, Lunn NJ, Stirling I (2004) Polar bears in a warming climate. Integr Comp Biol 44:163–176

Derocher AE, Andersen M, Wiig Ø, Aars J, Hansen E, Biuw M (2011) Sea ice and polar bear den ecology at Hopen Island, Svalbard. Mar Ecol Prog Ser 441:273–279

Dumont D, Gratton Y, Arbetter TE (2009) Modeling the dynamics of the North Water Polynya Ice Bridge. J Phys Oceanogr 39:1448–1461

Durner GM, Simac K, Amstrup SC (2013) Mapping polar bear maternal denning habitat in the National Petroleum Reserve – Alaska with an IfSAR Digital Terrain Model. Arctic 66(2):197–206

ESRI (2012) ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute

Ferguson SH, Taylor MK, Messier, F (1997) Space use by polar bears in and around Auyuittuq National Park, Northwest Territories, during the ice-free period. Can J Zool 75(10):1585–1594

Ferguson SH, Taylor MK, Rosing-Asvid A, Born EW, Messier F (2000) Relationships between denning of polar bears and conditions of sea ice. J Mammal 81:1118–1127

Field CB, Barros VR, Mach KJ, et al (2014) Technical summary. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate Change 2014: Impacts, Adaptation, and Vulnerability Part A: Global and Sectoral Aspects Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 35–94

Fischbach AS, Amstrup SC, Douglas DC (2007) Landward and eastward shift of Alaskan polar bear denning associated with recent sea ice changes. Polar Biol 30:1395–1405

Forchhammer MC, Post E, Stenseth NC (1998) Breeding phenology and climate. Nature 391:29–30

Ford MJ (1982) The Changing Climate. George Allen and Unwin, London

Forister ML, Shapiro AM (2003) Climatic trends and advancing spring flight of butterflies in lowland California. Global Change Biol 9:1130–1135

Freitas C, Lydersen C, Fedak MA, Kovacs KM (2008) A simple new algorithm to filter marine mammal Argos locations. Mar Mam Sci 24:315–325

Gleason HA (1917) The structure and development of the plant association. Bull Torrey Bot Club 43:463–481

Gordo O, Brotons L, Rerrer X, Comass P (2005) Do changes in climate patterns in wintering areas affect the timing of the spring arrival of trans-Saharan migrant birds? Global Change Biol 11(1):12–21

Graham RW, Grimm EC (1990) Effects of global climate change on the patterns of terrestrial biological communities. Trends Ecol Evol 5:289–292

Grinell J (1917) Field tests of theories concerning distributional control. Am Nat 51:115–128

Hansen JM, Sato M, Ruedy R, Lo K, Lea DW, Medina-Elizade M (2006) Global temperature change. PNAS 103:14288–14293

Harington CR (1962) Polar bear study – Resolute Bay area, Northwest Territories, 1961. Can Wild Serv Rep

Harington CR (1964) Field notes. Southampton Island, Northwest Territories, 1964

Harington CR (1968) Denning habits of the polar bear (*Ursus maritimus* Phipps). Can Wild Serv Rep 5:1–30

Harington CR (2008) The evolution of Arctic marine mammals. Ecol Appl 18:S23–S40

Harris RB, Fancy SG, Douglas DC, Garner GW, Amstrup SC, McCabe TR, Pank LF (1990) Tracking wildlife by satellite: current systems and performance. U.S. Fish and Wildl Serv Tech Rep 30

Heide-Jørgensen MP, Burt LM, Hansen RG, Nielsen NH, Rasmussen M, Fossette S, Stern H (2013) The significance of the North Water polynya to arctic top predators Ambio 42(5):596–610

Hickling R, Roy DB, Hill JK, Fox R, Thomas CD (2006) The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biol 12(3):450–455

Hinzman LD, Deal CJ, McGuire AD, Mernild SH, Polyakov IV, Walsh JE (2013) Trajectory of the Arctic as an integrated system. Ecol Appl 23(8):1837–1868

Hunter CM, Caswell H, Runge MC, Regehr EV, Amstrup SC, Stirling I (2010) Climate change threatens polar bear populations: a stochastic demographic analysis. Ecology 91(10):2883–2897

Hüppop O, Hüippop K (2003) North Atlantic Oscillation and timing of spring migration in birds. Proc R Soc London Ser B 270:233–40

Ingram RG, Bâcle J, Barber DG, Gratton Y, Melling H (2002) An overview of physical processes in the North Water Deep-Sea Res Pt II 49:4893–4906

Inouye DW, Barr B, Armitage K, Inouye BD (2000) Climate change is affecting altitudinal migrants and hibernating species. P Natl Acad Sci 97(4):1630–1633

IPCC (2013) Summary for Policymakers: In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TG, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds)]. Cambridge University Press, Cambridge, UK and New York, NY, USA

IPCC (2014) Climate Change 2014: Synthesis Report Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team: Pachauri RK, Meyer LA (eds)]. IPCC, Geneva, Switzerland, 151 pp

Jonkel CJ, Kolenosky GB, Robertson RJ, Russell RH (1972) Further notes on polar bear denning habits. Ursus 2:142–158

Kenkel NC (2006) On selecting an appropriate multivariate analysis. Can J Plant Sci 86(3):663-676.

Klopfer PH (1962) Behavioral aspects of ecology. Concepts of modern biology series. Prentice-Hall, Englewood Cliffs

Knowlton JL, Graham CH (2010) Using behavioral landscape ecology to predict species' responses to land-use and climate change. Biol Cons 143(6):1342–1354

Koettlitz R (1898) Contributions to the natural history of the polar bear (*Ursus maritimus*). Proc Roy Phys Soc 14:266–277

Kovacs KM, Lydersen C, Overland JE, Moore SE (2011) Impacts of changing sea-ice conditions on Arctic marine mammals. Mar Biodiv 41:181–194

Krupnik I, Jolly D (2002) The Earth is faster now: indigenous observations of Arctic environmental change. Arctic Research Consortium of the United States, Fairbanks

Kullman L (1983) Past and present tree lines of different species in the Handolan Valley, Central Sweden. In Tree Line Ecology. Morisset P, Payette S (eds), pp 25–42. Centre d'études nordiques de l'Université Laval, Quebec

Laidre KL, Stirling I, Lowry LF, Wiig Ø, Heide-Jørgensen MP, Ferguson SF (2008) Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecol App 18:S97–S125

Laidre KL, Stern H, Kovacs KM, Lowry L, Moore SE, Regehr EV, Ferguson SH, Wiig Ø, Boveng P, Angliss RP, Born EW, Litovka D, Quakenbush L, Lydersen C, Vongraven D, Ugarte F (2015a) Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st Century. Conserv Biol 29(3)724–737

Laidre KL, Born EW, Heagerty P, Wiig Ø, Stern H, Dietz R, Aars J, Andersen M (2015b) Shifts in female polar bear (*Ursus maritimus*) habitat use in East Greenland. Polar Biol 38:879–893

Lentfer JW, Hensel RJ (1980) Alaskan polar bear denning. Ursus 4:101–108

Liston GE, Perham CJ, Shideler RT, Cheuvront AN (2016) Modeling snowdrift habitat for polar bear dens. Ecol Model 320:114–134

MacArthur R (1972) Geographical ecology: Patterns in the distribution of species. Harper and Row, New York

Martin TE (2001) Abiotic vs. biotic influences on habitat selection of coexisting specie: climate change impacts? Ecology 82(1):175–188

Maxwell JB (1980) The climate of the Canadian arctic islands and adjacent waters. Volume 1. Environment Canada, Atmospheric Environment Service. Hull, Quebec. 531 pp

McGarigal K (2015) BIOSTATS documentation. www.umass.edu/landeco/teaching/ecodata/labs/biostats.pdf

Messier F, Taylor MK, Ramsay MA (1994) Denning ecology of polar bears in the Canadian Arctic Archipelago. J Mammal 75(2):420–430

Moore SE, Huntington HP (2008) Arctic marine mammals and climate change: impacts and resilience. Ecol Appl 18:157–165

Obbard ME, Thiemann GW, Peacock E, DeBruyn TD eds (2010) Polar bears: proceedings of the 15th working meeting of the IUCN/SSC Polar Bear Specialist Group, Copenhagen, Denmark, 29 June-3 July 2009 Gland, Switzerland and Cambridge, UK:IUCN Vii, 235 pp

Oksanen J, Blanchet FG, Kindt R, Legendre P, Michin PR, O'hara RB, Simpson PS, Solymos P, Stevens HH, Wagner HH (2013) Vegan: Community Ecology Package. R package version 2.0–9. http://CRAN.R-project.org/package=vegan

Paetkau D, Amstrup SC, Born EW et al (1999) Genetic structure of the world's polar bear populations. Mol Ecol 8:1571–1584

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37:637–669

Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) (2007) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge and New York

Perovich DK, Light B, Eicken H, Jones KF, Runciman K, Nghiem SV (2007) Increasing solar heating of the Arctic Ocean and adjacent seas, 1979-2005: attribution and role in the ice-albedo feedback. Geophys Res Lett 34(19): L19505

Peters RL (1992) Conservation of biological diversity in the face of climate change. In: Peters RL, Lovejoy TE (eds) Global warming and biological diversity. Yale University, New Haven and London, pp 15–30

R Core Team (2013) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Ramsay, MA, Andriashek DS (1986) Long distance route orientation of female polar bears (*Ursus maritimus*) in spring. J Zool 208:63–72

Ramsay MA, Stirling I (1988) Reproductive biology of female polar bears (*Ursus maritimus*). J Zool 214:601–634

Ramsay MA, Stirling I (1990) Fidelity of female polar bears to winter-den sites. J Mammal 71(2):233–236

Ramsay MA, Nelson RA, Stirling I (1991) Seasonal changes in the ration of serum urea to creatinine in feeding and fasting polar bears. Can J Zool 69:298–302

Regehr EV, Lunn NJ, Amstrup SC, Stirling I (2007) Effects of earlier sea ice breakup on survival and population size of polar bears in western Hudson Bay. J Wildl Manage 71:2673–2683

Regehr EV, Hunter CM, Caswall H, Amstrup SC, Stirling I (2010) Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice. J Anim Ecol 79:117–127

Rode KD, Amstrup SC, Regehr E (2010) Reduced body size and cub recruitment in polar bears associated with sea ice decline. Ecol Appl 20:768–782

Rode KD, Peacock E, Taylor M, Stirling I, Born EW, Laidre KL, Wiig Ø (2012) A tale of two polar bear populations: ice habitat, harvest, and body condition. Popul Ecol 54:3–18

Rode KD, Regehr EV, Douglas DC, Durner G, Derocher AE, Thiemann GW, Budge SM (2014) Variation in the response of an Arctic top predator experiencing habitat loss: feeding and reproductive ecology of two polar bear populations. Global Change Biol 20(1):76–88

Rode KD, Wilson RR, Regehr EV, St. Martin M, Douglas DC, Olson J (2015) Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. PLoS ONE 10(11):e0142213

Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA (2003) Fingerprints of global warming on wild animals and plants. Nature 421:57–60

Rosenzweig C, Karoly D, Vicarelli M, et al (2008) Attributing physical and biological impacts to anthropogenic climate change. Nature 453:353–357

Roy DB, Sparks TH (2000) Phenology of British butterflies and climate change. Global Change Biol 6:407–416

Rubenstein DI (1992) The Greenhouse Effect and changes in animal behavior: effects on social structure and life-history strategies. In: Peters RL, Lovejoy TE (eds) Global warming and biological diversity. Yale University, New Haven and London, pp 180–192

Schliebe S, Rode KD, Gleason JS, Wilder J, Proffitt K, Evans TJ, Miller S (2008) Effects of sea ice extent and food availability on spatial and temporal distribution of polar bears during the fall open-water period in the Southern Beaufort Sea. Polar Biol 31:99–1010

Schwartz MD, Ahas R, Aasa A (2006) Onset of spring starting earlier across the northern hemisphere. Glob Change Biol 12:343–351

Schweinsburg RE (1979) Summer snow dens used by polar bears in the Canadian high Arctic. Arctic 55:151–166

Schweinsburg RE, Spencer W, Williams D (1984) Polar bear denning area at Gateshead Island, Northwest Territories. Arctic 37(2):169–171

Seidel KH (1987) The climate of Auyuittuq National Park Reserve: a review. Government of the Northwest Territories, Yellowknife

Sheriff MJ, Buck CL, Barnes BM (2015) Autumn conditions as a driver of spring phenology in a free-living arctic mammal. Clim Chang Responses 2(1):4

Shokr M, Sinha N (2015) Sea ice: physics and remote sensing. John Wiley & Sons, Hoboken

Smith TG, Stirling I (1975) The breeding habitat of the ringed seal (*Phoca hispida*). The birth lair and associated structures. Can J Zool 53(9):1297–1305

Sparks TH, Menzel A (2002) Observed changes in seasons: an overview. Int J Climatol 22:1715–1725

Stefanescu C, Peñuelas J, Filella I (2003) Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin. Global Change Biol 9:1494

Stirling I, Calvert W, Andriashek D (1980) Population ecology studies of the polar bear in the area of southeastern Baffin Island. Canadian Wildlife Service Occasional Papers 44:1–33

Stirling I, Spencer C, Andriashek D (1989) Immobilization of polar bears (*Ursus maritimus*) with Telazol in the Canadian Arctic. J Wildl Dis 25(2):159–68

Stirling I, Andriashek D (1992) Terrestrial maternity denning of polar bears in the eastern Beaufort Sea area. Arctic 45:363–366

Stirling I, Parkinson CL (2006) Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. Arctic 59:261–275

Stirling I (2009) Polar bears. In: Perrin WF, Würsig B, Thewissen JGM (eds) Encyclopedia of marine mammals. Academic Press, San Diego, pp 88–890

Stirling I (2011) Polar bears: the natural history of a threatened species. Fitzhenry & Whiteside, Brighton

Stirling I, Derocher AE (2012) Effects of climate warming on polar bears: a review of the evidence. Global Change Biol 18:2694–2706

Stone RS, Dutton EG, Harris JM, Longenecker D (2002) Earlier spring snowmelt in northern Alaska as an indicator of climate change. J Geophys Res 107(D10):ACL 10-1 – ACL 10-13

Tang CCL, Ross CK, Yao T, Petrie B, DeTracey BM, Dunlap E (2004) The circulation, water masses and sea-ice of Baffin Bay. Prog Oceanogr 63:183–228

Taylor MK, Akeeagok S, Andriashek D, Barbour W, Born EW, Calvert W, Cluff HD, Ferguson S, Laake J, Rosing-Asvid A, Stirling I, Messier F (2001) Delineating Canadian and Greenland polar bear (*Ursus maritimus*) populations by cluster analysis of movements. Can J Zool 79:690–709

Taylor MK, Laake J, McLoughlin, Born EW et al (2005) Demography and viability of a hunted population of polar bears. Arctic 58(2):203–214

Taylor MK, Laake J, McLoughlin PD, Cluff HD, Born EW, Rosing-Asvid A, Messier F (2008) Population parameters and harvest risks for polar bears (*Ursus maritimus*) of Kane Basin, Canada and Greenland. Polar Biol 31:491–499

Tchernova J (2010) Denning characteristics and movement patterns of female polar bears with cubs in Svalbard during the first month after emergence: implication for detecting denning locations. Masters Thesis, University of Tromsø, Norway

Thackeray SJ, Sparks TH, Frederiksen M, et al (2010) Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. Global Change Biol 16:3304–3314

Uspenski SM, Chernyavski FB (1965) “Maternity home” of polar bears. Priroda 4:81–86

Valiela I, Bowen JL (2003) Shifts in winter distribution in birds: effects of global warming and local habitat change. AMBIO 32(7):476–480

Van de Velde F (1957) Nanuk, king of the arctic beasts. Eskimo 45:4–15

Vaughan DG, Comiso JC, Allison I, et al (2013) Observations: Cryosphere. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Walther G-R, Post E, Convey P, Menzel A, Parmesan C, Beebee TJ, Fromentin J-M, Hoegh-Guldberg O, Bairlein F (2002) Ecological responses to recent climate change. Nature 416(6879):389

Wassmann P, Duarte CM, Agustí S, Sejr MK (2011) Footprints of climate change in the Arctic marine ecosystem. Glob Change Biol 17:1235–1249

Wiig Ø (1998) Survival and reproductive rates for the polar bears at Svalbard. Ursus 10:25–32

Williams TM, Noren SR, Glenn M (2010) Extreme physiological adaptations as predictors of climate-change sensitivity in the narwhal, *Monodon monoceros*. Mar Mam Sci 27(2):334–349

Wolfe DW, Schwartz MD, Lakso AN, Otsuki Y, Pool R, Shaulis NJ (2005) Climate change and shifts in spring phenology of three horticultural woody perennials in northeastern USA. Int J Biometeorol 49:303–309

Zeng H, Jia G, Forbes BC (2013) Shifts in Arctic phenology in response to climate and anthropogenic factors as detected from multiple satellite time series. Environ Res Lett 8(3)

Figure Captions

Fig. 1. Map of the 19 polar bear subpopulations along with the boundaries of the four ecoregions.

