Biological Conservation 201 (2016) 192–200

Contents lists available at ScienceDirect

Biological Conservation

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

Camera-based occupancy monitoring at large scales: Power to detect trends in grizzly bears across the Canadian Rockies

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ARTICLE INFO

Article history:
Received 9 March 2016
Received in revised form 17 June 2016
Accepted 21 June 2016
Available online xxxx

Keywords:
Carnivore monitoring
Occupancy modeling
Power analysis
Non-invasive monitoring
Remote camera
Camera trapping
Ursus arctos

ABSTRACT

Monitoring carnivores is critical for conservation, yet challenging because they are rare and elusive. Few methods exist for monitoring wide-ranging species over large spatial and sufficiently long temporal scales to detect trends. Remote cameras are an emerging technology for monitoring large carnivores around the world because of their low cost, non-invasive methodology, and their ability to capture pictures of species of concern that are difficult to monitor. For species without uniquely identifiable spots, stripes, or other markings, cameras collect detection/non-detection data that are well suited for monitoring trends in occupancy as its own independent useful metric of species distribution, as well as an index for abundance. As with any new monitoring method, prospective power analysis is essential to ensure meaningful trends can be detected. Here we test camera-based occupancy models as a method to monitor changes in occupancy of a threatened species, grizzly bears (*Ursus arctos*), at large landscape scales, across 5 Canadian national parks (~21,000 km^2). With $n = 183$ cameras, the top occupancy model estimated regional occupancy to be 0.79 across all 5 parks. We evaluate the statistical power to detect simulated 5–40% declines in occupancy between two sampling years and test applied questions of how power is affected by the spatial scale of interest (park level vs. regional level), the number of cameras deployed, and duration of camera deployment. We also explore several ecological mechanisms (i.e., spatial patterns) of decline in occupancy, and examine how power changes when focusing only on grizzly bears family groups. As hypothesized, statistical power increased with the number of cameras and with the number of days deployed. Power was unaffected, however, by the ecological mechanisms of decline, indicating that our systematic sampling design can detect a decline regardless of whether occupancy declined due to range edge attrition, ecological trap or other mechanisms. Despite their lower occupancy, power was similarly high for grizzly bear family groups compared to grizzly bears in general. We highlight which study design attributes contributed to high power and we provide advice for establishing cost-effective camera-based programs for monitoring large carnivore occupancy at large spatial scales.

1. Introduction

Large carnivores are among the most vulnerable species to extinction and are often the first to become extirpated (Ripple et al., 2014). Carnivore conservation is a global priority (Gittleman et al., 2001), but monitoring their populations remains difficult because they are rare and elusive (Thompson, 2004). Common monitoring techniques for large carnivores include radio collaring animals for mark-recapture abundance estimates or demographic population models, but such invasive survey techniques are challenging because of high costs and risks to the animals (Gompper et al., 2006). Many non-invasive methods have been developed for monitoring large carnivores (Long et al., 2008). For example, abundance of species with individually-identifiable coat patterns like tigers (*Panthera tigris*), have been monitored with remote cameras (Karanth and Nichols, 1998); DNA-based spatial capture-recapture are used to methods to monitor bears (*Ursus* spp.; Kendall et al., 2009); wolverine (*Gulo gulo*) and lynx (*Lynx canadensis*) populations have been monitored using snow-tracking data (Whittington et al., 2014); brown hyenas (*Hyaena brunnea*) have been monitored using sign along roads (Thorn et al., 2011); and hunter surveys have been used to monitor wolves (*Canis lupus*; Rich et al., 2013). Regardless of the chosen monitoring technique, the economic challenge of estimating population size of many large carnivores often prevents

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http://dx.doi.org/10.1016/j.biocon.2016.06.020
0006-3207/

effective estimation of trends, especially at large spatial scales (Andelman and Fagan, 2000).

Grizzly bears are an iconic focal species for conservation and a difficult species to monitor, providing an archetypical example of the problems with large carnivore conservation. Globally, the threats to grizzly bears are diverse including habitat fragmentation, conflict with humans (McLellan et al., 2008), vehicle collisions, and in many parts areas, they continue to be poached and hunted unsustainably. Even in protected areas, the majority of grizzly bear mortalities can be human-caused (Nielsen et al., 2004). They are a common symbol of wilderness in support of conservation efforts; a useful umbrella species to protect species diversity range (Carroll et al., 2001); and an important keystone species in many parts of its range (Helfield and Naiman, 2006). Globally, grizzly bears (brown bears) are widely distributed across the northern hemisphere, but are highly fragmented in the southern parts of their range, having been extirpated from much of Europe, most of the contiguous US, and entirely from Northern Africa (McLellan et al., 2008). In some areas, such as the Greater Yellowstone Ecosystem (GYE), grizzly bears are expanding in range and abundance (Schwartz et al., 2008). In other regions like Alberta, however, grizzly bears have recently been listed as threatened at the provincial level and may be declining (Alberta Sustainable Resource Development and Alberta Conservation Association, 2010; Whittington and Sawaya, 2015).

