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# Acceptability of residential development in a regional landscape: Potential effects on wildlife occupancy patterns

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ABSTRACT

The conversion of natural lands to developed uses may pose the single greatest human threat to global terrestrial biodiversity. Continued human growth and development over the next century will further exacerbate these effects of habitat loss and fragmentation. Natural resource managers are tasked with managing wildlife as a public trust, yet often have little say in land use decisions. Generally speaking, decision makers could benefit from an understanding of what different regulations mean in terms of wildlife distribution. In a previous paper (Bettigole et al., 2013), we surveyed town residents throughout Vermont to measure how respondents feel about a range of development levels within their town boundaries. We estimated the "social carrying capacity for development" – or $SK_d$ – for 251 towns in Vermont. $SK_d$ provides an estimate of the level of developed land cover classes that town residents deem "acceptable" within their town boundaries. In this paper, we design a framework for linking the town-specific $SK_d$ estimates with the wildlife distribution patterns for three wide-ranging mammalian species: American black bear (*Ursus americanus*), fisher (*Martes pennanti*), and bobcat (*Lynx rufus*). We simulated landscape conditions at $SK_d$ for each town in Vermont, and then used existing occupancy models for the three target species to spatially map and compare occupancy rates in the baseline year 2000 with occupancy rates at $SK_d$. With nearly 90% of Vermont towns willing to increase developed landcover classes within town boundaries compared to baseline levels, significant state-wide changes in occupancy rates were predicted for all three focal species. Average occupancy rates declined by −15.9% and −3.1% for black bear and bobcats, respectively. Average occupancy rates for fisher increased by 9.0%. This study provides a method for linking development standards within a town with wildlife occurrence. Across towns, the methodology spatially identifies areas that may be at risk of future development, as well as identifying areas where wildlife distribution patterns may face future change as a result of increased human population growth and development.

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## 1. Introduction

The conversion of natural lands to developed uses may pose the single greatest human threat to global terrestrial biodiversity (Vitousek, 1994). This form of conversion is almost always permanent, and occurs world-wide at an exponential rate. Loss of habitat affects species extinction rates (Hughes et al., 1997) as well as local extirpations, with nearly three quarters of mammals worldwide having lost at least 50% of their historic geographic range (Ceballos and Ehrlich, 2002). The loss of natural areas to development reduces the total amount of habitat available to wildlife and changes the arrangement of the remaining habitat. This reduces species richness, population abundance and distribution, decreases genetic diversity, and alters species interactions (Komonen et al., 2000; Schmiegelow and Monkkonen, 2002).

Natural resource managers, tasked with managing wildlife as a public trust, require techniques for predicting *how much* and *where* wildlife habitat is likely to be converted in the future. Yet, resource managers often have little say in directing landscape change outside the boundaries of protected areas. In Vermont, the focus of our work, these external areas are largely shaped by town and city planning commissions, who consider a myriad of physical, social,

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cultural, economic, and conservation values when establishing zoning and development regulations. Town sizes in Vermont range from 3.9 to 32.37 $km^2$.

One method for gauging citizens' perception of development within a town boundary is to survey residents and identify the amount of development that an average resident deems "acceptable" (Manning, 2007). In a companion paper, Bettigole et al. (2013), used this "social norms" approach to elicit the acceptability of various levels of town development for an average resident. Briefly, Bettigole et al. (2013) surveyed >4000 residents of Vermont, USA and asked respondents to rate the acceptability of a range of development scenarios in a hypothetical Vermont town, where acceptability was scored on a Likert scale, with −4 being very unacceptable and +4 being very acceptable. The core of the survey was a set of six, three-dimensional illustrations of a fictional Vermont town that displayed a gradient of housing development levels. The fictional town began as 83% forested, 12% agriculture, 3% water and 2% development (the lowest level found currently found in Vermont). Each image incremented housing levels exponentially, culminating in an image with ~49% development. Build out followed past trends in Vermont, occurring on 60% forest land and 40% agricultural lands; care was taken to hold the arrangements of habitats constant across images. Additionally, respondents provided their opinions on whether new development should replace forested lands or agricultural lands, the two dominant landcover types throughout the state. Bettigole et al. then analyzed responses and developed a mathematical model that identified on a town-by-town basis the level of development where "acceptability" moved from the acceptable realm to the unacceptable on a town-by-town basis (Fig. 1a). They defined this point as the social carrying capacity for development, or $SK_d$. $SK_d$ identifies the percentage of developed lands within town boundaries that are acceptable to citizens. It is important to note that the $SK_d$ represents acceptable levels of development within a given town; it does not necessarily predict how land use change will occur in the future. Many other techniques exist to predict land use change and population growth, such as past trends and multi-agent models (Parker et al., 2003; Theobald, 2005). Here, using $SK_d$, we have measured the potential (rather than a prediction) for growth.

