Biological Conservation 207 (2017) 47–54

Contents lists available at ScienceDirect

Biological Conservation

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

Using non-invasive mark-resight and sign occupancy surveys to monitor low-density brown bear populations across large landscapes

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ARTICLE INFO

Article history:
Received 2 August 2016
Received in revised form 12 December 2016
Accepted 10 January 2017
Available online 29 January 2017

Keywords:
Abundance
Brown bear
Den survey
Landscape scale
Mark-recapture
Occupancy
Photographic marks
Population monitoring
Rare species

ABSTRACT

Reliable assessments of low-density carnivore populations such as brown bears *Ursus arctos* are often limited by a lack of sufficient information for strong inference at appropriate scales. Standard approaches often rely on physical marking of individuals or the use of inherently field-intensive hair-snag or distance sampling techniques. Although these tools are very useful, logistical and monetary costs often limit their successful application, particularly in large, remote areas. We developed a novel photographic mark-resight approach using physical characteristics and spatial locations of individual brown bears to temporarily mark individuals over a short revisit interval. We applied this approach along with site-occupancy techniques to evaluate a low-density brown bear population in northwestern Alaska. Based on the mark-resight approach, we estimated there were 420 [95% CrI:274–650] independent and 713 [95% CrI:474–1070] total brown bears in our 19,998km^2 study area. When expressed as densities, these estimates were consistent with those of other low-density populations from the surrounding area. Estimated den and bear site-occupancy rates were similar, 0.48 [95% CrI:0.37–0.63] and 0.40 [95% CrI;0.28–0.55], respectively. Close congruence among occupancy and abundance estimates supported the robustness of our new mark-resight approach and provided additional metrics for population monitoring. Together, these parallel metrics provide a general framework for monitoring low density populations of brown bears and other rare carnivores when physical marking or intensive survey techniques are impractical.

1. Introduction

Estimates of abundance and density are commonly used for monitoring and management of wildlife populations, although these state variables are difficult to measure for rare species (Thompson, 2004). Although many powerful approaches have been used to estimate the abundance and density of large carnivores in a variety of settings and habitats, strong inference is often lacking precisely because individuals are sparsely distributed and difficult to sample (MacKenzie et al., 2005). Mark-resight techniques, often employing radio-collars, are well developed and have been successfully used for many years (e.g., Hein and Andelt, 1995; Miller et al., 1997). Similarly, replicate photographs recorded by spatially distributed camera-traps have been used to 'mark' and subsequently 'resight' individuals based on unique marking patterns (e.g., tigers, Karanth and Nichols, 1998; pumas, Negrões et al., 2010). Spatially-explicit mark-recapture analytical techniques are then used to estimate population parameters of interest (Royle et al., 2009; Gardner et al., 2010a; Royle et al., 2011). Analogously, DNA samples collected with hair snag traps or other means can also be analyzed in a spatial capture-recapture analytical framework to assess abundance and density (Gardner et al., 2009; Gardner et al., 2010b; Kéry et al., 2011; Russell et al., 2012). Distance sampling approaches have also been used and have the advantage of not requiring the identification of individuals (Becker and Quang, 2009; Becker and Christ, 2015). Each of these approaches can provide useful assessments of population abundance and density, but their implementation can be logistically challenging at large spatial scales.

Capture operations required to physically mark individuals are generally expensive, particularly for species such as brown bears (*Ursus arctos*), often leading to relatively small sample sizes and restricted sampling areas. Alternative approaches such as distance sampling can be conducted over broad areas; however, intensive sampling may be required, sometimes over multiple seasons, in order to acquire sufficient numbers of detections (Becker and Quang, 2009; Reynolds et al., 2011). These requirements have obvious drawbacks when attempting

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http://dx.doi.org/10.1016/j.biocon.2017.01.005
0006-3207/Published by Elsevier Ltd.

to sample low density bear populations. Spatially-explicit mark-recapture techniques using DNA to identify individuals are often successful even when sample sizes are reduced, but the deployment and collection of traps at the scales necessary for desired inference can be logistically prohibitive (De Barba et al., 2010). Although each of these powerful approaches can be applied successfully in certain situations, high cost or restricted spatial inference may lead to the pursuit of other more easily estimated state variables closely related to abundance and density (e.g., occupancy).

Site-occupancy modeling approaches (MacKenzie et al., 2002, 2006) are a common alternative for monitoring populations of rare species when approaches for estimating abundance are not feasible. Site-occupancy surveys are often more practical logistically and provide useful information directly related to abundance (MacKenzie et al., 2005; Tempel and Gutierrez, 2013). Identification of individuals is not required, but rather the detection/non-detection of the species of interest at each site is used to estimate detection probability and the proportion of the sites that contain ≥1 individual. For species that are rare or otherwise difficult to detect, signs (e.g., tracks, feces, dens) may be used as an alternative to the direct detection of individuals to provide inference to the population of interest (Stanley and Royle, 2005; Karanth et al., 2009; Hines et al., 2010; Long et al., 2011; Wilson and Schmidt, 2015). The logistical efficiency of occupancy surveys can often be used to increase spatial inference, providing information at the landscape scale that would be impossible if more intensive methods were used (Karanth et al., 2011). Interestingly, multi-metric monitoring approaches that exploit the inferential benefits of both occupancy and abundance estimation are less well developed. In many cases, occupancy and abundance data could be collected simultaneously for little additional cost. If properly designed, parallel site-occupancy and abundance surveys could be used to provide more comprehensive inference useful for managers of species occurring at low densities.

