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Research Paper

Black bear recolonization patterns in a human-dominated landscape vary based on housing: New insights from spatially explicit density models

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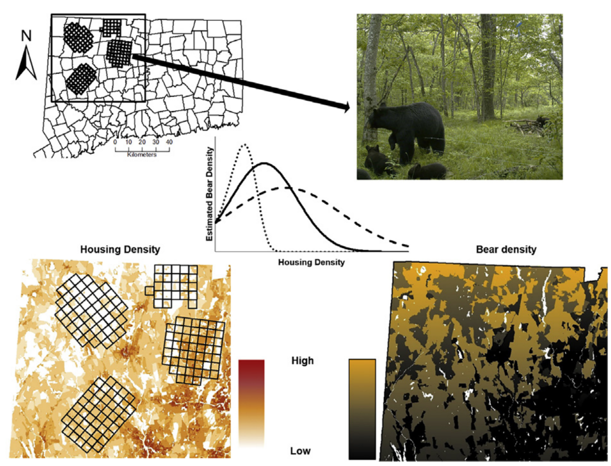
HIGHLIGHTS

- Housing density best predicted black bear distribution in intermixed ecosystem.
- Quadratic model best described relationship between bear density and housing.
- Greater proportions of males in more developed contexts.
- Bears may preferentially recolonize areas of exurban housing density.
- Development intensity will affect bear recolonization and continued persistence.

GRAPHICAL ABSTRACT



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ABSTRACT

Housing development is often intermixed within natural land cover, creating coupled human-natural systems that benefit some species, while eliminating critical habitat for others. As carnivore populations recover and expand in North America, understanding how populations may recolonize human-dominated landscapes is an important goal for conservation. We empirically test whether a population of American black bear (*Ursus americanus*) recolonizing a developed landscape is responding to land cover, housing density, or the amount of intermixture between forest and housing as quantified by the Wildland Urban Interface. Housing density was the most supported spatially explicit mark-recapture model and indicated that bear density was highest among exurban housing densities. Mean estimated bear density in exurban areas (6–49 houses/km^2) was 0.18 individuals/km^2 compared to 0.12 individuals/km^2 in rural areas (<6 houses/km^2). Bear densities also declined to zero as development approached 50 houses/km^2. We also tested for differences in sex ratio between more and less intensely developed areas, using hybrid mixture models. Sex ratios were significantly more male-biased in areas of higher housing density. Elevated bear densities provide evidence that exurban land-use can facilitate recolonization of black bears,

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yet high housing density may also limit the recovery of bear populations. Explicit relationships between land-use and bear density will allow managers to anticipate future population distribution, and areas where bears and people may come into frequent contact.

1. Introduction

Understanding the consequences of changing land-use patterns on ecological processes is critical to the conservation of natural resources (Ricketts & Imhoff, 2003), as urban areas are growing on average twice as fast as their human populations (Seto, Fragkias, Guneralp, & Reilly, 2011). In the United States exurban development has been the fastest growing pattern of land-use (Brown, Johnson, Loveland, & Theobald, 2005). Frequently this form of development integrates natural land cover and housing, potentially increasing habitat for wildlife (Clark, McChesney, Munroe, & Irwin, 2009; Theobald, 2004). This intermixing of development and natural land cover blurs traditional urban-rural distinctions, creating intermixed ecosystems (Zipperer, Wu, Pouyat, & Pickett, 2000). The Wildland Urban Interface (WUI) provides one way to describe these landscapes, using vegetated (i.e., little housing), intermixed (i.e., areas with where houses are located amidst natural cover), interfaced (i.e., areas where houses abut natural vegetation), and non-vegetated (i.e., houses and imperious surfaces) classifications (Radeloff et al., 2005). Wildlife response to intermixed ecosystems can differ among taxa (Bar-Massada, Radeloff, & Stewart, 2014; Hansen et al., 2005), and are not fully understood for species recolonizing urbanizing landscapes.