Fig. 2. Study area with the Baffin Bay (BB) and Kane Basin (KB) subpopulations labeled.

Fig. 3. Maternity den locations symbolized by subpopulation and with varying colors for the year groups (90s and 00s).

Fig. 4. Shelter den locations symbolized by subpopulation and with varying colors for the year groups (90s and 00s).

Fig. 5. Map of dens for bear #200968005. The bear built a maternity den in 2013 that was 1.25 km away from her previous den site in 2009.

Fig. 6. Boxplots comparing den duration of Baffin Bay (BB) maternity dens ($p = 0.017$) (1990s: $n = 8$; 2000s: $n = 16$).

Fig. 7. Boxplots comparing entry ($p = 0.018$) and exit dates ($p = 0.399$) of Baffin Bay (BB) maternity dens (1990s: $n = 8$; 2000s: $n = 16$).

Fig. 8. Boxplots comparing den duration of Kane Basin (KB) maternity dens ($p = 1$) (1990s: $n = 3$; 2000s: $n = 3$).

Fig. 9. Boxplots comparing entry ($p = 0.6$) and exit dates ($p = 1$) of Kane Basin (KB) maternity dens (1990s: $n = 3$; 2000s: $n = 3$).

Fig. 10. Boxplots comparing the first date on land (FDOL) of pregnant females from the 1990s ($n = 8$) and 2000s ($n = 16$) in Baffin Bay (BB) (First FDOL used; $p = 0.002$).

Fig. 11. Boxplots comparing the first date on land (FDOL) of pregnant females from the 1990s ($n = 3$) and 2000s ($n = 3$) in Kane Basin (KB) ($p = 1$).

Fig. 12. Plots comparing the aspect, slope, elevation, and distance to coast of the 1990s ($n = 8$) and 2000s ($n = 15$) maternity dens in Baffin Bay (the den on Greenland was omitted). The aspect plot consists of a compass face with lines marking the directions that dens faced. The lines are annotated with numbers noting how many dens were found at that aspect. Elevation and slope significantly differed between the two time periods ($p = 0.003$), whereas no significant difference was detected for aspect ($p = 0.392$) or distance to coast ($p = 0.776$).

Fig.13. Plots comparing the aspect, slope, elevation, and distance to coast of the 1990s ($n = 3$) and 2000s ($n = 3$) maternity dens in Kane Basin. The aspect plot consists of a compass face with lines marking the directions that dens faced. The lines are annotated with numbers noting how many dens were found at that aspect. None of the habitat variables significantly differed between the two time periods (elevation, aspect, distance to coast: $p = 0.2$; slope: $p = 0.4$).

Fig. 14. Biplot symbolizing the results for the principal component analysis (PCA) ordination of the Baffin Bay maternity dens and their habitat descriptors (elevation, slope, aspect, and distance to coast or 'coastdist'), with ordiellipses drawn around year groups (1990s and 2000s; confidence level = 0.95). The 1990s dens (*n* = 8) are symbolized by dark blue points and the light blue points are the 2000s dens (*n* = 15; the Greenland maternity den was omitted).

Fig. 15. Map of potential maternity den habitat as derived from the habitat characteristics results found for 1990s (*n* = 7) and 2000s (*n* = 13) maternity dens (elevation, slope, aspect, and distance to coast) on Baffin Island. The total area for the 1990s habitat polygon was 80,380.23 km^2 and the total area for the 2000s polygon was 119,191.4km^2. Human settlements on the island are labeled and the boundary of the Baffin Bay subpopulation is marked by the dashed line.

Tables

Table 1. Number of dens from each subpopulation (total *n* = 68).

BAFFIN BAY					
All Dens		**Maternity Dens**		**Shelter Dens**	
n	50	*n*	24	*n*	26
n 1990s Dens	29	*n* 1990s Dens	8	*n* 1990s Dens	21
n 2000s Dens	21	*n* 2000s Dens	16	*n* 2000s Dens	5
KANE BASIN					
All Dens		**Maternity Dens**		**Shelter Dens**	
n	18	*n*	6	*n*	12
n 1990s Dens	9	*n* 1990s Dens	3	*n* 1990s Dens	6
n 2000s Dens	9	*n* 2000s Dens	3	*n* 2000s Dens	6

Table 2. Summary table of the habitat characteristics for Baffin Bay maternity and shelter dens (note that the two Greenland dens were not included in this table). Elev. = elevation (meters), Asp. = aspect (degrees), CoastDist = distance to nearest coastline (kilometers).

BAFFIN BAY									
ALL MATERNITY DENS (*n* = 24)					**ALL SHELTER DENS (*n* = 26)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	583.3	166.2	19.2	9.5	Mean	421.8	224.7	19.9	7.4
Min	101.0	0.0	2.4	0.4	Min	0	–1	0	0.1
Max	1323.0	357.6	32.9	20.2	Max	1116	357.2	46.7	54.5
Median	623.0	175.2	18.5	7.8	Median	354	249.3	19.4	4.7
SD	306.1	102.4	8.8	6.3	SD	320.5	124.8	12.6	10.7
1990s Dens									
MATERNITY DENS (*n* = 8)					**SHELTER DENS (*n* = 21)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	351.3	150.6	11.9	10.2	Mean	414.9	210.1	20.4	7.9
Min	131	18.4	2.4	2.2	Min	0	–1	0	0.1
Max	623	357.6	21.4	20.2	Max	1116	357.2	46.7	54.5
Median	279	99.1	12.1	7.6	Median	354	247.6	20.1	4.9
SD	194.5	135.7	6.4	6.5	SD	335.5	128.5	13.5	11.4
2000s Dens									
MATERNITY DENS (*n* = 15)					**SHELTER DENS (*n* = 4)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	707.0	174.4	23.1	9.2	Mean	458.3	301.7	17.1	4.9
Min	101.0	0.0	6.1	0.4	Min	169.0	196.4	10.3	0.2
Max	1323.0	320.6	32.9	18.6	Max	728.0	344.4	26.9	15.3
Median	693.0	182.2	23.0	8.3	Median	468.0	332.9	15.5	2.0
SD	284.9	83.9	7.4	6.3	SD	263.2	70.4	7.4	7.0

Table 3. Summary table of the habitat characteristics for Kane Basin maternity and shelter dens. Elev. = elevation (meters), Asp. = aspect (degrees), CoastDist = distance to nearest coastline (kilometers).

KANE BASIN									
ALL MATERNITY DENS (*n* = 6)					**ALL SHELTER DENS (*n* = 12)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	327	165.8	13.4	5.2	Mean	366.6	141.8	15.4	3.4
Min	9	28.3	3.7	0.7	Min	6	5.5	1.8	0.1
Max	506	229	17.8	12.5	Max	855	350	36.9	8
Median	408	186.8	15.9	3.4	Median	318	168.3	12	2.8
SD	188.4	69.8	5.4	4.8	SD	274.8	126.3	10.8	2.4
1990s Dens									
MATERNITY DENS (*n* = 3)					**SHELTER DENS (*n* = 6)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	207.7	201	11.9	2.1	Mean	386.7	134	12.9	2.6
Min	9	185.9	3.7	0.7	Min	6	12	1.8	0.1
Max	422	229	16.1	4.3	Max	855	349.7	36.9	5.5
Median	192	188.1	15.8	1.2	Median	257	105.7	9.9	2.3
SD	206.9	24.3	7.1	1.9	SD	378.5	137.4	12.4	2.1
2000s Dens									
MATERNITY DENS (*n* = 3)					**SHELTER DENS (*n* = 6)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	446.3	130.6	15	8.3	Mean	346.5	149.5	17.9	4.2
Min	394	28.3	10.7	2.6	Min	149	5.5	7.2	1.6
Max	506	187.7	17.8	12.5	Max	500	350	32.5	8
Median	439	175.9	16.5	9.7	Median	355.5	168.3	16.4	4.1
SD	56.4	88.8	3.8	5.1	SD	148.2	126.7	9.3	2.5

Table 4. Summary table of the habitat characteristics for maternity and shelter dens in the north latitudinal zone (note that the two Greenland dens were not included in this table). Elev. = elevation (meters), Asp. = aspect (degrees), CoastDist = distance to nearest coastline (kilometers).

NORTH ZONE (Latitude: >75° N)									
ALL MATERNITY DENS (*n* = 7)					**ALL SHELTER DENS (*n* = 12)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	342.3	178.3	13.9	4.6	Mean	349.4	141.4	13.6	3.4
Min	9	28.3	3.7	0.7	Min	6	5.5	1.8	0.1
Max	506	252.9	17.8	12.5	Max	855	350	36.9	8
Median	422	187.7	16.1	2.6	Median	292.5	168.3	11.3	2.8
SD	176.7	71.7	5.1	4.7	SD	272.1	126.1	9.3	2.4
1990s Dens									
MATERNITY DENS (*n* = 3)					**SHELTER DENS (*n* = 7)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	207.7	201	11.9	2.1	Mean	373.4	141	12.6	2.4
Min	9	185.9	3.7	0.7	Min	6	12	1.8	0.1
Max	422	229	16.1	4.3	Max	855	349.7	36.9	5.5
Median	192	188.1	15.8	1.2	Median	294	182.6	11.3	2
SD	206.9	24.3	7.1	1.9	SD	347.2	126.8	11.3	2
2000s Dens									
MATERNITY DENS (*n* = 4)					**SHELTER DENS (*n* = 5)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	443.3	161.2	15.4	6.4	Mean	315.8	142.1	15	4.7
Min	394	28.3	10.7	0.9	Min	149	5.5	7.2	1.8
Max	506	252.9	17.8	12.5	Max	498	350	24	8
Median	436.5	181.8	16.6	6.2	Median	291	163.9	14	5
SD	46.4	94.9	3.2	5.5	SD	142.7	140.2	6.6	2.4

Table 5. Summary table of the habitat characteristics for maternity and shelter dens in the central latitudinal zone. Elev. = elevation (meters), Asp. = aspect (degrees), CoastDist = distance to nearest coastline (kilometers).

CENTRAL ZONE (Latitude: 70–75° N)									
ALL MATERNITY DENS (*n* = 14)					**ALL SHELTER DENS (*n* = 14)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	540.4	180.2	20.1	10.1	Mean	308.1	235.9	17.7	10
Min	131	0	2.4	2.2	Min	0	–1	0	0.1
Max	820	357.6	32.9	20.2	Max	728	350.9	40.8	54.5
Median	600	178.7	20.5	8	Median	349	274	19.3	7.9
SD	214	111.6	9.5	6.3	SD	232.5	116.8	11.8	13.7
1990s Dens									
MATERNITY DENS (*n* = 5)					**SHELTER DENS (*n* = 11)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	326.2	196.7	11.2	12.9	Mean	223.4	221.7	16	11
Min	131	18.4	2.4	4.6	Min	0	–1	0	0.1
Max	563	357.6	21.4	20.2	Max	466	350.9	40.8	54.5
Median	248	175.2	7.7	14.2	Median	144	249.3	19.1	8.3
SD	209.2	155.8	8.3	6.7	SD	175.7	123.1	12	15.1
2000s Dens									
MATERNITY DENS (*n* = 9)					**SHELTER DENS (*n* = 3)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	659.3	171	25.1	8.5	Mean	618.7	288	24	6.4
Min	508	0	17.2	2.2	Min	500	186.6	12.6	1.6
Max	820	320.6	32.9	18.6	Max	728	344.4	32.5	15.3
Median	651	182.2	27.3	7.8	Median	628	333.1	26.9	2.4
SD	89.1	88.5	6	5.8	SD	114.3	88	10.3	7.7

Table 6. Summary table of the habitat characteristics for maternity and shelter dens in the south latitudinal zone. Elev. = elevation (meters), Asp. = aspect (degrees), CoastDist = distance to nearest coastline (kilometers).

SOUTH ZONE (Latitude: < 70° N)									
ALL MATERNITY DENS (*n* = 8)					**ALL SHELTER DENS (*n* = 11)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	677	130.7	18	9.6	Mean	585.3	210.9	24.6	4.2
Min	101	21	6.1	0.4	Min	169	6.4	6.2	0.2
Max	1323	239.7	31.6	17.2	Max	1116	357.2	46.7	11.2
Median	716.5	143.6	16.1	10.2	Median	471	196.4	20.5	3.4
SD	438.8	83.1	8.5	6.3	SD	357.3	138.6	13.4	3.2
1990s Dens									
MATERNITY DENS (*n* = 3)					**SHELTER DENS (*n* = 9)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	393	73.8	13.1	5.6	Mean	662.3	198.9	26.8	4.9
Min	246	37.6	11	2.2	Min	197	6.4	6.2	0.6
Max	623	120.3	15.1	7.8	Max	1116	357.2	46.7	11.2
Median	310	63.4	13.2	6.9	Median	520	124.5	28.8	4.7
SD	201.7	42.3	2.1	3	SD	348.8	148.2	13.7	3.1
2000s Dens									
MATERNITY DENS (*n* = 5)					**SHELTER DENS (*n* = 2)**				
	Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)		Elev. (m)	Asp. (°)	Slope (°)	CoastDist (km)
Mean	847.4	164.9	20.9	12.1	Mean	238.5	264.6	14.4	0.9
Min	101	21	6.1	0.4	Min	169	196.4	10.3	0.2
Max	1323	239.7	31.6	17.2	Max	308	332.7	18.4	1.6
Median	848	180.8	23	14.7	Median	238.5	264.6	14.4	0.9
SD	468.9	85.4	9.8	6.7	SD	98.3	96.4	5.7	1

Table 7. Summary table of the phenology for Baffin Bay maternity dens. The Greenland maternity den was included, and one maternity den from the 2000s data did not have an exit date and was thus excluded from the table. Entry and exit dates were quantified as day of year (DOY; Day #1 is 1 January).

