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Relative influences of climate change and human activity on the onshore distribution of polar bears☆

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ABSTRACT

Climate change is altering habitat for many species, leading to shifts in distributions that can increase levels of human-wildlife conflict. To develop effective strategies for minimizing human-wildlife conflict, we must understand the relative influences that climate change and other factors have on wildlife distributions. Polar bears (*Ursus maritimus*) are increasingly using land during summer and autumn due to sea ice loss, leading to higher incidents of conflict and concerns for human safety. We sought to understand the relative influence of sea ice conditions, onshore habitat characteristics, and human-provisioned food attractants on the distribution and abundance of polar bears while on shore. We also wanted to determine how mitigation measures might reduce human-polar bear conflict associated with an anthropogenic food source. We built a Bayesian hierarchical model based on 14 years of aerial survey data to estimate the weekly number and distribution of polar bears on the coast of northern Alaska in autumn. We then used the model to predict how effective two management options for handling subsistence-harvested whale remains in the community of Kaktovik, Alaska might be. The distribution of bears on shore was most strongly influenced by the presence of whale carcasses and to a lesser extent sea ice and onshore habitat conditions. The numbers of bears on shore were related to sea ice conditions. The two management strategies for handling the whale carcasses reduced the estimated number of bears near Kaktovik by > 75%. By considering multiple factors associated with the onshore distribution and abundance of polar bears we discerned what role human activities played in where bears occur and how successful efforts to manage the whale carcasses might be for reducing human-polar bear conflict.

1. Introduction

Climate change is significantly altering habitat for many species (Durner et al., 2009; Dirnböck et al., 2011) and has been observed to alter distributions of wildlife populations (Nye et al., 2009; Chen et al., 2011). Similarly, species are using new areas within their existing ranges to adjust to changing environmental conditions (Melin et al., 2014). These changes have the potential to lead to increased levels of human-wildlife conflict (Baruch-Mordo et al., 2014). For example, in Nepal, climate change-related shifts in vegetation have led blue sheep (*Pseduois nayaur*) to forage at lower elevations where they consume human crops, leading to conflict (Aryal et al., 2014). Snow leopards (*Panthera uncia*) have followed blue sheep to these areas, leading to increased levels of livestock depredation (Aryal et al., 2014).

Polar bears (*Ursus maritimus*) have exhibited shifts in habitat use due to sea ice loss associated with climate change (Rode et al., 2015; Atwood et al., 2016). As sea ice has declined, the number of polar bears coming on shore and time spent there has increased for some subpopulations (Rode et al., 2015; Atwood et al., 2016) and has led to higher incidences of human-polar bear conflict (Dyck, 2006; Towns et al., 2009). In two studies researchers found that the majority of polar bears killed in defense-of-life occurred during the open water season (Stenhouse et al., 1988; Dyck, 2006). Thus, as more bears come on shore during summer, there is an increased risk of human-polar bear

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conflict. This has the potential to result in more defense-of-life kills, direct concerns for human safety (Derocher et al., 2013), and disruption to industrial, recreational, and subsistence activities.

Previous research has shown that use of onshore habitat by polar bears during summer and autumn is not randomly distributed (Schliebe et al., 2008; Rode et al., 2015). For example, Rode et al. (2015) found that polar bear use of onshore areas in the Chukchi Sea was related to the date of sea ice retreat, with areas of coastline having later dates of retreat receiving greater use by bears. Further, when on shore, polar bears in the southern Beaufort Sea are disproportionately distributed along barrier islands rather than mainland coastal areas (Gleason and Rode, 2009). Polar bears can also be drawn to areas with human attractants, such as garbage dumps (Towns et al., 2009) and the remains of marine mammals harvested for subsistence (Miller et al., 2015). While numerous links have been documented relating polar bear onshore distribution to biotic and abiotic factors, it remains unclear what the relative roles each of these factors play in determining polar bear abundance and distribution.

Determining the relative influence of sea ice conditions, onshore habitat, and anthropogenic food sources and other attractants have on where bears occur on shore is important for understanding how to mitigate human-polar bear conflict. For example, if polar bears are drawn to communities primarily due to the availability of food, then moving or removing the food attractant could reduce conflict. Conversely, if bears are drawn to the area primarily due to onshore habitat conditions (e.g., barrier islands) or preferable sea ice dynamics, such as earlier return of sea ice, then mitigation to remove attractants might be less effective.

Mitigating emergent conflicts with wildlife that could be caused, in part, by climate change requires an understanding of the relative influences that climate change and other factors have on the altered species' distribution (White and Ward, 2010). We therefore developed a Bayesian hierarchical model to understand the relative roles sea ice, coastal habitat, and human activity had on the weekly number and distribution of polar bears along the northern coast of Alaska. Our analysis was based on aerial survey data and systematic ground-based counts collected from late August through October between 2000 and 2014. We then used the model to predict how different management strategies for a human-derived food source might decrease the number of polar bears near to the coastal community of Kaktovik, Alaska (where large aggregations of polar bears can be found within and adjacent to the community), while controlling for the influences of sea ice and onshore habitat conditions.