One effective method to monitor large carnivores at large spatial scales is DNA-based mark-recapture. This technique has been used for species such as tigers (Mondol et al., 2009), puma (*Puma concolor*; Miotto et al., 2014) and grizzly bear (*Ursus arctos*) populations (Kendall et al., 2009; Whittington and Sawaya, 2015). In the Northern Continental Divide Ecosystem (NCDE; 31,410 km^2), DNA mark-recapture provided a powerful and robust method to monitor grizzly bears. This first estimate of 765 bears (Kendall et al., 2009), however, cost ~$4.8 million (Ballantyne, 2008). Similarly, in Southern and Central Alberta (111,691 km^2), another DNA mark-recapture study over 5 years (2004–2008) led to an estimate of 691 grizzlies in Alberta (Alberta Sustainable Resource Development and Alberta Conservation Association, 2010) and cost a total of $2.1 million (Alberta Grizzly Bear Recovery Plan 2008-2013, 2008). Estimating a trend in grizzly bear number will require conducting additional full studies, making long-term monitoring using this method very expensive. Furthermore, grizzly bears in the US are currently listed as Threatened under the Endangered Species Act and have been proposed for delisting (USFWS, 2016), removing both federal protection and federal sources of funding for monitoring. Other economically sustainable methods may be required to monitor grizzly bears and other wide-ranging large carnivores.

The most robust and cost-efficient method for monitoring large carnivores is often species-and location-specific. For example, grizzly bear in Sweden, can be tracked through bear sighting reported from moose hunters Kindberg et al. (2011); where hunted legally, grizzly bear harvest data can be used (Apps et al., 2004); in protected areas, such as Yellowstone National Park, researchers track grizzly bear family groups (i.e., females with cubs; Schwartz et al., 2008). In other areas, like the Canadian Rockies, however, this method is not possible due to lower grizzly-bear densities, fewer observers and more densely forested landscape (Brodie and Gibeau, 2007). Radio-collared grizzlies can also provide survival and reproductive rates to use in a life table analysis to estimate population growth rate (Mace et al., 2012). In small populations, like the Apennines, Italy, total population size can be estimated from mark-resight methods because the total population is <50, allowing a large percentage of the population to be easily captured and recaptured (Gervasi et al., 2012). These techniques all have limitations when long-term monitoring is required at large spatio-temporal scales (Noon et al., 2012).

Camera-based occupancy models may offer an inexpensive alternative for estimating trends in large carnivore populations. Cameras are increasingly being adopted for monitoring because they are low cost, non-invasive, and capture pictures of rare and understudied species (Burton et al., 2015; Steenweg et al., In Revision). For animals with individual marks, camera traps provide a mechanism to estimate abundance (e.g. Karanth and Nichols, 1998). However, for grizzly bears and other species that are not individually identifiable, occupancy may allow trends monitoring through changes of the proportion of area occupied (Stanley and Royle, 2005), which is itself, a key conservation trend metric. The size of a species' entire distribution, for example, can be the best predictor of extinction risk (Harris and Pimm, 2008). The IUCN uses the occupancy metrics "area of occupancy" and "extent of occurrence" in 2 of the 5 criteria for assessing the threatened status of a species (Mace et al., 2008). Occupancy models explicitly incorporate the detection process, correcting for this potential bias (MacKenzie et al., 2006). Although promising, using occupancy modeling to detect trends in population status over time has been rarely tested at large spatial scales in populations of large carnivores (Ellis et al., 2014).

Prospective power analysis can help evaluate monitoring efforts by examining our ability to detect trends over time (Steidl et al., 1997). For monitoring questions, the null hypothesis tested is that there is no population trend, i.e. no difference among population estimates across time. The resulting Type I error, α, is the probability of falsely detecting a change (increase or decline) in the population when no change has occurred (i.e., a false alarm; commission error). Type II error, β, is defined as the probability of falsely concluding a population is not changing, even though in reality it is changing (i.e., failing to detect a change; omission error). Power, $1 - \beta$, represents the probability of correctly rejecting a false null hypothesis, thus supporting the alternative hypothesis that a change in the population has occurred. There is a tradeoff between these two errors, and in the context of conservation, failing to detect a real decline of a threatened species can have much graver consequences (increased extinction risk with long time lags for recovery) than a false alarm (short-term financial cost; Field et al., 2004). Occupancy analysis corrects for detection probability, and therefore creates another tradeoff: between the number of samples and the number of repeat visits (Bailey et al., 2007; Guillera-Arroita and Lahoz-Monfort, 2012; MacKenzie and Royle, 2005). With cameras, these are analogous to the number of cameras sites and the duration of camera deployment, respectively. To help evaluate this tradeoff, we address three questions pertaining to camera study design. First, at what spatial scale can a trend in occupancy be detected, i.e., can a trend be detected with sufficient power at both small (e.g. single park) and large (e.g. many adjacent parks together) spatial scales? Second, how many cameras are required to detect trends with sufficient power? Third, how long should cameras be deployed? We hypothesize that statistical power to detect trends will be high at the regional scale, but that smaller parks may not have adequate power. We hypothesize that when monitoring species with low daily detection probabilities, like wary carnivores, cameras may need to be deployed year-round.

We also address two additional questions pertinent to occupancy-based monitoring. First, it is unknown how the distribution of a carnivore will change when the population is declining. Through simulation, we investigate 4 different ways that grizzly bear distribution could decline, each of which may affect our ability to detect trends. The 4 scenarios are: random site occupancy decline, low-quality sites declining first, high-quality sites declining first (i.e. an ecological trap), and range-edge sites declining first. Second, our main goal was to evaluate occupancy trend monitoring using all photos of grizzly bears. However, because adult females drive population growth, large carnivore monitoring often focuses on adult females. We compare power to detect trends for all grizzly bears, to power to detect trends in grizzly bear family groups.

2. Materials and methods

2.1. Study system

The Canadian Rockies study area spans over 4° of latitude from Waterton Lakes National Park (WLNP) to the northern extent of Jasper National Park (JNP), encompassing 5 national parks (Fig. 1). Throughout