BAFFIN BAY							
1990s Dens				**2000s Dens**			
MATERNITY DENS (*n* = 8)				**MATERNITY DENS (*n* = 15)**			
	Entry DOY	Exit DOY	Duration (# days)		Entry DOY	Exit DOY	Duration (# days)
Mean	249.8	78.9	194.1	Mean	277.7	79.8	167.1
Min	230	73	163	Min	237	60	121
Max	281	82	217	Max	324	91	212
Median	240	79.5	201	Median	276	80	164
SD	21.3	3.6	21	SD	27.7	8.7	27.6

Table 8. Summary table of the phenology for Kane Basin maternity dens.

KANE BASIN							
1990s Dens				**2000s Dens**			
MATERNITY DENS (*n* = 3)				**MATERNITY DENS (*n* = 3)**			
	Entry DOY	Exit DOY	Duration (# days)		Entry DOY	Exit DOY	Duration (# days)
Mean	279	78.3	164.3	Mean	274	77.7	168.7
Min	274	69	145	Min	252	65	144
Max	289	89	180	Max	301	88	184
Median	274	77	168	Median	269	80	178
SD	8.7	10.1	17.8	SD	24.9	11.7	21.6

Table 9. Results of the two-sample Mann-Whitney U tests comparing first date on land (FDOL) for pregnant females between the 1990s and 2000s for Baffin Bay (BB) and Kane Basin (KB). Significant *p*-values are underlined and in bold.

Mann-Whitney Test			**Kendall Test (Latitude)**			**Kendall Test (Elevation)**		
	W	***p*-value**		**Tau**	***p*-value (two-sided)**		**Tau**	***p*-value (two-sided)**
1st FDOL/ All	175.5	**0.002**	1st FDOL/ All	0.135	0.308	1st FDOL/ All	−0.27	**0.04**
2nd FDOL/ All	159	**0.018**	2nd FDOL/ All	0.074	0.58	2nd FDOL/ All	−0.372	**0.005**
1st FDOL/ BB	112	**0.002**	1st FDOL/ BB	−0.118	0.441	1st FDOL/ BB	−0.14	0.357
2nd FDOL/ BB	100.5	**0.02**	2nd FDOL/ BB	−0.147	0.332	2nd FDOL/ BB	−0.278	0.062
KB	5	1	KB	−0.067	1	KB	−0.2	0.71

Table 10. Results of the two-sample Mann-Whitney U tests comparing habitat characteristics for maternity and shelter dens by subpopulation (note that the two dens in Greenland were not included). Significant *p*-values are underlined and in bold.

BAFFIN BAY					
Maternity Dens (*n* = 23)			**Shelter Dens (*n* = 25)**		
	W	***p*-value**		**W**	***p*-value**
Elevation	105	**0.003**	Elevation	20	0.695
Slope	105	**0.003**	Slope	25	0.695
Aspect	74	0.392	Aspect	17	0.262
Distance to Coast	55	0.776	Distance to Coast	24	0.369
KANE BASIN					
Maternity Dens (*n* = 6)			**Shelter Dens (*n* = 12)**		
	W	***p*-value**		**W**	***p*-value**
Elevation	8	0.2	Elevation	20	0.818
Slope	7	0.4	Slope	25	0.31
Aspect	1	0.2	Aspect	17	0.937
Distance to Coast	8	0.2	Distance to Coast	24	0.394

Table 11. Results of the two-sample Mann-Whitney tests comparing habitat characteristics between the 1990s and 2000s by latitudinal zone for the maternity and shelter dens (note that the two dens in Greenland were not included). Significant *p*-values are underlined and in bold.

NORTH ZONE (Latitude: > 75° N)					
Maternity Dens (*n* = 7)			**Shelter Dens (*n* = 12)**		
	W	***p*-value**		**W**	***p*-value**
Elevation	1	0.114	Elevation	17	1
Slope	2	0.229	Slope	12	0.432
Aspect	8	0.629	Aspect	21	0.639
Distance to Coast	3	0.4	Distance to Coast	8	0.149
CENTRAL ZONE (Latitude: 70–75° N)					
Maternity Dens (*n* = 14)			**Shelter Dens (*n* = 14)**		
	W	***p*-value**		**W**	***p*-value**
Elevation	2	**0.004**	Elevation	0	**0.006**
Slope	5	**0.019**	Slope	8	0.225
Aspect	24	0.898	Aspect	10	0.368
Distance to Coast	30	0.364	Distance to Coast	19	0.769
SOUTHERN ZONE (Latitude: < 70° N)					
Maternity Dens (*n* = 8)			**Shelter Dens (*n* = 11)**		
	W	***p*-value**		**W**	***p*-value**
Elevation	3	0.25	Elevation	17	0.073
Slope	3	0.25	Slope	15	0.218
Aspect	3	0.25	Aspect	8	0.909
Distance to Coast	3	0.25	Distance to Coast	17	0.073

Table 12. Summary table of results from the principal component analysis on the Baffin Bay maternity dens matrix (the Greenland maternity den was omitted). None of the principal components (PC) were significant, though PC 1 and 2 were able to capture over half of the variation in the data. Principal component loadings greater than 0.6 or less than –0.6 were considered significant (in bold).

Principal Component Analysis Summary					**Principal Component Loadings**		
	Eigenvalue	% Var.	Cum. % Var.	*p*-value		PC 1 (37.31%)	PC 2 (28.38%)
PC 1	1.49	37.31	37.31	0.465	Elevation	**–0.659**	0.375
PC 2	1.24	28.38	65.69	0.413	Aspect	–0.210	**–0.770**
PC 3	0.99	24.64	90.33	0.061	Slope	**–0.604**	–0.375
PC 4	0.39	9.67	100	0.908	CoastDist	–0.396	0.356

Figures

Fig.1

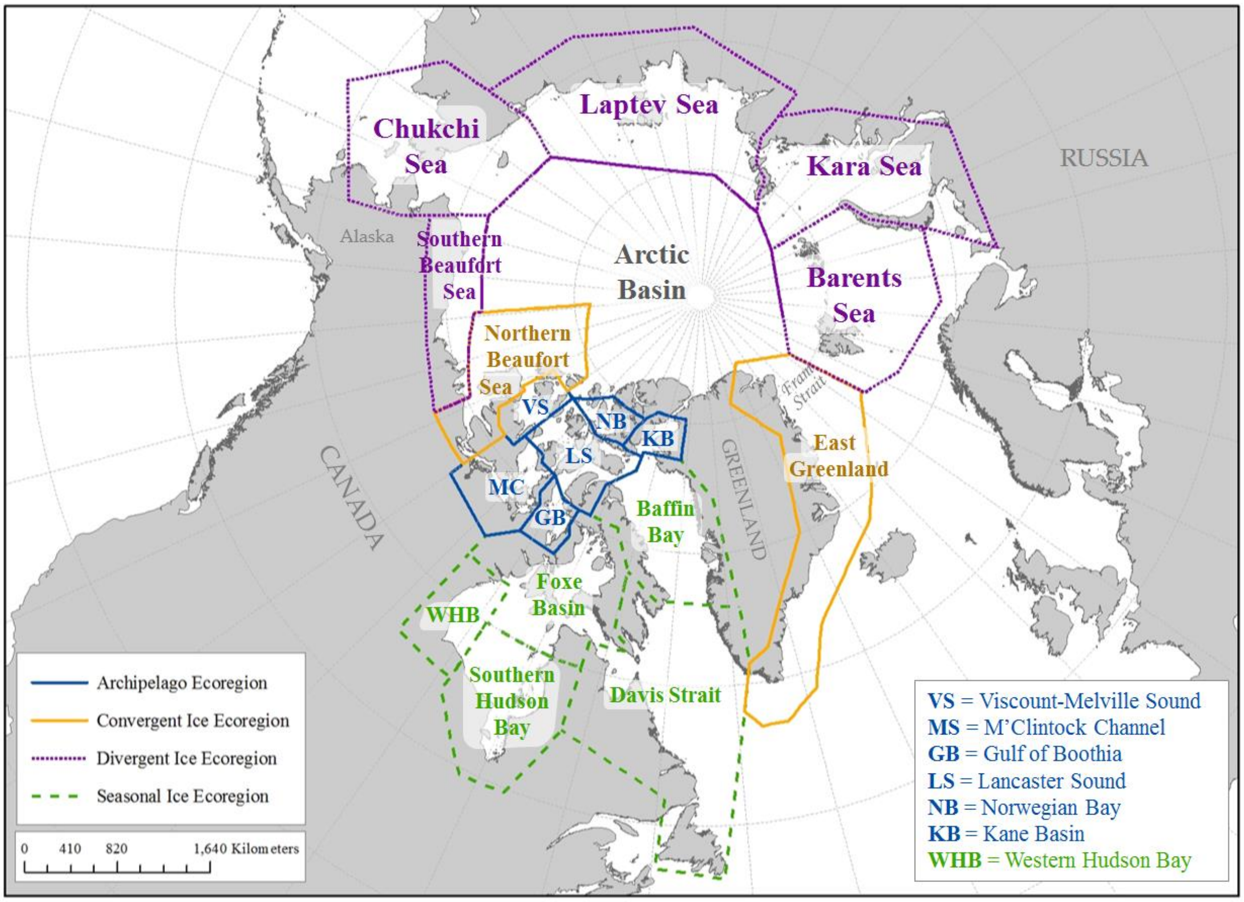
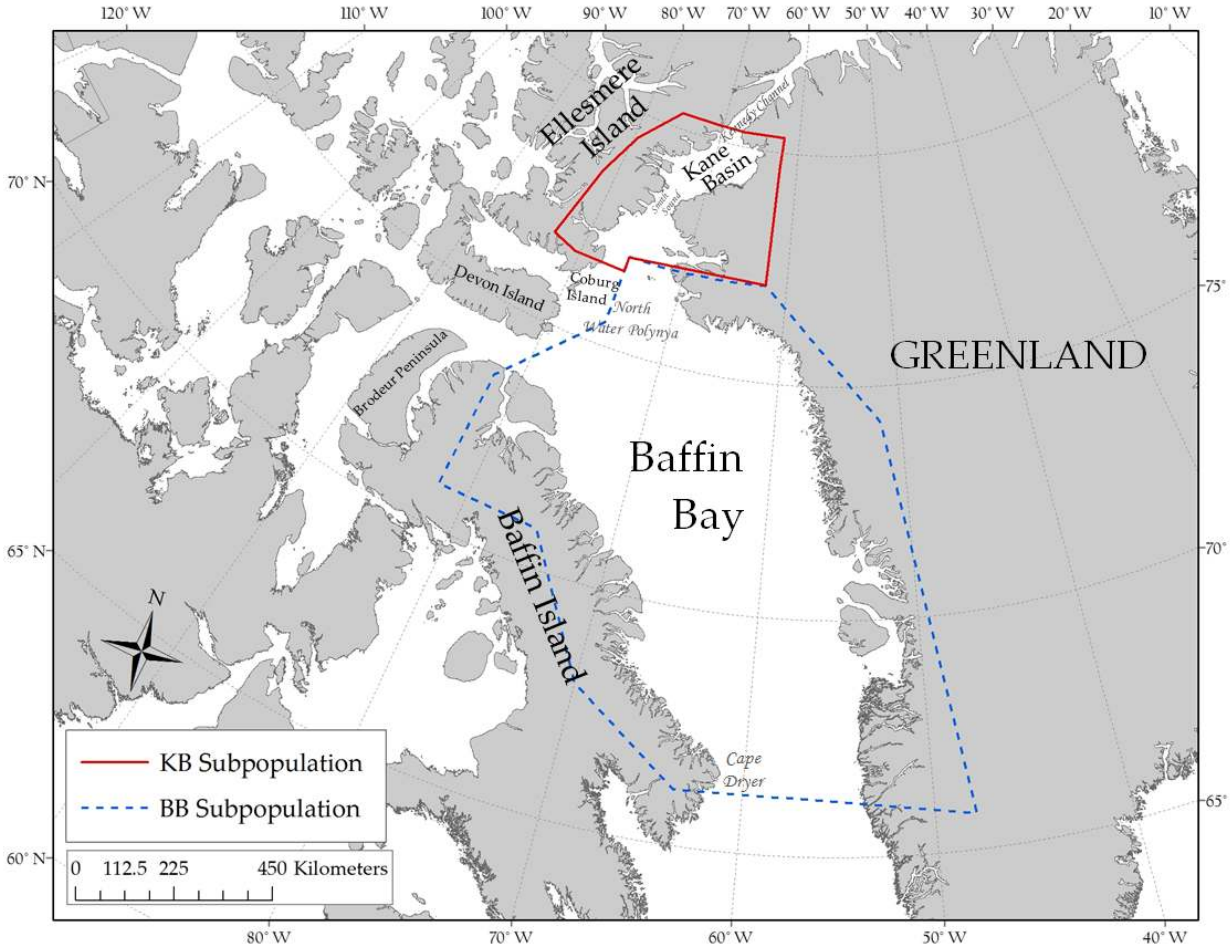


Fig. 2



120° W
110° W
100° W
90° W
80° W
70° W
60° W
50° W
40° W
30° W
20° W
10° W
70° N
65° N
60° N
75° N
70° N
65° N
80° W
70° W
60° W
50° W
40° W
Ellesmere Island
Kennedy Channel
Kane Basin
Smith Sound
Devon Island
Coburg Island
North Water Polynya
GREENLAND
Brodeur Peninsula
Baffin Bay
Baffin Island
Cape Dryer
N
KB Subpopulation
BB Subpopulation
0 112.5 225 450 Kilometers