2. Materials and methods

2.1. Study area

Our study area extended from Point Barrow, Alaska, east to the Canadian Border (Fig. 1) along the Beaufort Sea coast. The Beaufort Sea has a narrow band of continental shelf along the Alaskan coast, stretching < 100 km offshore, then quickly dropping off to some of the deepest waters in the Arctic Ocean. We divided the study area into 10 equal-width (60.5 km) grids, which contained different lengths of coastline (Table A1). The study area encompasses three communities (i.e., Barrow, Nuiqsut, and Kaktovik; Fig. 1), all of which annually harvest bowhead whales (*Balaena mysticetus*) in autumn for subsistence purposes. Whaling in Barrow and Kaktovik occurs adjacent to town, and residents of Nuiqsut base their whaling efforts on Cross Island (Fig. 1). In addition to the three whaling communities, a large oil production complex is located in Deadhorse and adjacent areas, consisting of oil production facilities and supporting infrastructure (Fig. 1).

Polar bears from the Southern Beaufort Sea (SB) subpopulation are most likely to occur in the study area, but bears from the Chukchi Sea and Northern Beaufort Sea subpopulations can be present (Amstrup et al., 2004). There are currently 900 animals estimated to be in the SB subpopulation (Bromaghin et al., 2015). The proportion of bears from the SB subpopulation coming on shore each summer and the period of time spent on shore has increased in the past decade (2000–2014) from a period (1986–1999) before precipitous declines in sea ice extent occurred (Overland and Wang, 2013; Atwood et al., 2016).

2.2. Aerial surveys

We flew aerial surveys annually in 2000–2014, except during 2006. Surveys occurred between early August and late October, although timing and frequency varied among years (i.e., the number of surveys ranged from 2 to 5 in a given year). Only one survey occurred during any given week. We restricted our analyses to the time period between the last week of August through the last week of October, because these periods were represented in most years of the survey. The majority of surveys occurred between Barrow, Alaska and the Canadian Border (Fig. 1) along the mainland coast and barrier islands, although poor weather conditions often limited our ability to complete all sections of coastline during each survey week. From 2000 to 2002, surveys were restricted to the area between Cape Halkett and Barter Island (Fig. 1).

Four aircraft types were used for surveys during the study; a Turbo Commander plane from 2000 to 2008, an R-44 helicopter from 2009 to 2010 and 2012–2014, a Bell 206 helicopter in 2011, and an A-Star helicopter for a portion of the 2013 surveys. During surveys all aircraft flew approximately 300 m offshore, at an altitude of approximately 90 m, and at a speed of 150–185 km/h. We implemented a double-observer design in which a front and rear observer independently spotted groups of polar bears (Supplementary appendix B). Across all aircraft types, we estimated very high detectability (98.2%; 95% C.I.: 97.5–98.7) of polar bear groups (Supplementary appendix B), likely due to the low altitudes we flew and the stark contrast between bears and coastline substrates. Thus, to simplify modeling, we assumed that polar bears were observed 100% of the time if they occurred on the coastline. Our surveys did not include distance-sampling methodology because most polar bears were concentrated on the mainland coast or barrier islands, so we considered our sampling area to be the linear coastline.

2.3. Ground-based surveys

We supplemented aerial survey data with three datasets of daily, systematically collected, ground-based counts of polar bears from Cooper Island (Fig. 1a), Cross Island (Fig. 1b), and Barter Island (where Kaktovik is located; Fig. 1c). For each location, we obtained the maximum number of bears observed during daily counts within a week for input into the model (see below, Observation model section). During most years of the study, counts on Cooper Island were restricted to the last week of August (2000–2014), with one year providing counts during the first week of September 2005. Counts on Cooper Island were conducted from a fixed point and covered a distance of approximately 4 km of coastline, nearly 50% of the island. Counts on Cross Island occurred from 2002 to 2004 during mid-September through the end of the month (corresponding to the period when whaling occurs, except in 2004 when it occurred after whaling). Counts were from a fixed location on the island that allowed observers to count bears over the entire island, totaling approximately 5 km of coastline. Barter Island counts occurred during September each year in 2002–2014. Counts on Barter Island were made along a road transiting the northern end of Barter Island, and from two fixed locations that allowed observers to count polar bears along two adjacent islands, totaling approximately 12 km of coastline (Fig. 1c).

2.4. Analytical methods

We used a Bayesian hierarchical modeling framework to estimate onshore abundance of polar bears that was able to account for multiple levels of uncertainty in the data as well as incorporate ground-based