$SK_d$ is just one metric identifying resident's feelings towards development. Bettigole et al. (2013) also identified the average preferred level of development (preference), the average level of development where one would move from their town to another (displacement), and the average level of development where town planners should take action to curtail development (management). Any of these metrics could be used by town planners as a means for setting development guidelines.

Vermonters had an average $SK_d$ of 9.1% development, which contrasts with the current town average of 5.4% development. Importantly, $SK_d$ varied across towns, with some towns more accepting of development than others. Given a scenario where development levels within each town were at $SK_d$, Bettigole et al. (2013) predicted a 16,753.91 $km^2$ reduction in forested land statewide (−11.16%) and a 1,038.42 $km^2$ reduction in farmland (−60.45%), based on respondent preferences from the survey. From a conservation perspective, these outputs may be more meaningful if they were related to potential changes in wildlife distribution patterns in a quantitative manner. In the face of habitat reduction, species of high conservation concern that require forested, agricultural, or riparian areas to carry out their life cycles may be expected to decline. Such assessments could provide additional information to help land planners make more informed decisions.

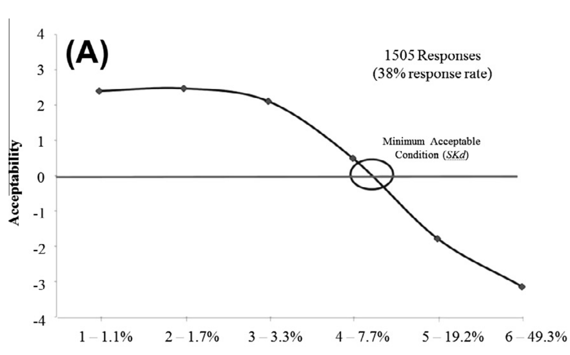
One method for estimating the landscape capacity for wildlife species is occupancy modeling (MacKenzie et al., 2006). Wildlife occupancy modeling takes inputs in the form of detection and non-detection data of target species at multiple sites, and allows researchers to estimate the probability of occurrence ($\psi$) at any number of locations, given the characteristics of the site. Occupancy models in Vermont for American black bear (*Ursus americanus*), fisher (*Martes pennanti*), and bobcat (*Lynx rufus*) (Long et al., 2010) were developed by surveying sites with non-invasive techniques (e.g. hair traps, remote cameras, scat detection dogs). Each of these species exhibits some sensitivity to the amount of habitat (e.g., forest) within a given area. For example, in Vermont, black bear occurrence ($\psi$) was very sensitive to changes in forest cover within a 5 km radius of a site (Fig. 1b), with a sharp decline in occupancy as forest habitat drops from 85% to 40%.

In this paper, we design a framework for linking the social carrying capacity for development ($SK_d$) within towns with the capacity of a landscape to host three wide-ranging mammalian species: American black bear, fisher, and bobcat. Our objectives were to (1) transform the results from town level norm curve analysis into a spatially explicit land use scenario that represents landscape conditions at $SK_d$, (2) adapt existing occupancy models for black bear, fisher, and bobcat to predict species occurrence under present landscape conditions (year 2000) and landscape conditions associated at $SK_d$, and (3) compare species occurrence at the town scale between present conditions and at $SK_d$.

## 2. Materials and methods

### 2.1. Study area

Our study area included the entire state of Vermont (24,963 $km^2$). Mean elevation was 370 m, ranging from 30 m in



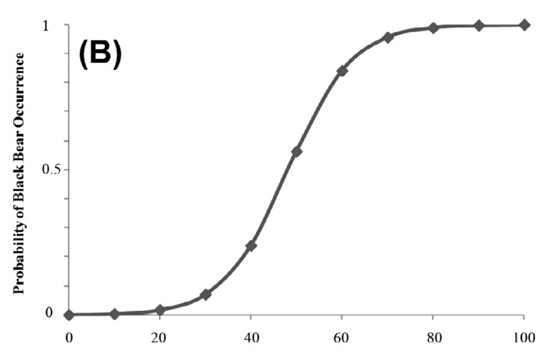




**Fig. 1.** (A) Average acceptability curve across all towns in Vermont, USA. As percent developed shown in each of the six illustrations increases, mean acceptability ratings decrease (housing density = 1.707 $*$ $2.68^{(\text{Illustration\#1})}$, percent developed = 0.0075 + 0.0021 $*$ housing density). Acceptability moves from the positive realm to the negative at 9.1% development, which is the state-wide average $SK_d$. (B) Response of black bear occurrence to varying levels of percent forest within 5 km of a location (30 $m^2$ pixel) in Vermont.