Fig. 3

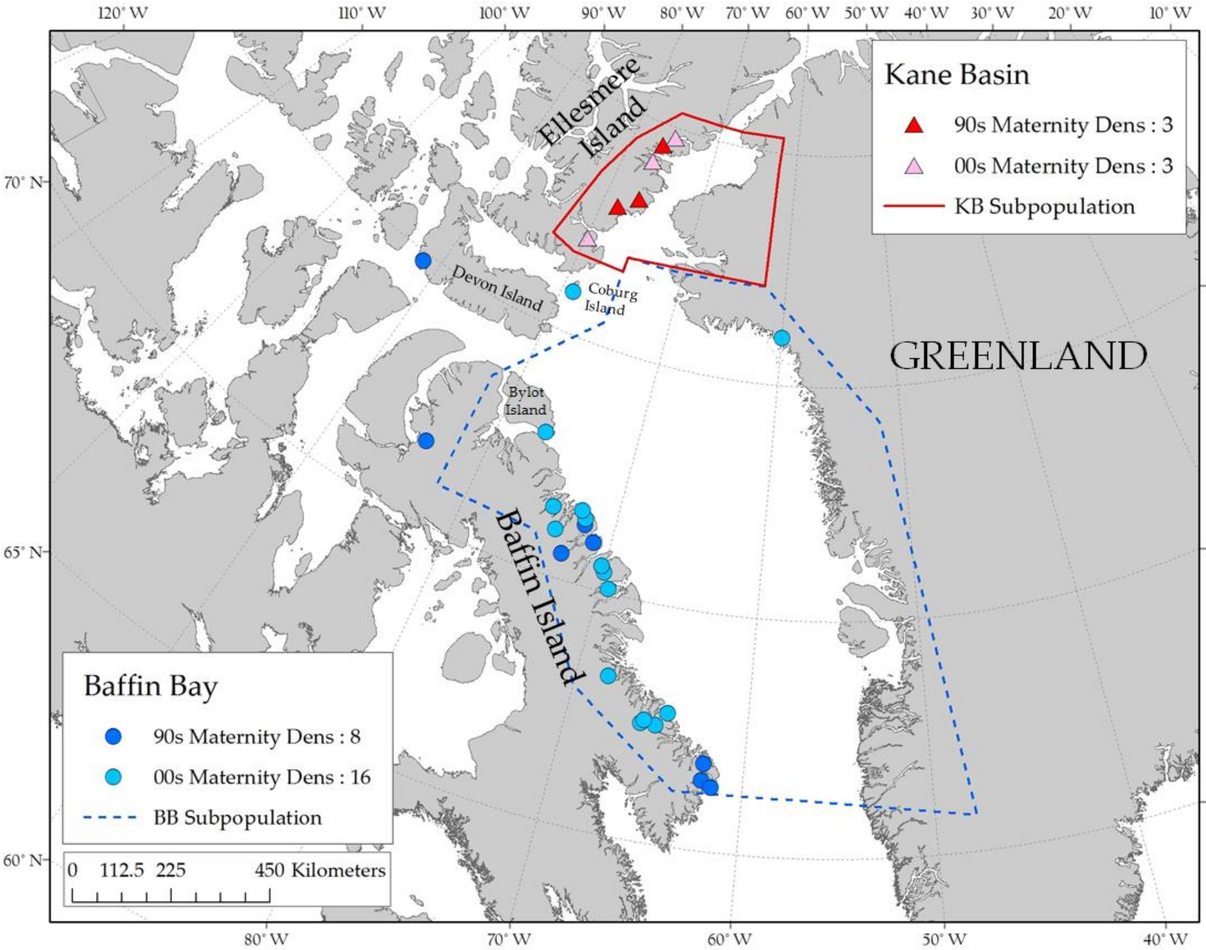
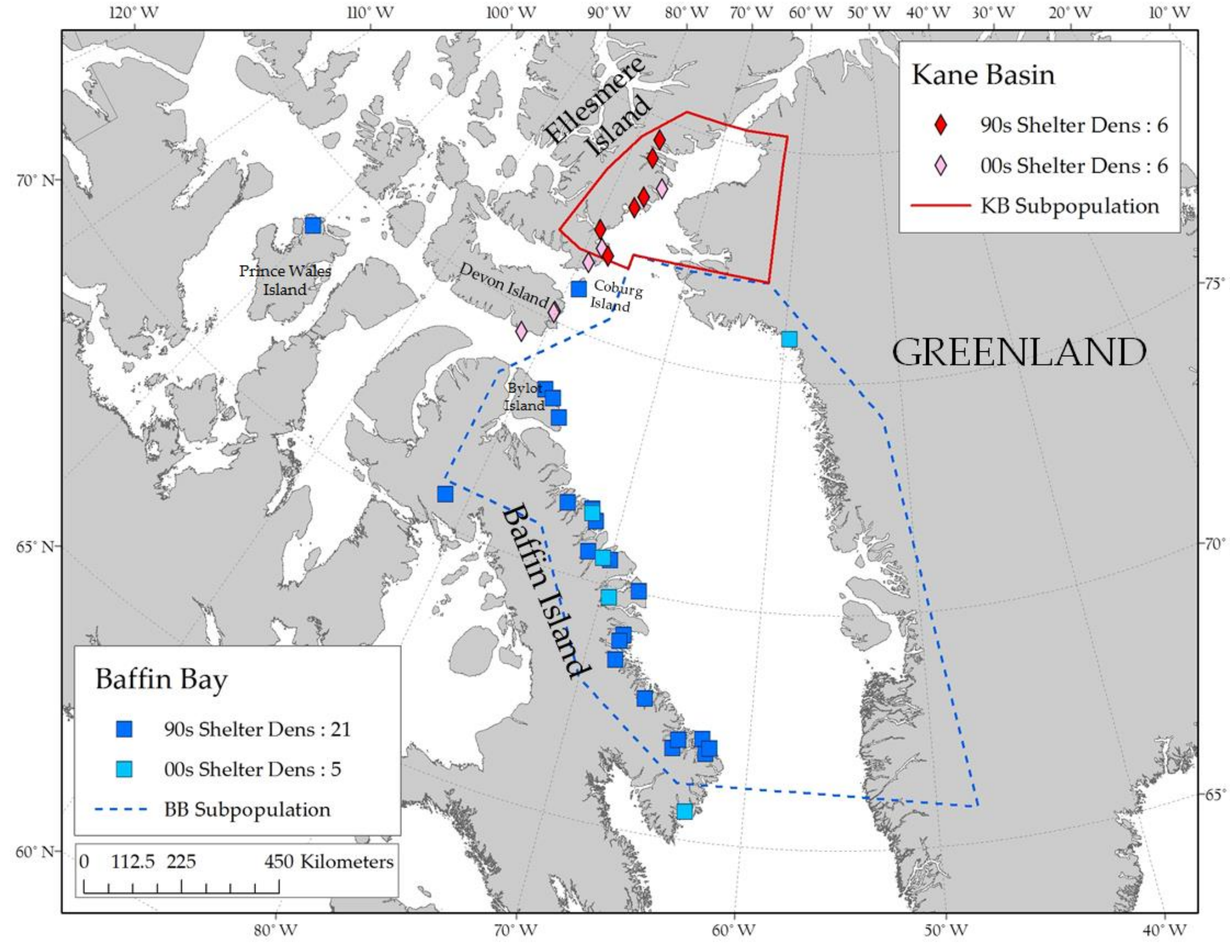

120° W
110° W
100° W
90° W
80° W
70° W
60° W
50° W
40° W
30° W
20° W
10° W
70° N
65° N
60° N
75° N
70° N
65° N
80° W
70° W
60° W
50° W
40° W
Ellesmere Island
Devon Island
Coburg Island
Bylot Island
Baffin Island
GREENLAND
Kane Basin
▲ 90s Maternity Dens : 3
△ 00s Maternity Dens : 3
KB Subpopulation
Baffin Bay
● 90s Maternity Dens : 8
● 00s Maternity Dens : 16
BB Subpopulation
0 112.5 225 450 Kilometers

Fig. 4


120° W
110° W
100° W
90° W
80° W
70° W
60° W
50° W
40° W
30° W
20° W
10° W
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65° N
60° N
75° N
70° N
65° N
80° W
70° W
60° W
50° W
40° W
Ellesmere Island
Prince Wales Island
Devon Island
Coburg Island
Bylot Island
Baffin Island
GREENLAND
Kane Basin
◆ 90s Shelter Dens : 6
◇ 00s Shelter Dens : 6
KB Subpopulation
Baffin Bay
■ 90s Shelter Dens : 21
■ 00s Shelter Dens : 5
BB Subpopulation
0 112.5 225 450 Kilometers

Fig. 5

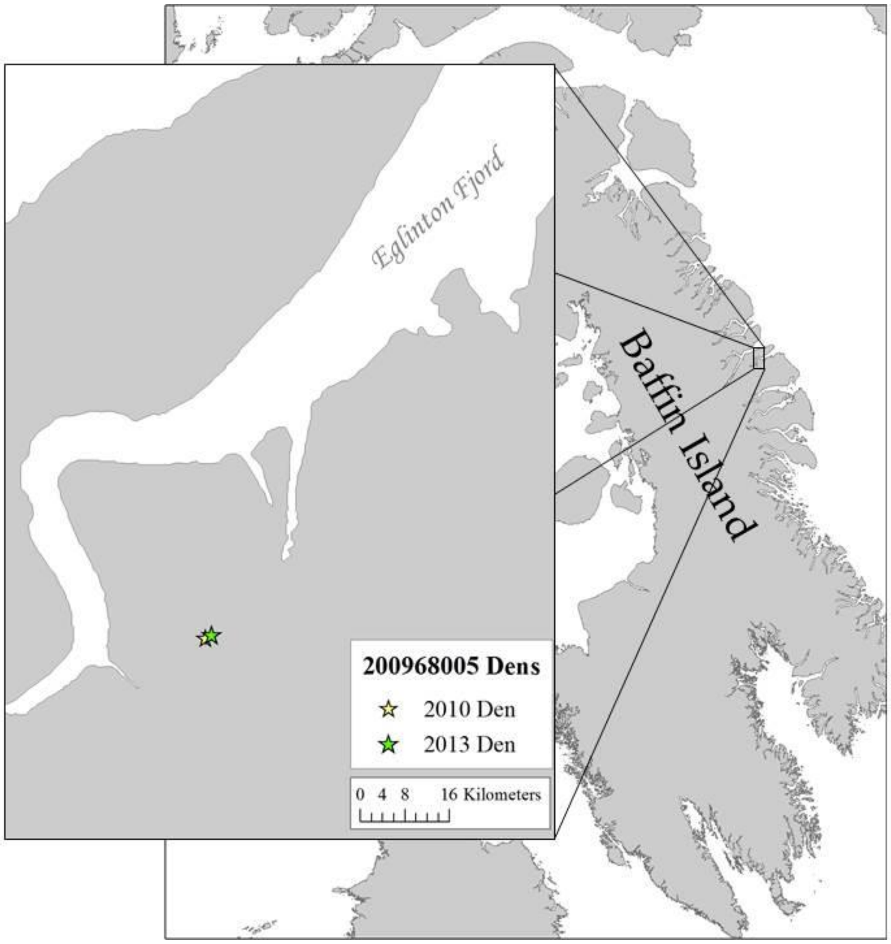

Eglinton Fjord
Baffin Island
200968005 Dens
2010 Den
2013 Den
0 4 8 16 Kilometers

Fig. 6

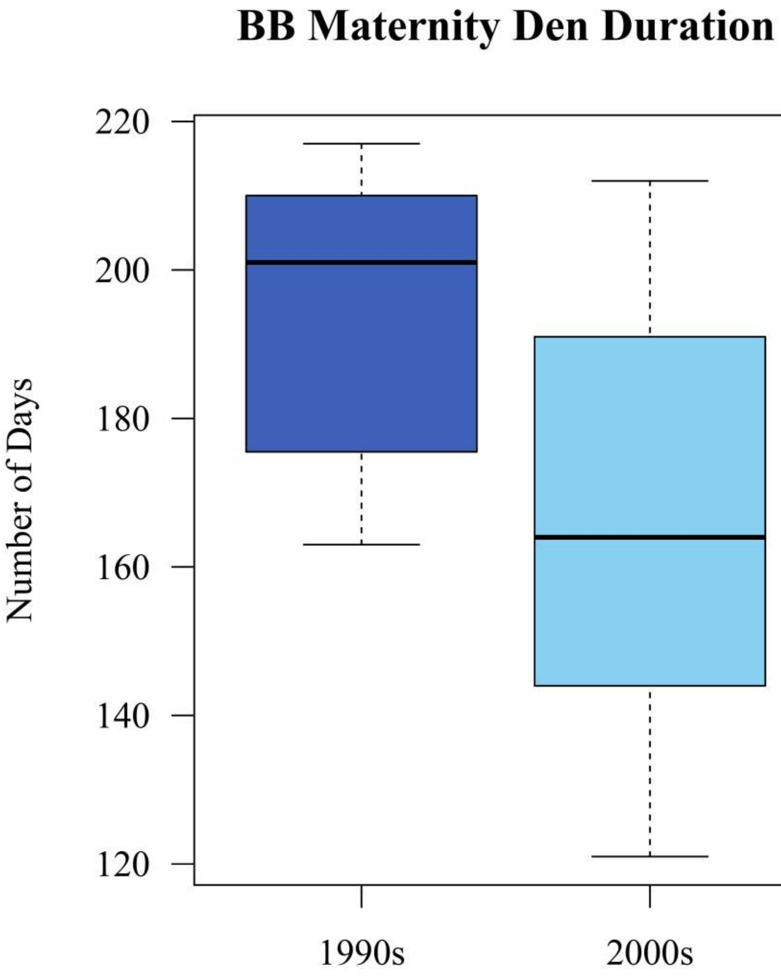

BB Maternity Den Duration
Number of Days
220
200
180
160
140
120
1990s
2000s

Fig. 7

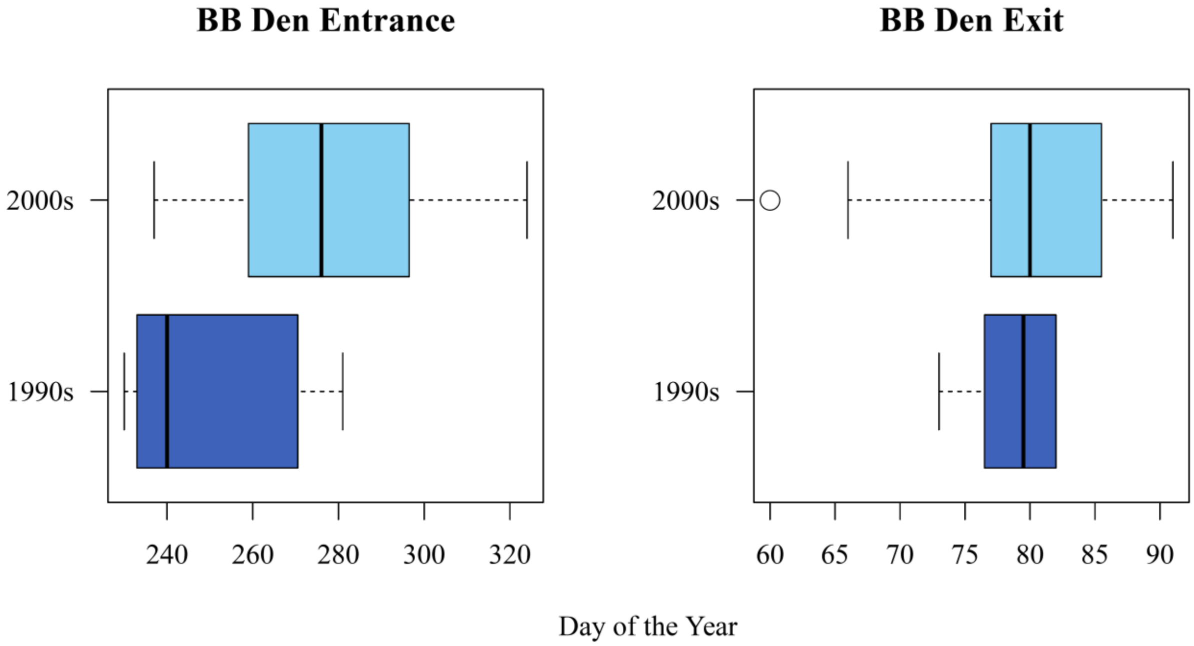

BB Den Entrance
BB Den Exit
2000s
1990s
2000s
1990s
240
260
280
300
320
60
65
70
75
80
85
90
Day of the Year

