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Compounding effects of human development and a natural food shortage on a black bear population along a human development-wildland interface

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ABSTRACT

Human development and climate change are two stressors that threaten numerous wildlife populations, and their combined effects are likely to be most pronounced along the human development-wildland interface where changes in both natural and anthropogenic conditions interact to affect wildlife. To better understand the compounding influence of these stressors, we investigated the effects of a climate-induced natural food shortage on the dynamics of a black bear population in the vicinity of Durango, Colorado. We integrated 4 years of DNA-based capture-mark-recapture data with GPS-based telemetry data to evaluate the combined effects of human development and the food shortage on the abundance, population growth rate, and spatial distribution of female black bears. We documented a 57% decline in female bear abundance immediately following the natural food shortage coinciding with an increase in human-caused bear mortality (e.g., vehicle collisions, harvest and lethal removals) primarily in developed areas. We also detected a change in the spatial distribution of female bears with fewer bears occurring near human development in years immediately following the food shortage, likely as a consequence of high mortality near human infrastructure during the food shortage. Given expected future increases in human development and climate-induced food shortages, we expect that bear dynamics may be increasingly influenced by human-caused mortality, which will be difficult to detect with current management practices. To ensure long-term sustainability of bear populations, we recommend that wildlife agencies invest in monitoring programs that can accurately track bear populations, incorporate non-harvest human-caused mortality into management models, and work to reduce human-caused mortality, particularly in years with natural food shortages.

1. Introduction

Human development and climate change are two important stressors threatening global biodiversity (Bellard et al., 2012; Newbold et al., 2015). Expanding human development and infrastructure affect wildlife by eliminating habitat (Theobald, 2010), fragmenting and degrading existing habitat (Riitters et al., 2009), and increasing human disturbance (Trombulak and Frissell, 2000; Hansen et al., 2005), impacts which have been shown to displace wildlife (Vogel, 1989; Sawyer et al., 2006), affect movement behavior (Hurst and Porter, 2008; Cushman and Lewis, 2010), reduce demographic rates (Hansen et al., 2005), and contribute to population declines (Sorensen et al., 2008). Climate change affects wildlife by shifting long-term averages of climatic variables (e.g., warmer overall temperatures, earlier growing season) and increasing the frequency and intensity of extreme climatic events (e.g., droughts, floods; Stocker et al., 2013), which all can have substantial effects on animal behavior (Wong and Candolin, 2015), physiology (Vázquez et al., 2015), distributions (Chen et al., 2011), and population dynamics (Koenig and Liebhold, 2016).

Recent research efforts have increasingly focused on understanding the cumulative and interactive effects of multiple stressors on wildlife populations as investigators have recognized the diverse pressures influencing animals and the potential for detrimental additive or synergistic effects (Brook et al., 2008; Mantyka-Pringle et al., 2012; Côté et al., 2016). Such interactions are likely to be particularly pronounced along the human development-wildland interface where multiple stressors can converge and have compounding impacts on wildlife populations. Animals living along the development-wildland interface

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must contend with climate change-induced stressors in the natural environment such as shifts in vegetative phenology (Post and Forchhammer, 2008; Monteith et al., 2011), altered weather patterns (Rodenhouse et al., 2009; Skagen and Adams, 2012), and increased frequency of extreme climatic events (Altwegg et al., 2006; Boersma and Rebstock, 2014), while also coping with development-induced habitat loss and fragmentation, and increased exposure to disease, pollution, and human-caused mortality (McCleery et al., 2014). For example, climate-induced declines in sea-ice have reduced foraging opportunities for some polar bears (*Ursus maritimus*), and have forced them to reside on land during summer months. While this shift to land has been associated with reduced body condition of bears, it has also been accompanied by increases in conflicts with people (Stirling and Derocher, 2012), which can result in higher rates of human-caused mortality.

The compounding effects of multiple stressors along the human development-wildland interface are particularly concerning for the American black bear (*Ursus americanus*). Black bear behavior and demography are strongly tied to climate-induced variation in natural vegetative foods (Reynolds-Hogland et al., 2007; Baruch-Mordo et al., 2014; Johnson et al., 2015), and extreme weather events can cause seasonal food shortages which have been associated with reduced reproduction (Rogers, 1987a; Elowe and Dodge, 1989) and cub survival (Rogers, 1987a; Obbard and Howe, 2008). However, such events can also elevate levels of human-bear conflicts and human-caused mortalities (Zack et al., 2003; Baruch-Mordo et al., 2014) as bears increase their use of areas of human development in search of alternative food resources (Johnson et al., 2015). Because bear populations occurring along the human development-wildland interface are subject to the combined effects of climate-induced food shortages and increased human-caused mortality (e.g., vehicle collisions, lethal management removals, and illegal kills), their populations may be particularly susceptible to decline (Lewis et al., 2014). Improving our understanding of how multiple stressors drive black bear population dynamics is critical for developing future management policies that will ensure the sustainability of bear populations as changes in climate and land use continue.