Intermixed ecosystems have led to a proliferation of synanthropic wildlife – species that exhibit positive demographic or numeric responses in the presence of people (Johnston, 2001; McKinney, 2006). Wildlife may benefit from humans because the anthropogenic resources and refuges provided (Waite, Chhangani, Campbell, Rajpurohit, & Mohnot, 2007) can increase survival and reproduction (DeStefano & DeGraaf, 2003; Gehrt et al., 2010; Marzluff & Ewing, 2001). For example, while many carnivores avoid roads and houses (Cardillo et al., 2004), a number of species have increased densities in urban landscapes (see Bateman & Fleming, 2012 for a review). Carnivore cohabitation with humans spans a gradient from avoidance, to urban adapters that tolerate development while relying on natural resources, to exploiters (i.e., synanthropes) with positive association with people (McKinney, 2006). The recovery and expansion of carnivore populations across North America and Europe (Chapron et al., 2014; Linnell, Swenson, & Anderson, 2001) has increased the presence of carnivores within human-modified landscapes, creating a need to understand how recolonizing populations respond to human activities.

Our goal was to understand how recolonizing wildlife populations respond to human-modified landscapes. Here we focus on the American black bear (*Ursus americanus*), a prominent species in urban wildlife research. Once extirpated from much of North America, populations have been recolonizing the former range over the last several decades (Garshelis & Hristienko, 2006). Black bears were thought to require large amounts of natural land cover – including forest, shrubland, and wetland habitats (Powell, Zimmerman, & Seaman, 1997) – and to be negatively affected by human activity (Brodeur, Ouellet, Courtois, & Fortin, 2008; Dixon et al., 2006). However, populations are expanding into urban landscapes, often exploiting anthropogenic foods (Johnson et al., 2015; Merkle, Robinson, Krausman, & Alaback, 2013; Ranglack, Signor, Bunnell, & Shivik, 2009). In landscapes classified as interface, bears select high quality natural land cover, and portions of the home range extend into urban areas, indicating urban avoidance (Baruch-Mordo et al., 2014; Johnson et al., 2015). This research has occurred primarily in the western United States. However, bears are increasingly recolonizing intermixed areas (Ellingwood, 2003; Evans, Hawley, Rego, & Rittenhouse, 2014) throughout the eastern US, where there are no rural areas within entire bear populations and individual home ranges.

The recent re-establishment of a black bear population in western Connecticut presents an opportunity quantify bear population distributions when recolonizing urbanized landscapes. While bear range in the state is composed primarily of forested land cover (i.e., National Land Cover Database; Fry et al., 2011), housing density within the range is predominantly exurban, with small patches of rural and urban areas (U.S. Census, 2011), and the WUI map depicts Connecticut as 72% intermixed (Fig. 2). Our first objective was to use spatially explicit mark-recapture models to test competing hypotheses regarding whether bears densities vary with land cover, housing density, or the amount of intermixture between forest and housing as quantified by the Wildland Urban Interface. We hypothesized that both forest cover and housing density influence the spatial distribution of bears, and thus predicted that the WUI would best explain spatial variation in bear density.

Our second objective was to identify where black bear density is highest, by quantifying the relationship between bear density and identified landscape classifications. We expected bear densities would be highest in intermixed areas, because these landscapes contain both forest cover and anthropogenic foods such as garbage and bird feeders (Greenleaf, Matthews, Wright, Beecham, & Leithead, 2009; Mazur & Seher, 2008). Finally, we expected this relationship to differ between males and females due to differences in dispersal (Costello, Creel, Kalinowski, Vu, & Quigley, 2008; Moyer, McCown, Eason, & Oli, 2006) and behavior at range peripheries between the sexes (Beckmann & Berger, 2003b; Sato, Itoh, Mori, Satoh, & Mano, 2011). Quantifying the response of expanding black bear populations to human-modified landscapes will help wildlife managers and land-use planners anticipate the future patterns of bear recolonization, and plan conservation strategies.

2. Methods

2.1. Study area and sample collection

Spatially explicit mark-recapture (SMRC) models (Gardner, Royle, & Wegan, 2009) use the locations of individual detections to directly estimate population densities. We used non-invasive hair corrals (Woods et al., 1999) to collect hair samples from black bears in northwest Connecticut, which provided genetic material used for individual identification. Corrals consisted of two strands of barbed wire spaced at 30 cm and 45 cm off of the ground, creating an enclosure of $\sim 5 \times 5$ m. We attracted bears to corrals using non-nutritional scent lures applied to log piles at the center of corrals, and rags hung over corrals. Scent lures did not provide a food reward, minimizing the potential for bears becoming conditioned to return to corrals. We used multiple, intensive (Wilton et al., 2014) sampling grids to systematically distribute hair corrals across four study areas. Grids encompassed the entire reproductive range of