Fig. 8

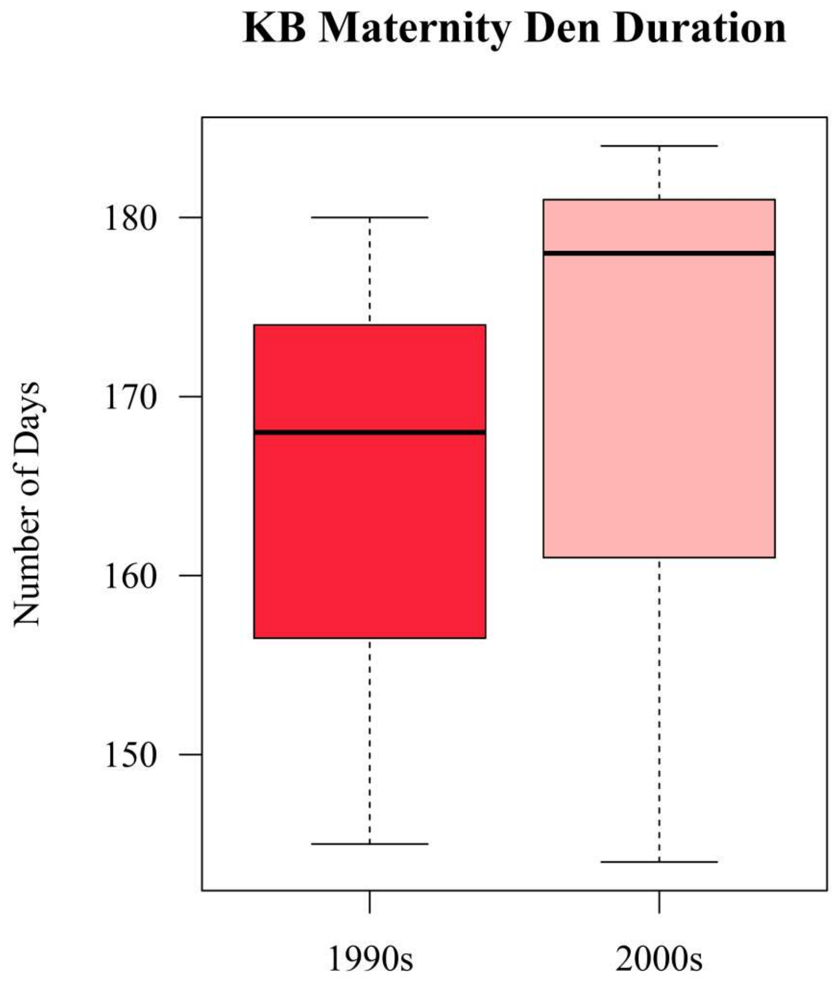

KB Maternity Den Duration
Number of Days
180
170
160
150
1990s
2000s

Fig. 9

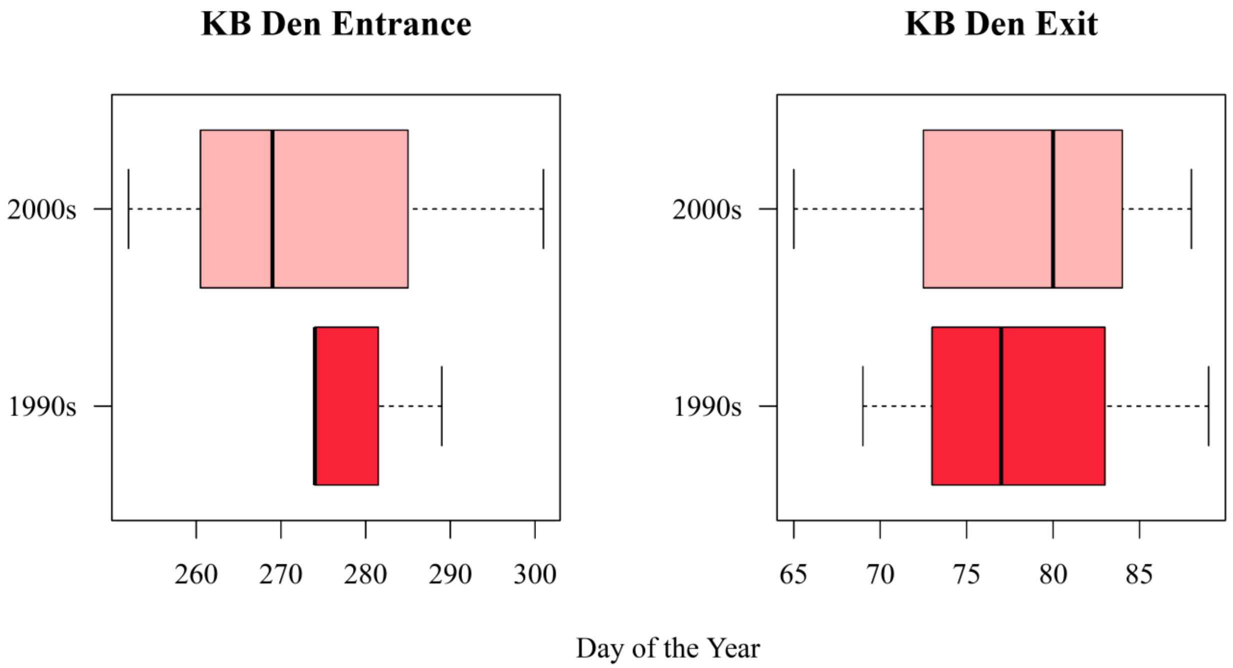

KB Den Entrance
KB Den Exit
2000s
1990s
2000s
1990s
260
270
280
290
300
65
70
75
80
85
Day of the Year