Brown bears often occur at low densities presenting many challenges for sampling. Collar-mark-resight (e.g., Miller et al., 1997), DNA mark-recapture (Solberg et al., 2006; Boulanger et al., 2008; Kendall et al., 2008), or distance sampling approaches are the most commonly employed methods for assessing brown bear populations, although, costs often limit the successful application of such field methods in large, remote areas. Unfortunately, such areas often support large components of the overall population important for conservation and management. The desire to assess and manage populations occurring in large, remote areas can lead to the pursuit of abundance estimates despite high risk of poor estimator performance due to low sample sizes (Reynolds et al., 2011). Occupancy methods require less data than abundance approaches, tend to be more precise, and can provide important trend information. However, occupancy surveys in continuous habitat require careful consideration of plot size and individual movements during the revisit period (Efford and Dawson, 2012). Abundance information, while generally more difficult to obtain, is often relied on for management, particularly for harvested species. We propose that the collection of both occupancy and abundance information may provide a tractable solution to the problem of monitoring and managing bears and other rare species in a variety of settings.

Here we introduce a novel non-invasive mark-resight survey approach, applied concurrently with site-occupancy and sign surveys, to estimate abundance and site-occupancy rates for a low density brown bear population in northwestern Alaska. Our primary objectives were to: 1) estimate den site-occupancy, 2) estimate bear site-occupancy, and 3) estimate brown bear abundance and density. We show that each data type provides information useful for addressing unique monitoring and management goals and strengthens overall conclusions. We expect our approach could be used to improve monitoring of brown bears throughout much of their range, in addition to being broadly applicable to other rare carnivore species.

2. Material and methods

2.1. Study area

Our study area encompassed a 19,998 km^2 area of the central Seward Peninsula in western Alaska, USA (Fig. 1). The terrain ranges from flat tussock-tundra, to rolling hills and steep rugged terrain in the Bendelaben and Kigluaik Mountains. Woody vegetative cover is generally sparse in northern areas of tussock tundra, consisting primarily of willow (*Salix* spp.) thickets along riparian corridors. Shrub patches become more common in the southern portion of the study area where alder (*Alnus* spp.) is also present. Areas of spruce (*Picea* spp.) forest are restricted to the extreme southeast portion of the study area. Black bears do not generally occur on the central Seaward Peninsula, so all observations of bears and bear sign were assumed to be related to brown bears. Brown bears occur throughout the area in all habitat types, although densities are generally greater further south.

2.2. Sampling design

We used a systematic sampling design to provide uniform coverage over the entire area and to minimize movement of bear groups between sampled units during the survey period (Fig. 1). We began by generating a systematic grid of 31 km^2 cells across the entire study area. Individual cells represented potential sampling subunits. Our choice of cell size was based on anticipated bear densities (1–2 bear groups/subunit) based on past work (Miller et al., 1997) and the expected amount of time required to adequately search each subunit (≤1 h). We selected groups of 4 adjacent cells, regularly spaced throughout the area, to form 48 primary sampling units each consisting of 4 subunits (Fig. 1). Spacing between primary units (i.e., >11 km) was intended to be large enough to minimize the probability that an individual bear could be observed in adjacent units on the same or separate days. As much as was practical, we surveyed groups of primary units in sequence to further avoid the potential effects of movement of individual bears among units between days.

2.3. Field methods

Aerial surveys were conducted in both 2013 and 2015 and were timed to coincide with the end of den-emergence, just prior to leaf-out of the woody vegetation (i.e., late May/early June). A single pilot and observer formed a 'team' given the task of searching subunits for bears. Each day pairs of teams were assigned 2 primary units (8 subunits) to survey. Each of the 2 teams independently searched each subunit for bear groups (i.e., 2 independent visits, one by each pilot-observer team) using a tandem seat fixed-wing aircraft. Teams were instructed to search each subunit thoroughly for bears with the guideline of attempting to spend ≤1 h of search time in each subunit. Pilots were free to choose the search pattern as long as the entire subunit was covered (see online Appendix; Fig. A1). Subunits were searched sequentially so that the second team covered each subunit completed by the first team within 4 h, minimizing the possibility of bears moving into or out of a given subunit between visits. The separation in time and differences in flight patterns helped address the potential problem of incomplete availability (e.g., Laake et al., 2008; Wilson et al., 2014). In 2015, teams were also instructed to search for and record observations of bear dens. Up to 8 teams conducted surveys each day, and units were generally surveyed from north to south to further limit the possibility of individual bear groups from being detected in >1 unit due to movements between days.

When a bear den was observed, the location of the den was recorded and the subunit was classified as 'occupied' by bear dens. Although photographs were taken of many dens, identification of individual dens was not always possible due to high den density which caused observer swamping in some areas. In addition, spatial locations often lacked