We investigated the combined effects of human development and a climate-induced natural food failure on a black bear population located near the city of Durango in southwestern Colorado. In 2012, our study area experienced a late-spring hard freeze (Peterson, 2013; Rice et al., 2014) which caused a widespread natural food shortage for black bears in the region. Johnson et al. (2015) found that, under those conditions, black bears increased their use of human development to obtain anthropogenic resources for subsidy, a behavioral shift that had unknown consequences on the bear population. Our objective was to evaluate the effects of human development and the food shortage on the population of bears in our study area based on the hypothesis that combination of those stressors would result in a substantial population decline. We integrated spatial capture-recapture data and GPS collar data to quantify the abundance, density, and population growth rate of bears before and after the food shortage along the development-wildland interface. In addition, we used our integrated spatial capture-recapture models to investigate the influence of human development on the distribution of bears on the landscape (2nd order selection; Johnson, 1980) before and after the food failure. Our analysis provides important insight about the combined effects of multiple stressors facing black bear populations along the development-wildland interface, with key implications for bear management and conservation.

2. Study area

Our study area (Fig. 1) was located in southwestern Colorado and contained the city of Durango, Colorado (37.2753°N, 107.8801°W). Durango (~18,000 residents; https://www.census.gov/quickfacts/) is surrounded by mountainous terrain ranging in elevation from 1930 to 3600 m, and is generally characterized as having mild winters and warm summers that experience monsoon rains. Vegetation in the region is dominated by ponderosa pine (*Pinus ponderosa*), aspen (*Populus tremuloides*), pinyon pine (*Pinus edulis*), juniper (*Juniperus* ssp.), mountain shrubs (*Prunus virginiana*, *Amelanchier alnifolia*, etc.) and agriculture. Agriculture in the region is primarily irrigated pasture for grazing livestock, which provides negligible food resources or cover habitat for black bears. Durango is largely surrounded by public land managed by the San Juan National Forest, Bureau of Land Management (BLM), Colorado Parks and Wildlife (CPW), La Plata County and the City of Durango.

3. Methods

3.1. General approach

To estimate population parameters for bears before and after the food shortage, we combined DNA-based spatial capture-recapture (SCR) data with GPS-telemetry based resource selection data into a single integrated spatial capture-recapture (ISCR) analysis. We limited our analysis to female black bears because we had reliable DNA and telemetry data for this segment of the population and because female demography is the key to understanding changes in the population dynamics of bears (Freedman et al., 2003; Beston, 2011). We assumed our estimates of demographic parameters applied only to the population of bears ≥ 1 year old because bears < 1 year old are unlikely to be detected by the sampling methods we used (Drewry et al., 2013; Laufenberg et al., 2016). Our approach was organized into a 2-stage analysis. In the first stage, we used GPS data and resource selection function (RSF) models to identify important 3rd-order resource selection covariates (within the home-range; Johnson, 1980) that were then used in the second stage. In the second stage, we integrated GPS and SCR data into a single model that allowed us to estimate abundance, density, detection probabilities, 3rd-order resource selection coefficients for habitat covariates identified in the first analysis, coefficients relating habitat covariates to the distribution of bears across the landscape (2nd-order selection; Johnson, 1980), and relative variable importance measures for 2nd-order habitat covariates. We obtained productivity data on important black bear foods collected during our study to characterize the natural food shortage caused by the late-spring freeze in 2012. We also obtained records of observed bear mortalities collected by CPW within our study area to use as an index of annual human-caused mortality during before and after the food shortage.

3.2. Data sources

3.2.1. Non-invasive DNA data

We used non-invasive hair sampling methods to obtain unique, multilocus genotypes for individual bears, determine individual identities, and record capture histories for capture-mark-recapture analysis (Woods et al., 1999). Each year from 2011 to 2014 we constructed an array of baited, barbed-wire enclosures (hereafter referred to as hair snares) from which we collected hair samples over multiple survey occasions. Hair snare locations were based on a regular 6×6 grid pattern with the grid-cell size set at 4×4 km. Each cell contained 1 hair snare consisting of a single strand of 4-point barbed wire stretched around and attached to ≥ 3 trees at 50 cm above ground and enclosing an area 6–10 m in diameter. We baited each hair snare with liquid scent applied to burlap hung in a tree approximately 3 m above ground and to an imitation "cache" of woody debris constructed at the center of the wire enclosure. Scent bait consisted of decomposing fish liquids, various commercial bear scents, and decomposing road-killed deer liquids. Following construction, hair snares were baited and subsequently checked every 7 days for 6 consecutive weeks each year from approximately the second week of June through the last week of July. Prior to initial baiting and after subsequent sample collections, we heat-