Ecological Modelling 320 (2016) 114–134

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Modeling snowdrift habitat for polar bear dens

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ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form
14 September 2015
Accepted 15 September 2015

Keywords:
Polar bear
Den habitat
Snowdrift
Model
SnowDens-3D
Climate

ABSTRACT

Throughout the Arctic most pregnant polar bears (*Ursus maritimus*) construct maternity dens in seasonal snowdrifts that form in wind-shadowed areas. We developed and verified a spatial snowdrift polar bear den habitat model (SnowDens-3D) that predicts snowdrift locations and depths along Alaska's Beaufort Sea coast. SnowDens-3D integrated snow physics, weather data, and a high-resolution digital elevation model (DEM) to produce predictions of the timing, distribution, and growth of snowdrifts suitable for polar bear dens. SnowDens-3D assimilated 18 winters (1995 through 2012) of observed daily meteorological data and a 2.5 m grid-increment DEM covering 337.5 km^2 of the Beaufort Sea coast, and described the snowdrift depth distributions on 30 November of each winter to approximate the timing of polar bear den entrance. In this region of Alaska, winds that transport snow come from two dominant directions: approximately NE to E (40–110°T) and SW to W (210–280°T). These wind directions control the formation and location of snowdrifts. In this area, the terrestrial, coastal mainland and barrier island banks where polar bear dens are found average approximately 3 m high. These banks create snowdrifts that are roughly 2 m deep, which historical den analyses suggest is approximately the minimum snow depth required for a polar bear den. We compared observed den locations ($n = 55$) with model-simulated snow-depth distributions for these 18 winters. For the 31 den locations where position accuracy estimates were available in the original field notes, 29 locations (97%) had a simulated snowdrift suitable for denning within that distance. In addition, the model replicated the observed inter-annual variability in snowdrift size and location at historical den sites, suggesting it simulates interactions between the terrain and annual weather factors that produce the snowdrifts polar bears use for dens. The area of viable den habitat ranged from 0.0 ha to 7.6 ha (0.00–0.02% of the 337.5 km^2 simulation domain), depending on the winter. SnowDens-3D is available to help management agencies and industry improve their prediction of current polar bear den sites in order to reduce disturbance of denning bears by winter recreational and industrial activities.

1. Introduction

With few exceptions, pregnant female polar bears (*Ursus maritimus*) den in seasonal snowdrifts that form on sea ice or land (Amstrup, 2003). On sea ice, these snowdrifts typically form downwind of ice pressure ridges. On land, snowdrifts can form in the lee of ridges and tall vegetation stands, and along lee banks of rivers, barrier islands, and the mainland coast (e.g., Fig. 1). On Alaska's Beaufort Sea coast where this study took place, pregnant polar bears typically excavate and occupy their dens during November and early December, with >99% of them in dens by 10 December (Amstrup and Gardner, 1994; Amstrup, 2000, 2003). They presumably give birth in early January and emerge from their dens and leave the denning area with their cub(s) during March and April (Amstrup and Gardner, 1994; Amstrup, 2003; Smith et al., 2007).

Historically, pregnant polar bears in the Southern Beaufort Sea have denned on drifting and land-fast sea ice, and barrier islands and other land where sufficient snow for den excavation has accumulated (Amstrup and Gardner, 1994; Amstrup, 2003; Fischbach et al., 2007). Between 1981 and 1991, 42% of the maternal dens used by radio-collared polar bears were located on land (Amstrup and Gardner, 1994). Recently, sea ice extent and thickness have been decreasing and there has been a marked transition from the relatively stable multiyear ice of the past, to an Arctic Ocean

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http://dx.doi.org/10.1016/j.ecolmodel.2015.09.010
0304-3800/

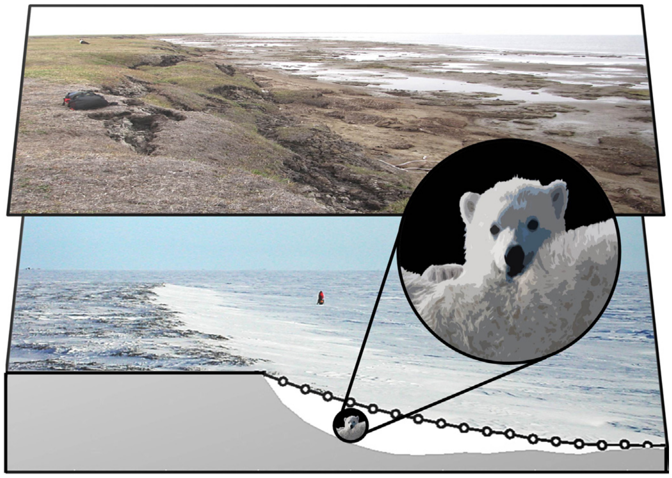

Fig. 1. Typical summer bank (top) and winter snowdrift (bottom) den habitat on a barrier island along Alaska's Beaufort Sea coast, with a stylized polar bear den positioned in the snowdrift (inset). The banks are only a few meters high, as seen in the summer photograph. In the bottom image the wind blew from left to right, filing the right-facing bank with snow. Photos courtesy of R. Shideler, Alaska Department of Fish & Game (top); C. Perham, U.S. Fish and Wildlife Service (bottom); and J. Aars, Norwegian Polar Institute (inset).

dominated by relatively thin and unstable one- and two-year-old sea ice (Comiso et al., 2008; Kwok and Rothrock, 2009; Maslanik et al., 2011; Polyakov et al., 2012). This loss of stable sea ice has corresponded to an increase in dens on land and barrier islands (Fischbach et al., 2007). Between 1998 and 2004, 63% of the dens used by pregnant polar bears with satellite-collars were on land (Fischbach et al., 2007).