Fig. 10

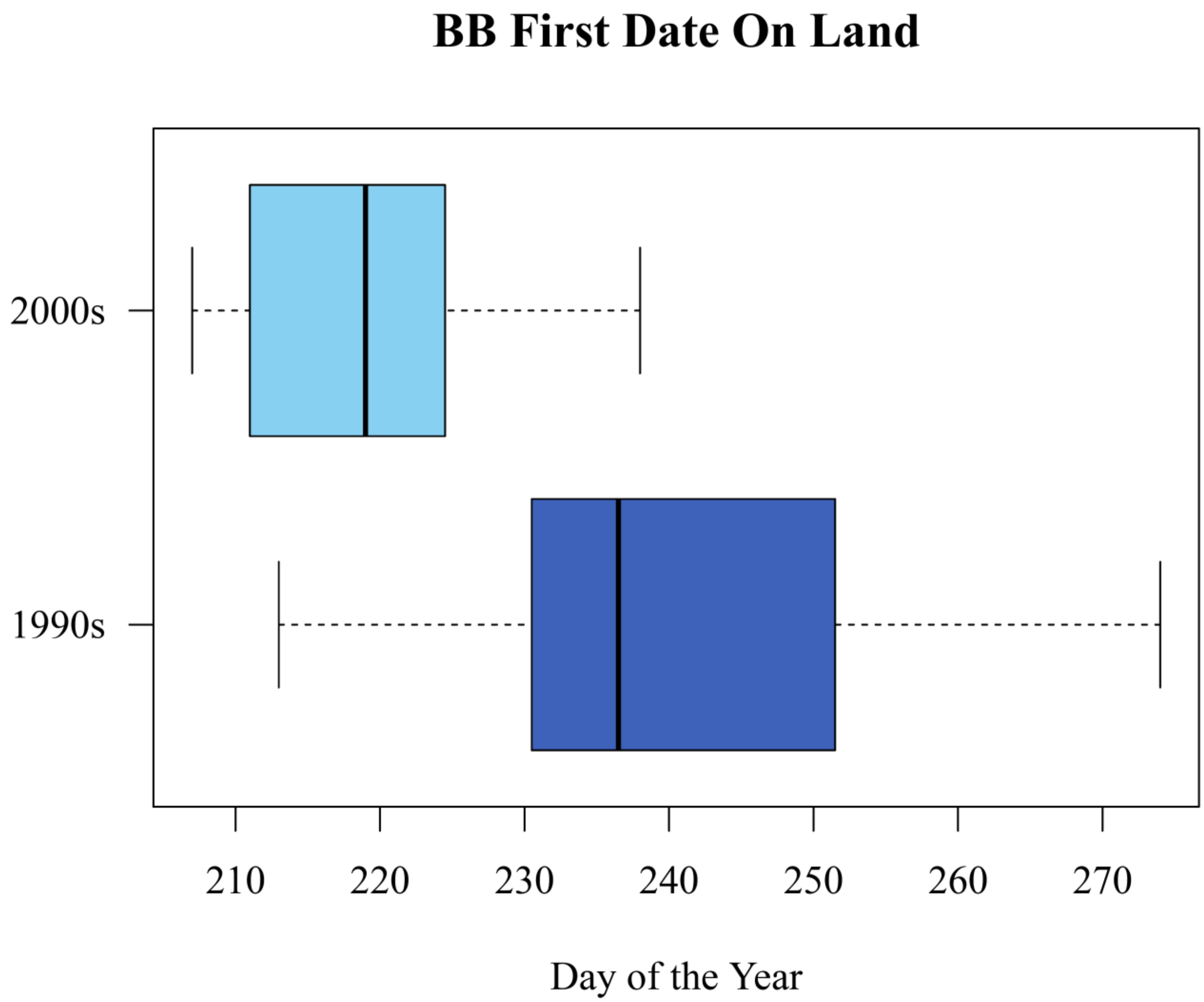

BB First Date On Land
2000s
1990s
210
220
230
240
250
260
270
Day of the Year

Fig. 11

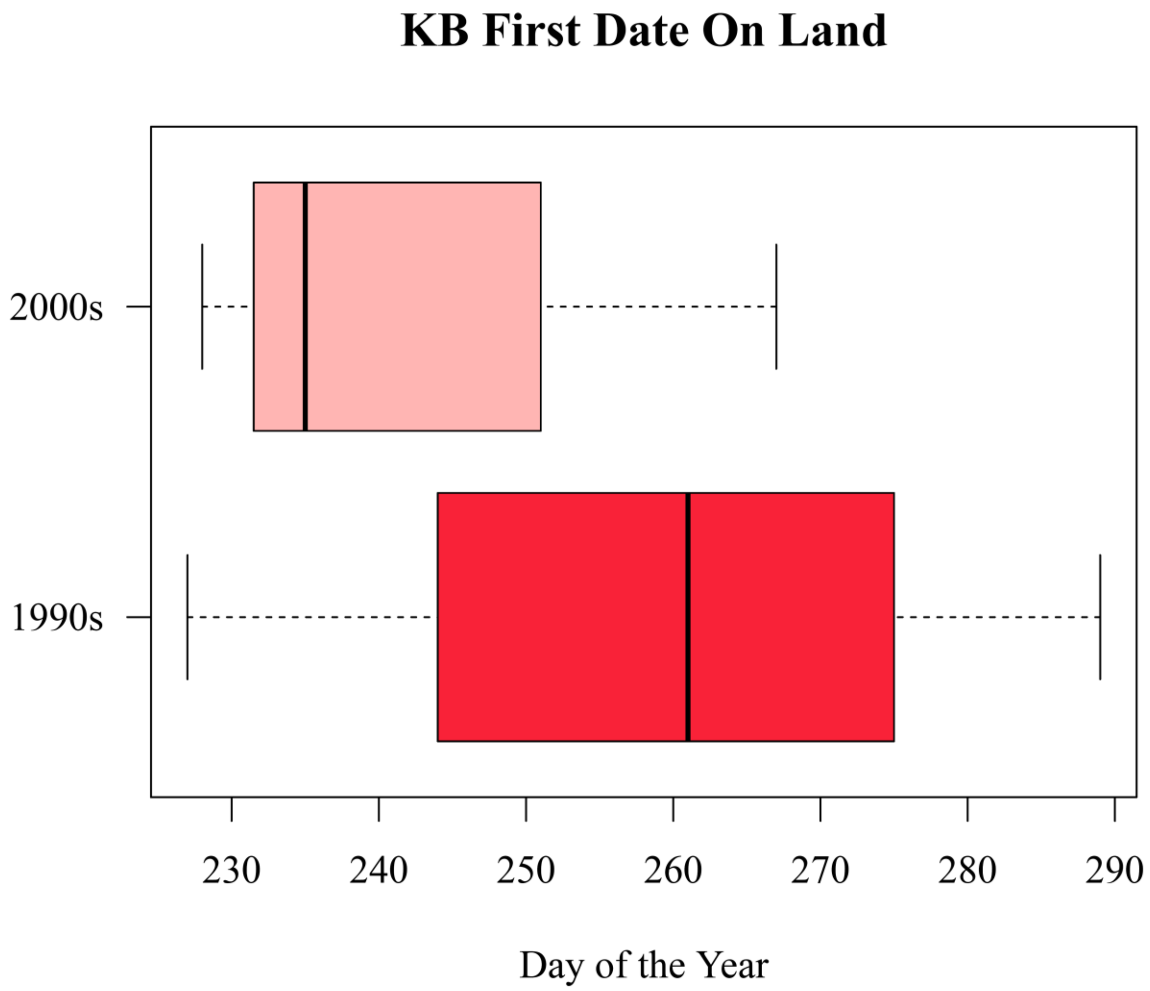

KB First Date On Land
2000s
1990s
230
240
250
260
270
280
290
Day of the Year

Fig. 12

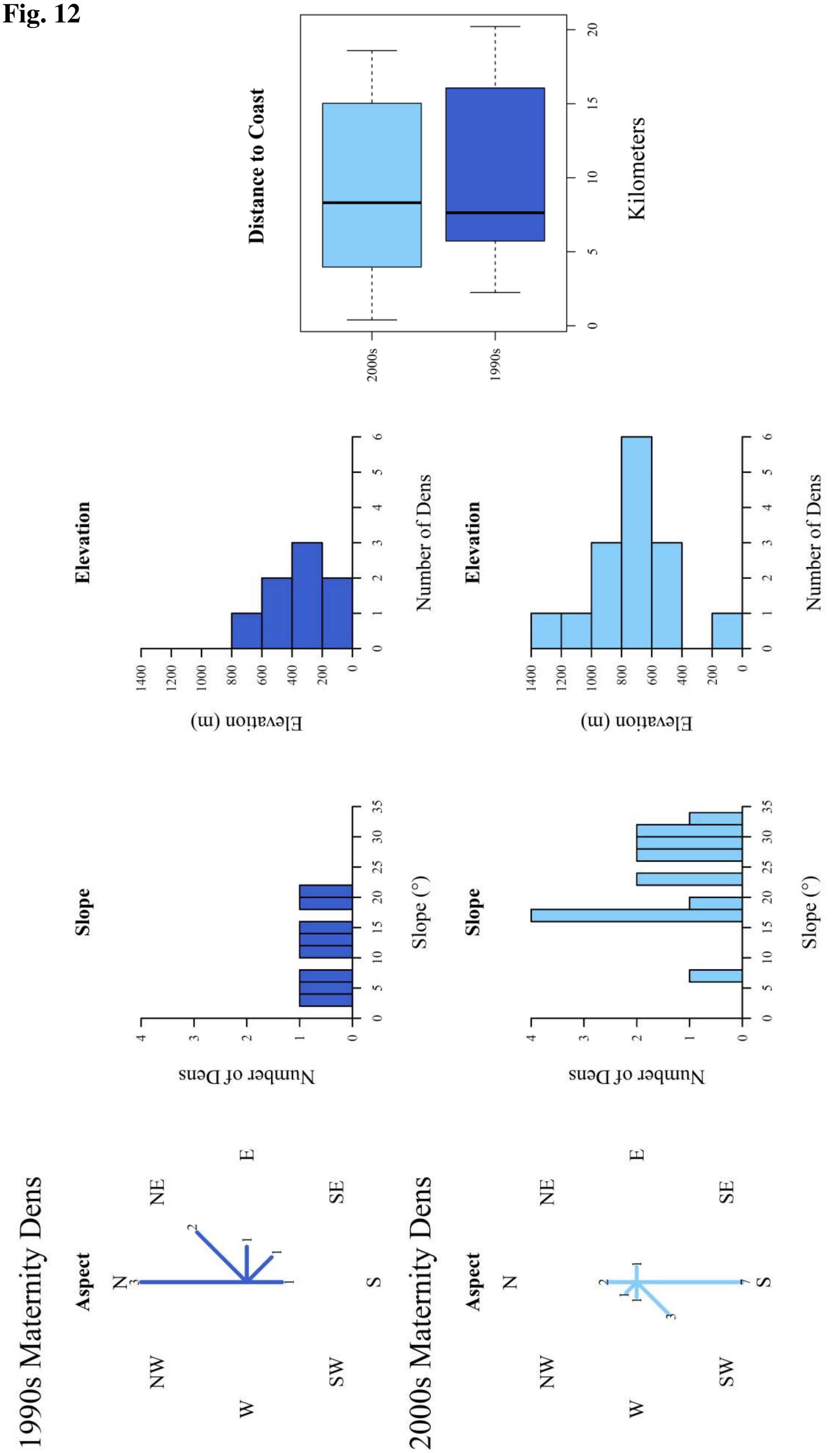

1990s Maternity Dens
Aspect
N
NE
E
SE
S
SW
W
NW
3
2
1
1
1
Slope
Number of Dens
Slope (°)
0
1
2
3
4
0
5
10
15
20
25
30
35
Elevation
Elevation (m)
Number of Dens
0
200
400
600
800
1000
1200
1400
0
1
2
3
4
5
6
2000s Maternity Dens
Aspect
N
NE
E
SE
S
SW
W
NW
7
3
2
1
1
Slope
Number of Dens
Slope (°)
Elevation
Elevation (m)
Number of Dens
Distance to Coast
2000s
1990s
Kilometers
0
5
10
15
20

Fig. 13

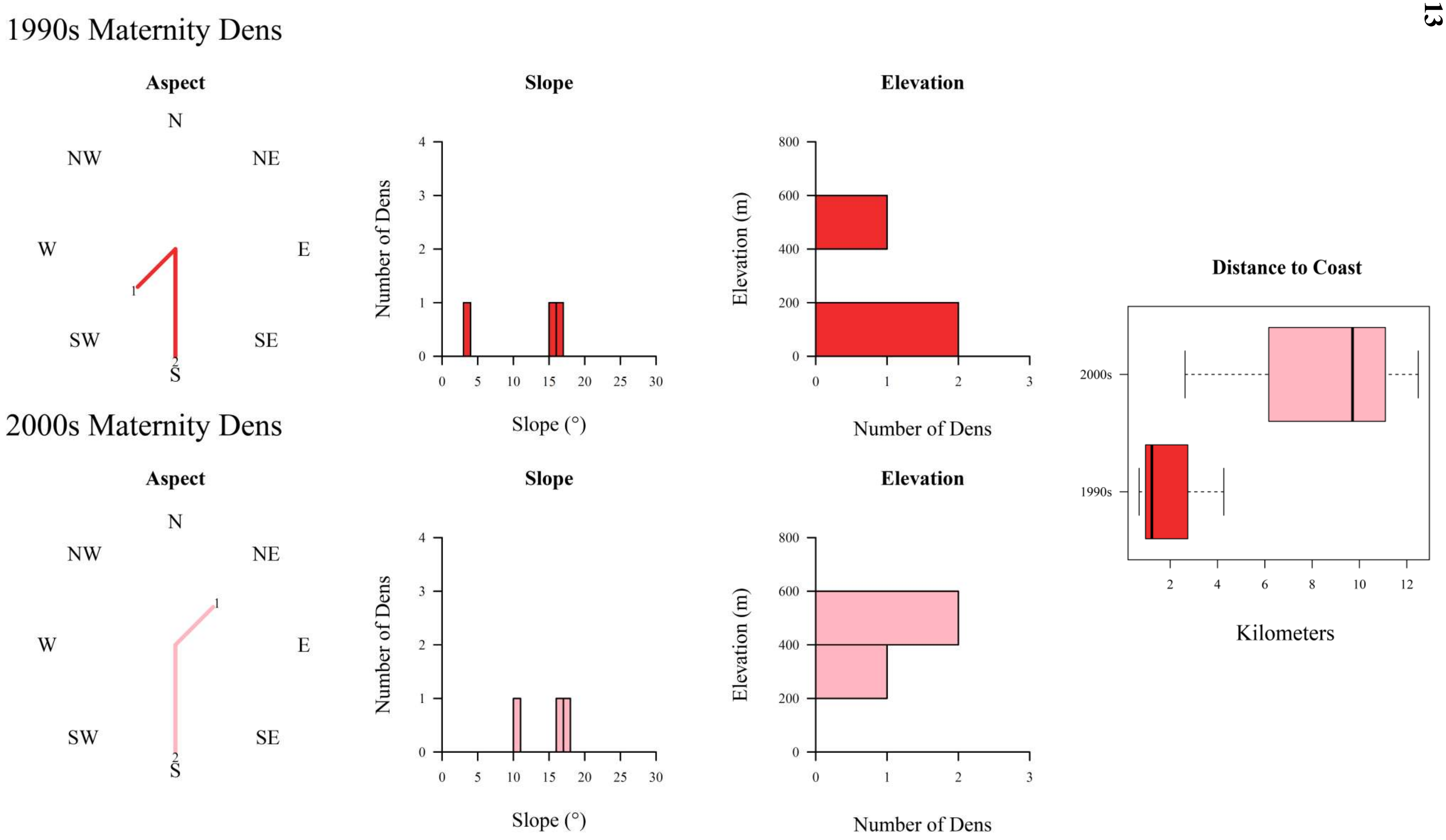
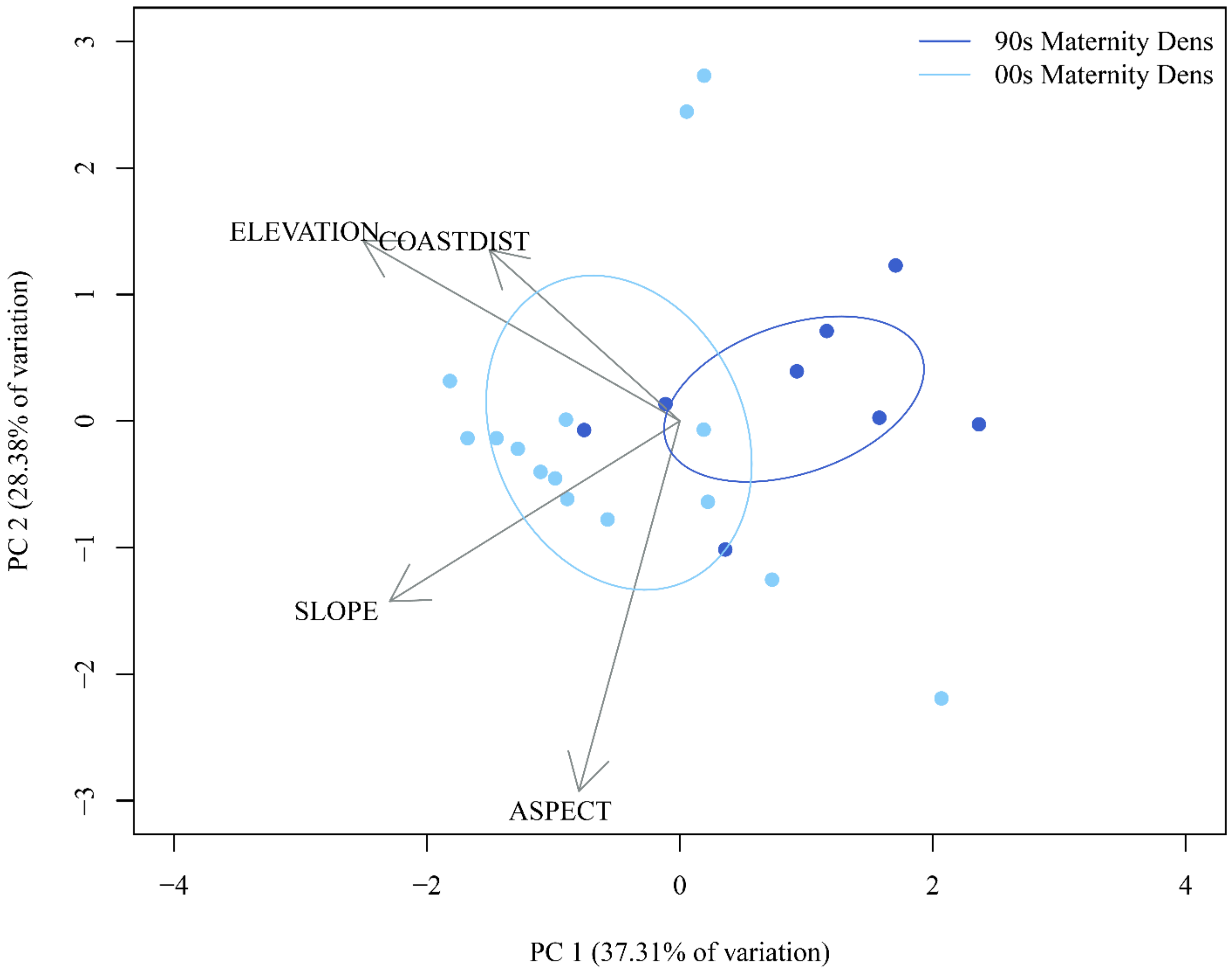
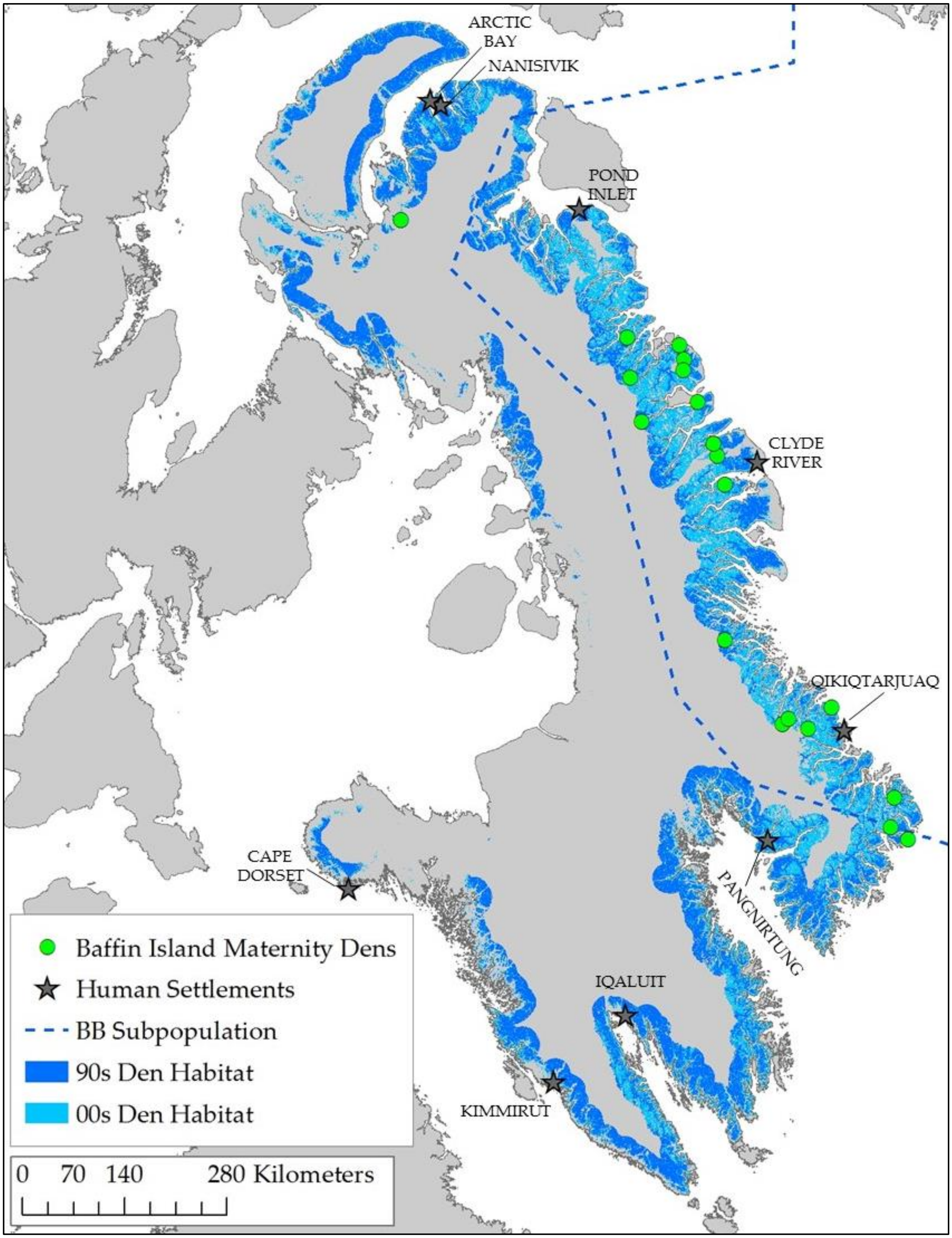

1990s Maternity Dens
Aspect
N
NE
E
SE
S
SW
W
NW
1
2
Slope
Number of Dens
0
1
2
3
4
0
5
10
15
20
25
30
Slope (°)
Elevation
Elevation (m)
0
200
400
600
800
0
1
2
3
Number of Dens
2000s Maternity Dens
Aspect
N
NE
E
SE
S
SW
W
NW
1
2
Slope
Number of Dens
0
1
2
3
4
0
5
10
15
20
25
30
Slope (°)
Elevation
Elevation (m)
0
200
400
600
800
0
1
2
3
Number of Dens
Distance to Coast
2000s
1990s
2
4
6
8
10
12
Kilometers

Fig. 14



90s Maternity Dens
00s Maternity Dens
ELEVATION
COASTDIST
SLOPE
ASPECT
PC 2 (28.38% of variation)
PC 1 (37.31% of variation)
3
2
1
0
−1
−2
−3
−4
−2
0
2
4

Fig. 15


ARCTIC BAY
NANISIVIK
POND INLET
CLYDE RIVER
QIKIQTARJUAQ
PANGNIRTUNG
CAPE DORSET
IQALUIT
KIMMIRUT
● Baffin Island Maternity Dens
★ Human Settlements
- - - BB Subpopulation
90s Den Habitat
00s Den Habitat
0 70 140 280 Kilometers

Appendix I. Notes on determination of entry and exit dates for all maternity and shelter dens, separated by subpopulation (final entry and exit dates are in parentheses). Dates are in the format DD/MM/YY.