This trend, and the increase in human activity along the Beaufort Sea coast, has magnified the potential for human–bear interactions. These exchanges can compromise human safety and result in disturbance of bears at maternal den sites. Although the U.S. Fish and Wildlife Service (USFWS) and the Alaska Department of Natural Resources have long required winter oil and gas off-road activities be restricted within 1.6 km of active polar bear maternal dens, only recently have techniques other than radio-telemetry been tested for detecting dens. Application of these new techniques, which include airborne Forward-Looking Infrared (FLIR; Amstrup et al., 2004), handheld infrared (IR) imagers (Shideler, 2014), and scent-trained dogs (Perham and Williams, 2003; Shideler and Perham, 2008; Shideler, 2014) has resulted in more dens being located. In addition, in 2008 polar bears were listed as "Threatened" under the U.S. Endangered Species Act (73 Fed. Reg. 28212; 15 May 2008). These considerations led to increased interest in identifying potential polar bear den habitat to assist in detecting active maternal den locations and to minimize anthropogenic disturbance around them (MacGillivray et al., 2003; Stirling and Derocher, 2012).

1.1. Polar bear maternity den characteristics

The characteristics of polar bear maternity dens and the landscapes where they are found have been well documented (Harington, 1968; Lentfer and Hensel, 1980; Amstrup and Gardner, 1994; Durner et al., 2001, 2003; Richardson et al., 2005). Collectively, these studies suggest that, with the exception of those around Hudson Bay, Canada, virtually all pregnant polar bears den in snowdrift caves that are at least 0.8 m high, 1.6 m long, and 1.4 m wide, with a roof typically 0.7 m thick. Therefore, the combined den dimensions and roof thickness suggest a minimum snowdrift cross-section diameter (in directions oriented vertically and in the same direction as the wind that formed the snowdrift) of approximately 2.0 m, and a drift length (oriented perpendicular to the wind and typically the long axis of the drift) of approximately 2.0 m, is required for a viable den.

1.2. Arctic snow processes and characteristics

This study focused on terrestrial polar bear maternity dens. Since snow is such a necessary component of this den habitat, a brief explanation of Arctic terrestrial snow characteristics is warranted. Land-based Arctic snow-covers are largely comprised of two kinds of snow formations (Benson and Sturm, 1993): (1) a thin, veneer-snow formation that covers the majority of the landscape; and (2) a snowdrift-snow formation that accumulates blowing snow in topographic or vegetation drift traps. Sturm et al. (2001a) estimated that for a typical Arctic Alaska landscape the veneer-snow covers 95% of the area and the snowdrift-snow covers the remainder. However, these proportions varied widely depending on local and regional topography and vegetation. In the veneer-snow formation the snow depth is typically 0.4–0.6 m deep by the end of the winter accumulation season (April, May, or June; Liston and Hiemstra, 2011). By late November or early December, when pregnant polar bears commonly excavate and occupy dens, snow depths in the veneer-snow formation are more typically 25–50% of these values or 0.1–0.3 m deep (Olsson et al., 2003). Therefore, veneer-snow snow depths are generally too shallow for a polar bear den.

In non-forested Arctic landscapes, wind is a dominant influence on snow depth. The frequent occurrence of wind-blown snow leads to considerable snow redistribution, transporting the snow from veneer-snow areas and depositing it in the lee of banks, ridges, and taller vegetation, and within topographic depressions (Seligman, 1936; Elder et al., 1991; Sturm et al., 2001a,b; Hiemstra et al., 2002). The associated wind redistribution processes affect snow depths over horizontal length scales varying from tens of centimeters to hundreds of meters (Blöschl, 1999; Liston, 2004). Since the snowdrifts polar bears select fit within this range, blowing snow must play an important role in creating snowdrifts that are deep enough and large enough for dens.

When wind blows across topographic features that have sharp slope changes on their lee sides, the flow separates from the ground surface and the speed is reduced across the lee slopes. This wind speed reduction means the wind cannot carry as many snow particles as it did at the higher speeds. Therefore, the particles fall out of the wind-flow field and accumulate on the ground in these sheltered, lee-slope areas. Conceptually, the wind-flow field that exists across a given landscape describes the snow erosion and deposition patterns that will exist. Accelerating winds are associated with erosion and decelerating winds are associated with accumulations in the form of snowdrifts (Liston and Sturm, 1998; Liston et al., 2007). These differences in wind speeds can arise from variations in topographic slope and changes in surface roughness such as that produced by differences in vegetation height (Sturm et al., 2001b; Hiemstra et al., 2002). In some areas of the Arctic, these snowdrifts can accumulate to depths over 10 m by the end of winter (Benson, 1982; Benson and Sturm, 1993). These processes of increasing wind speed eroding snow particles from the surface, and decreasing wind speed depositing snow particles on the surface, are fundamental to the formation of snowdrifts that polar bears use for dens.

Although snowdrifts form predominantly on lee slopes, under special circumstances snowdrifts can also form on windward slopes. When wind approaches a long, steep step or rise in topography that faces into the wind, the wind slows down near the bottom of the slope in response to that upwind obstruction, allowing snow to accumulate there. This only occurs if the topographic obstruction is steep, high, and long enough. If it is not sufficiently long, the wind accelerates around the sides and bottom of the obstruction and a windward snowdrift does not form.