– Baffin Bay –

MATERNITY DENS:

200968005 Den (2010): entry date determined by the location data (10/09/2009); exit date determined by the location data, temperature data were consulted (21/03/2010).

201068004 Den (2011): the location data were very sparse, therefore the temperature data were used for both the entry (08/11/2010) and exit dates and (01/04/2011).

201068010 Den (2011): location data were used for entry date since temperature data were inconclusive (11/10/2010); temperature data were used for exit date since they show a distinct drop (16/03/2011).

200974767 Den (2011): the bear seemed to be leaving the denning area on 14/03/2011 and temperature data show negative readings – exit date determined using the location data (12/03/2011); the date of entry was determined by using Location Quality (LQ) ABZ0 data in coordination with the temperature data (both agree) (09/09/2011).

201074768 Den (2011): this den has very sparse location data – therefore it was very difficult to determine when the bear entered the den – the temperatures zig-zag and begin to climb on (13/10/2010), the chosen entry date; location and temperature data were a perfect match for the exit date (28/03/2011).

2011105809 Den (2012): the temperature data did not help discerning the entry date, so location data were used to find the entry date (03/11/2011); perfect match between the location and temperature data for the exit date (28/03/2012).

2011105813 Den (2012): the bear first crosses the den buffer on 28 September, after which the location data become sparse – it is possible that the bear left the den on 22 October, so (28/09/2011) will be the date of entry; the only definitive way of determining the exit date was to use the temperature data since the location data were scattered, the first dip in temperature occurs on 18 March and there is only one location for that date (outside of the den buffer zone) – exit date occurred thereafter on (20/03/2012).

2011105814 Den (2012): the bear meanders into the denning area on 24 September but then meanders away, there was a temperature increase on 14 October that also corresponds to ABZ0 points within the 1 km buffer, therefore the entry date was (12/10/2011); the exit date was determined from the temperature data (29/02/2012).

2011105816 Den (2012): date of entry into the denning area on 17 November was very similar to an increase in temperature on 23 November so the entry date will be the median (20/11/2011); the temperature sharply decreases after 18 March so the exit date will be (20/03/2012).

200974771 Den (2012): entry date was determined by temperature data since the location data were sparse (04/09/2011); location data were used for exit date, though temperature data were close (06/03/2012).

201074774 Den (2012): location data were used to determine the entry date (22/09/2011) though the date predicted by the temperature data was close, 26 September; temperature data were used for the exit date since they show a distinct drop (24/03/2012) though this date is not too far off from the date predicted by the location data, 20 March.

2011105809 Den (2013): location data were used to determine the entry date (20/09/2012) since the location data were not helpful; temperature data were used for the exit date since they show a distinct drop below zero degrees (27/03/2013).

200968005 Den (2013): location data were used for entry date (29/08/2012); temperature data were used for exit date (17/03/2013).

2011105813 Den (2014): entry into the 1 km buffer occurred on 27 October, so entry date was determined as (25/10/2013), however bear stopped transmitting before she exited the den so this bear was *excluded from the duration analysis.*

2012105829 Den (2014): entry date was determined by location data (23/09/2013); exit date was determined by temperature data (30/03/2014).

201374774 Den (2015): entry date determined from the location data, 27 August marks the first date within the 1 km buffer and the temperature data were fairly high thereafter. Exit date determined by temperature data, there is a distinct drop between 15 and 19 March, however the location point for 19 March is still within the buffer. Therefore, the exit date will be between 23 and 27 March (25/03/2015).

SHELTER DENS:

200974767 Shelter Den (2013): entry date determined by the temperature data (03/12/2012); exit date determined by location data (17/03/2013).

200974771 Shelter Den (2010): used the location data for entry date (no temperature data were available for 2009) (06/09/09); location data were sparse so only temperature data were used for the exit date (04/01/2010).

200974771 Shelter Den (2011): location data were used for the entry date (21/09/2010); temperature data were used for the exit date since they show a sharp decrease in temperature before the last positions within the 1 km buffer (15/01/2011).

2011105808 Shelter Den (2012): temperature data were used for the entry date since the location data were too sparse (11/12/2011); the location data were used for the exit date since the temperature drops after the bear was clearly moving out of the den area –the date estimated by the temperature data was close (17/04/2012).

– Kane Basin –

MATERNITY DENS:

2013115642 Den (2014): *no temperature data*—entry (09/09/2013) and exit date (06/03/2014) had to be determined from location data only using the 1 km buffer around the den site.

2013128258 Den (2015): really sparse data, only positions during the denning period are on 24 September, 22 October, 1 December, 5 December, and 19 March. The bear was still far from the den site on 22 October so the entry date was thereafter, the temperature data show high temperatures starting on 30 October, entry date on (28/10/2014). For the exit date, the bear moved far from the denning area on 23 March so the exit date had to have been before the 23rd and after the 19th (21/03/2015).

2013128263 Den (2015): very sparse data, only 3 positions between 16 September and March. Temperature data show sustained high temperatures on and between 24 and 28 September, entry date on (26/09/2014). Temperatures remained fairly warm through the end of the record of transmissions, therefore location data were used for the exit date. Bear moves away from the denning area after 31 March, so (29/03/2015) was the exit date.

SHELTER DENS:

2012115635 Shelter Den (2013): *no temperature data*—location data were used for both the entry date and the exit date. The first location in the den area (within the 1 km buffer) was on 29 November so the entry date was before on (25/11/2012); the bear exited the 1 km buffer after 9 March, so the exit date was thereafter on (11/03/2013). Duration of denning is very close to a maternity den, but the bear was captured with two cubs-of-the-year (COY) in spring 2012.

2012115639 Shelter Den (2013): *no temperature data*—location data were used for both the entry (15/11/2012) and the exit date (05/02/2013). In an independent analysis of the data, Harry Stern identified the dates 17/11/2012 and 01/02/2013 as the starting and ending dates for the shelter den, and the location data match this.

2013115640 Shelter Den (2013): *no temperature data*—location data were used for both the entry (09/10/2013) and the exit date (30/12/2013).

2013128261 Shelter Den (2014): temperature plot shows a spike on 14 December with elevated temperatures until after 16 February – location data were very sparse with only one point in January. Though the temperature was still high on 16 February, the bear was located far away from the probable shelter den site. Entry date thus was between 14 and 18 December (16/12/2013) and the exit date was before 16 February (14/02/2014).

2013115640 Shelter Den (2015): *no temperature data*—location data were used for both the entry (05/11/2014) and the exit date (26/01/2015).

2013128261 Shelter Den (2015): temperature plot shows a spike on 5 December but the position of the bear on that date was out of the den area, there was only one location for that date and one location for all the dates in December – so it is possible that the bear entered the den area earlier but the location data is off. Therefore the entry date had to be before 5 December (01/12/2014). The temperature data were similarly used to determine the exit date which had to be before 3 February (28/01/2015).

Appendix Table II. First date on land (FDOL) data for Baffin Bay maternity dens. COY = cubs-of-the-year, 1YR = one-year-old cubs, 2YR = two-year-old cubs. Dates are written in the format: DD/MM/YYYY. Note the bears that had a second FDOL were bear #201068004 (06/11/2010) and bear #2011105816 (19/11/2011). The first FDOLs for the two bears are listed below.

Bear ID #	Status	Year	Longitude (DD)	Latitude (DD)	Date In	First Date on Land (FDoL)	Entry Date – FDOL	FDOL Latitude	Distance from FDoL to Den (km)
X13123	2-2YR?	1993	-72.861	70.536	17/09/1992	17/09/1992	0	70.536	0
X13196	Solitary	1993	-71.116	70.952	17/08/1992	17/08/1992	0	70.952	0
D07104	1-1YR	1994	-91.333	74.813	08/10/1993	01/10/1993	7	74.605	38.766
D11902	Solitary?	1994	-71.975	71.268	19/08/1993	19/08/1993	0	71.268	0
X13295	2-1YR?	1994	-62.152	66.826	26/08/1993	26/08/1993	0	66.826	0
X13428	1-1YR?	1995	-62.167	66.474	30/08/1994	30/08/1994	0	66.474	0
X13635	1-2YR?	1995	-83.934	71.6	07/10/1994	01/08/1994	67	71.313	367.876
X14099	Solitary	1997	-61.622	66.353	22/08/1996	22/08/1996	0	66.353	0
200968005	COY(s)	2010	-70.17738	70.523449	10/09/2009	23/08/2009	18	70.74693	25.667
201068004	Mating Pair	2011	-78.969187	75.868005	08/11/2010	26/08/2010	74	71.01993	593.884
201068010	2YR(s)	2011	-65.057239	67.47907	11/10/2010	10/08/2010	62	67.80349	41.378
200974767	Solitary	2011	-69.411584	70.091038	03/10/2010	29/07/2010	66	70.12205	3.976
201074768	2YR(s)	2011	-65.7065	67.54872	04/11/2010	14/08/2010	82	67.554544	24.72
2011105809	Solitary	2012	-76.633	72.86	15/11/2011	07/08/2011	100	73.06	21.878
2011105813	1YR(s)	2012	-73.755208	70.989113	16/09/2011	07/08/2011	40	71.582	78.255
2011105814	1YR(s)	2012	-72.054966	71.39615	12/10/2011	26/07/2011	78	71.393	30.963
2011105816	Mating Pair	2012	-64.468514	67.766744	20/11/2011	30/07/2011	113	70.707	384.359
200974771	Solitary	2012	-72.399809	71.543015	08/10/2011	13/08/2011	56	71.557	1.849
201074774	2-2YR	2012	-74.343	71.427	16/09/2011	07/08/2011	40	71.806	40.52
2011105809	COY(s)	2013	-69.94044	70.401147	20/09/2012	28/07/2012	54	70.657	49.426
200968005	2YR(s)	2013	-70.167559	70.525262	29/08/2012	30/07/2012	30	70.774	26.656
2011105813	1-1YR?	2014	-65.868587	67.47706	29/10/2013	12/08/2013	78	67.821	38.683
2012105829	Solitary	2014	-68.179063	68.303969	19/09/2013	12/08/2013	38	68.325	37.859
201374774	1-1YR?	2015	-59.929333	76.022961	25/08/2014	30/07/2014	26	75.971	26.065

Appendix Table III. First date on land (FDOL) data for Baffin Bay shelter dens

Bear ID #	Status	Year	Longitude (DD)	Latitude (DD)	Date In	First Date on Land (FDoL)	Entry Date − FDOL	FDOL Latitude	Distance from FDoL to Den (km)
X13053	Solitary	1992	-66.074	67.824	22/10/1991	27/09/1991	25	67.926	30.928
X13115	Solitary?	1992	-68.202	68.501	19/09/1992	19/09/1992	0	68.501	0
X13128	1-1YR?	1992	-67.729	70.036	30/08/1992	27/08/1992	3	69.934	33.257
X13224	2-COY	1992	-71.497	70.593	03/09/1992	03/09/1992	0	70.593	0
D07106	1-COY	1993	-71.577	71.264	04/09/1993	01/09/1993	3	71.624	128.188
D11904	Solitary	1993	-76.458	73.12	18/12/1992	15/12/1992	3	72.997	57.972
X08536	1-1YR?	1993	-64.088	66.9	27/08/1993	27/08/1993	0	66.9	0
X08536	1-COY	1993	-68.064	69.062	02/01/1993	16/12/1992	16	69.172	92.137
X13112	1-1YR?	1993	-77.388	73.459	19/09/1992	06/08/1992	44	73.495	14.432
X13123	2-COY?	1993	-73.79	71.468	26/08/1993	26/08/1993	0	71.468	0
X13196	2-COY?	1993	-69.995	70.547	29/08/1993	29/08/1993	0	70.547	0
D07106	1-COY	1994	-72.042	71.502	16/01/1994	16/01/1994	0	71.502	0
D11904	Solitary?	1994	-78.956	75.859	02/02/1994	02/02/1994	0	75.859	0
X08536	1-1YR?	1994	-100.176	73.679	19/12/1993	07/12/1993	12	68.815	30.837
X13635	1-1YR	1994	-81.469	70.612	08/11/1993	06/08/1993	94	73.016	0
X13746	2-YLG?	1994	-63.87	67.088	27/09/1994	10/09/1994	17	67.26	39.181
D11904	Solitary?	1995	-78.176	73.575	08/12/1994	08/12/1994	0	73.575	0
X13295	2-YLG?	1995	-68.198	68.912	25/08/1995	25/08/1995	0	68.912	0
X14574	?	1995	-62.563	67.173	26/09/1995	23/09/1995	3	67.203	3.646
X14577	1-YRL	1995	-62.284	66.875	28/09/1995	25/09/1995	3	67.141	32.224
X14577	Solitary	1996	-62.118	66.995	24/09/1996	24/09/1996	0	66.995	0
200974771	Solitary	2010	-70.484862	70.551816	06/09/2009	23/08/2009	14	70.79094	28.258
2011105811	Solitary	2011	-59.516411	75.929111	01/10/2011	30/07/2011	63	75.991	7.452
200974771	Solitary	2011	-71.954285	71.411483	21/09/2010	10/08/2010	42	71.4559	10.894
2011105808	1-1YR	2012	-62.956785	65.605057	11/12/2011	23/08/2011	110	71.779	785.767
200974767	2YR(s)	2013	-69.471173	69.765254	03/12/2012	26/07/2012	130	69.436	87.026

Appendix Table IV. First date on land (FDOL) data for Kane Basin maternity and shelter dens

Bear ID #	Status	Year	Den Type	Longitude (DD)	Latitude (DD)	Date In	First Date on Land (FDoL)	Entry Date – FDOL	FDOL Latitude	Dis. from FDoL to Den (km)
X13176	Solitary	1993	M	-78.316	77.942	30/09/1992	17/09/1992	13	77.61	27.889
X13558	1-2YR	1995	M	-76.553	78.256	16/10/1994	16/10/1994	0	78.256	0
X13721	Solitary	1995	M	-76.269	79.54	01/10/1994	15/08/1994	47	79.225	191.7
2013115642	Mating Pair	2014	M	-79.829148	77.038863	09/09/2013	16/08/2013	24	76.979	60.149
2013128258	1-COY	2015	M	-76.686455	79.127455	28/10/2014	24/09/2014	34	79.223	0
2013128263	1-2YR	2015	M	-75.198484	79.772002	26/09/2014	23/08/2014	34	79.861	63.826
X13168	2-COY	1994	S	-79.409	77.226	22/12/1993	22/12/1993	0	77.226	0
X13176	2-COY?	1994	S	-77.723	76.771	24/12/1993	24/12/1993	0	76.771	0
X13330	2-COY	1994	S	-77.118	77.96	29/01/1994	29/01/1994	0	77.96	0
X13558	1-1YR	1994	S	-77.291	79.108	16/12/1993	16/12/1993	0	79.108	0
X13560	Solitary	1994	S	-77.391	79.544	20/11/1993	02/11/1993	18	79.551	14.244
X13558	1-2YR	1995	S	-76.593	78.253	18/08/1994	18/08/1994	0	78.253	0
2012115635	2-COY	2013	S	-78.532469	76.865497	25/11/2012	20/07/2012	128	77.339	79.728
2012115639	2-1YR (2YR?)	2013	S	-75.078944	78.554152	15/11/2012	28/10/2012	18	78.221	40.84
2013115640	1-1YR	2013	S	-80.077912	75.200478	09/10/2013	04/08/2013	66	77.932	308.505
2013128261	Mating Pair	2014	S	-79.156	76.46	16/12/2013	16/12/2013	0	76.46	0
2013115640	1-1YR	2015	S	-81.859909	74.485727	05/11/2014	03/08/2014	94	75.558	121.613
2013128261	Mating Pair	2015	S	-80.080646	75.159961	01/12/2014	01/12/2014	0	75.159961	0

Appendix Table V. Baffin Bay maternity dens

Bear ID #	Status	Year	Longitude (DD)	Latitude (DD)	Lat. Zone	Date In	Date Out	Duration (# Days)	Coast Distance (km)	Slope (°)	Aspect (°)	Elevation (m)	Direction	Dis. To Human Settlements (km)	Location Notes
X13123	2-2YR?	1993	-72.861	70.536	C	17/09/1992	23/03/1993	186	14.161	21.354	175.236	563	S	167.484	Baffin Island
X13196	Solitary	1993	-71.116	70.952	C	17/08/1992	23/03/1993	217	4.565	5.868	78.024	537	E	114.124	Baffin Island
D07104	1-1YR	1994	-91.333	74.813	C	08/10/1993	20/03/1994	163	7.480	7.682	18.435	248	N	99.594	Devon Island
D11902	Solitary?	1994	-71.975	71.268	C	19/08/1993	23/03/1994	216	17.971	2.409	354.289	131	N	160.183	Baffin Island
X13295	2-1YR?	1994	-62.152	66.826	S	26/08/1993	14/03/1994	200	6.880	15.078	120.256	623	SE	115.956	Baffin Island
X13428	1-1YR?	1995	-62.167	66.474	S	30/08/1994	20/03/1995	202	7.787	10.983	63.435	310	NE	147.949	Baffin Island
X13635	1-2YR?	1995	-83.934	71.6	C	07/10/1994	21/03/1995	165	20.215	18.547	357.647	152	N	168.606	Baffin Island
X14099	Solitary	1997	-61.622	66.353	S	22/08/1996	15/03/1997	204	2.244	13.227	37.569	246	NE	173.947	Baffin Island
200968005	COY(s)	2010	-70.17738	70.523449	C	10/09/2009	21/03/2010	192	5.152	30.931	182.203	707	S	64.741	Baffin Island
201068004	Mating Pair	2011	-78.969187	75.868005	N	08/11/2010	01/04/2011	144	0.947	16.730	252.897	434	W	122.512	Coburg Island
201068010	2YR(s)	2011	-65.057239	67.47907	S	11/10/2010	24/03/2011	164	17.209	31.551	215.981	848	SW	49.443	Baffin Island
200974767	Solitary	2011	-69.411584	70.091038	C	03/10/2010	12/03/2011	160	9.035	29.057	198.048	710	S	55.292	Baffin Island
201074768	2YR(s)	2011	-65.7065	67.54872	S	04/11/2010	28/03/2011	144	14.683	26.559	167.005	1323	S	77.654	Baffin Island
2011105809	Solitary	2012	-76.633	72.86	C	15/11/2011	28/03/2012	134	2.784	17.176	86.424	627	E	47.285	Bylot Island
2011105813	1YR(s)	2012	-73.755208	70.989113	C	16/09/2011	20/03/2012	186	7.775	19.630	0.000	693	N	208.165	Baffin Island
2011105814	1YR(s)	2012	-72.054966	71.39615	C	12/10/2011	29/02/2012	140	18.585	32.887	172.875	645	S	171.070	Baffin Island
2011105816	Mating Pair	2012	-64.468514	67.766744	S	20/11/2011	20/03/2012	121	0.395	22.953	180.830	101	S	34.769	Baffin Island
200974771	Solitary	2012	-72.399809	71.543015	C	08/10/2011	06/03/2012	150	8.312	22.634	320.572	508	NW	191.305	Baffin Island
201074774	2-2YR	2012	-74.343	71.427	C	16/09/2011	24/03/2012	190	2.233	17.447	171.384	573	S	188.561	Baffin Island
2011105809	COY(s)	2013	-69.94044	70.401147	C	20/09/2012	19/03/2013	179	17.213	27.303	225.000	651	SW	55.849	Baffin Island
200968005	2YR(s)	2013	-70.167559	70.525262	C	29/08/2012	17/03/2013	199	5.578	28.447	182.726	820	S	64.387	Baffin Island
2011105813	1-1YR?	2014	-65.868587	67.47706	S	29/10/2013	N/A	N/A	15.372	6.066	21.000	1155	N	85.273	Baffin Island
2012105829	Solitary	2014	-68.179063	68.303969	S	19/09/2013	30/03/2014	192	12.618	17.202	239.744	810	SW	204.147	Baffin Island
201374774	1-1YR?	2015	-59.929333	76.022961	N	25/08/2014	25/03/2015	212	3.861	10.557	353.000	348	N	241.047	West Greenland

Appendix Table VI. Baffin Bay shelter dens

Bear ID #	Status	Year	Longitude (DD)	Latitude (DD)	Lat. Zone	Date In	Date Out	Duration (# Days)	Coast Distance (km)	Slope (°)	Aspect (°)	Elevation (m)	Direction	Dis. To Human Settlements	Location Notes
X13053	Solitary	1992	-66.074	67.824	S	22/10/1991	17/01/1992	87	3.412	30.599	49.086	852	NE	99.002	Baffin Island
X13115	Solitary?	1992	-68.202	68.501	S	19/09/1992	28/11/1992	70	4.937	28.844	349.509	197	N	215.125	Baffin Island
X13128	1-1YR?	1992	-67.729	70.036	C	30/08/1992	24/10/1992	55	11.025	4.556	326.310	73	NW	57.335	Baffin Island
X13224	2-COY	1992	-71.497	70.593	C	03/09/1992	11/11/1992	69	0.560	0.000	-1.000	0	N/A	115.774	On sea ice near Baffin Isl.
D07106	1-COY	1993	-71.577	71.264	C	04/09/1993	28/10/1993	54	12.719	21.202	303.024	354	NW	147.944	Baffin Island
D11904	Solitary	1993	-76.458	73.12	C	18/12/1992	17/03/1993	88	0.081	24.636	350.910	144	N	70.139	Bylot Island
X08536	1-1YR?	1993	-64.088	66.9	S	27/08/1993	02/11/1993	67	11.209	20.480	124.509	1034	SE	74.422	Baffin Island
X08536	1-COY	1993	-68.064	69.062	S	02/01/1993	06/02/1993	35	4.659	6.195	85.601	471	E	161.981	Baffin Island
X13112	1-1YR?	1993	-77.388	73.459	C	19/09/1992	01/03/1993	162	7.528	40.757	1.259	362	N	91.765	Bylot Island
X13123	2-COY?	1993	-73.79	71.468	C	26/08/1993	28/11/1993	94	3.227	11.614	298.610	344	NW	198.550	Baffin Island
X13196	2-COY?	1993	-69.995	70.547	C	29/08/1993	23/10/1993	55	2.927	24.166	249.341	461	W	58.152	Baffin Island
D07106	1-COY	1994	-72.042	71.502	C	16/01/1994	07/02/1994	22	8.302	19.442	302.471	466	NW	178.276	Baffin Island
D11904	Solitary?	1994	-78.956	75.859	N	02/02/1994	07/03/1994	33	1.419	11.266	182.564	294	S	123.373	Coburg Island
X08536	1-1YR?	1994	-100.176	73.679	C	19/12/1993	04/01/1994	16	11.209	3.256	209.055	25	SW	205.353	Prince of Wales Island
X13635	1-1YR	1994	-81.469	70.612	C	08/11/1993	11/02/1994	95	54.501	7.302	247.620	126	W	141.679	Baffin Island
X13746	2-YLG?	1994	-63.87	67.088	S	27/09/1994	16/11/1994	50	7.942	12.348	357.184	1040	N	52.482	Baffin Island
D11904	Solitary?	1995	-78.176	73.575	C	08/12/1994	04/03/1995	86	9.008	19.135	151.390	102	SE	104.078	Bylot Island
X13295	2-YLG?	1995	-68.198	68.912	S	25/08/1995	01/11/1995	68	3.025	46.734	342.588	520	N	178.761	Baffin Island
X14574	?	1995	-62.563	67.173	S	26/09/1995	26/10/1995	30	0.614	45.716	352.648	345	N	75.325	Baffin Island
X14577	1-YRL	1995	-62.284	66.875	S	28/09/1995	24/10/1995	26	5.412	30.584	6.450	1116	N	107.671	Baffin Island
X14577	Solitary	1996	-62.118	66.995	S	24/09/1996	16/11/1996	53	2.898	20.114	122.661	386	SE	103.831	Baffin Island
200974771	Solitary	2010	-70.484862	70.551816	C	06/09/2009	04/01/2010	120	2.388	26.924	344.427	628	N	76.799	Baffin Island
2011105811	Solitary	2011	-59.516411	75.929111	N	01/10/2011	16/01/2012	107	2.211	28.648	351.000	94	N	255.240	West Greenland
200974771	Solitary	2011	-71.954285	71.411483	C	21/09/2010	15/01/2011	182	15.317	12.611	333.083	728	NW	169.231	Baffin Island
2011105808	1-1YR	2012	-62.956785	65.605057	S	11/12/2011	17/04/2012	128	0.202	10.337	196.390	169	S	141.294	Baffin Island
200974767	2YR(s)	2013	-69.471173	69.765254	S	03/12/2012	17/03/2013	103	1.617	18.387	332.745	308	NW	88.557	Baffin Island

Appendix Table VII. Kane Basin maternity and shelter dens

Bear ID #	Status	Year	Den Type	Longitude (DD)	Latitude (DD)	Lat. Zone	Date In	Date Out	Duration (# Days)	Coast Distance (km)	Slope (°)	Aspect (°)	Elevation (m)	Direction	Dis. To Human Settlements	Location Notes
X13176	Solitary	1993	M	-78.316	77.942	N	30/09/1992	18/03/1993	168	0.689	3.686	188.130	9	S	205.983	Ellesmere Island
X13558	1-2YR	1995	M	-76.553	78.256	N	16/10/1994	10/03/1995	145	1.225	16.130	185.906	192	S	191.516	Ellesmere Island
X13721	Solitary	1995	M	-76.269	79.54	N	01/10/1994	30/03/1995	180	4.267	15.762	229.000	422	SW	277.747	Ellesmere Island
2013115642	Mating Pair	2014	M	-79.829148	77.038863	N	09/09/2013	06/03/2014	178	12.485	16.455	28.301	394	NE	105.027	Ellesmere Island
2013128258	1-COY	2015	M	-76.686455	79.127455	N	28/10/2014	21/03/2015	144	2.630	10.657	175.914	439	S	248.919	Ellesmere Island
2013128263	1-2YR	2015	M	-75.198484	79.772002	N	26/09/2014	29/03/2015	184	9.708	17.837	187.734	506	S	287.426	Ellesmere Island
X13168	2-COY	1994	S	-79.409	77.226	N	22/12/1993	08/03/1994	76	0.142	36.923	20.191	169	N	127.074	Ellesmere Island
X13176	2-COY?	1994	S	-77.723	76.771	N	24/12/1993	03/02/1994	41	1.991	1.790	210.964	6	SW	140.176	On sea ice near Elles. Isl.
X13330	2-COY	1994	S	-77.118	77.96	N	29/01/1994	04/04/1994	65	2.513	11.400	26.565	345	NE	194.175	Ellesmere Island
X13558	1-1YR	1994	S	-77.291	79.108	N	16/12/1993	05/03/1994	79	5.548	12.537	11.976	855	N	256.956	Ellesmere Island
X13560	Solitary	1994	S	-77.391	79.544	N	20/11/1993	05/03/1994	105	4.570	6.066	349.695	852	N	292.820	Ellesmere Island
X13558	1-2YR	1995	S	-76.593	78.253	N	18/08/1994	27/09/1994	40	0.656	8.455	184.899	93	S	192.233	Ellesmere Island
2012115635	2-COY	2013	S	-78.532469	76.865497	N	25/11/2012	11/03/2013	105	3.143	14.038	349.992	149	N	123.527	Ellesmere Island
2012115639	2-1YR (2YR?)	2013	S	-75.078944	78.554152	N	15/11/2012	05/02/2013	81	1.802	11.087	163.887	291	S	179.858	Ellesmere Island
2013115640	1-1YR	2013	S	-80.077912	75.200478	N	09/10/2013	30/12/2013	82	8.030	24.032	172.648	498	S	158.367	Devon Island
2013128261	Mating Pair	2014	S	-79.156	76.46	N	16/12/2013	14/02/2014	60	4.964	7.181	5.528	221	N	98.142	Ellesmere Island
2013115640	1-1YR	2015	S	-81.859909	74.485727	C	05/11/2014	26/01/2015	82	1.553	32.525	186.633	500	S	188.168	Devon Island
2013128261	Mating Pair	2015	S	-80.080646	75.159961	N	01/12/2014	28/01/2015	58	5.423	18.738	18.435	420	N	162.416	Devon Island