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Use of patch selection models as a decision support tool to evaluate mitigation strategies of human–wildlife conflict

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ABSTRACT

Human-dominated landscapes offer spatially concentrated and reliable food resources that attract wildlife and lead to human–wildlife conflicts. Conflict management is often directed at humans (e.g., education) to reduce attractants, or foraging benefits to wildlife, or at wildlife (e.g., hazing) to increase foraging costs; but strategies can be expensive and ineffective. Because a key driver of conflict is the pursuit of food by wildlife, we used patch selection models, a dynamic, state-dependent modeling approach based on foraging theory, to assess how benefit reduction and cost increase resulting from conflict mitigation affect wildlife foraging decisions. We applied the patch selection models to a system in which American black bears (*Ursus americanus*) forage in urban and urban-interface patches and conflicts are common. We used survival as a fitness currency and body fat reserves as a state variable. We incrementally reduced availability of anthropogenic foods (benefit reduction) and increased energetic costs of movement in response to aversive conditioning treatments (cost increase) to search for thresholds resulting in avoidance of human-dominated patches. Benefit reduction ⩾55% in urban patches and ⩾70% in urban-interface patches resulted in avoidance by bears of almost all states. Cost increases achieving similar results exceeded 1100% and 400% in urban and urban-interface patches respectively, and are likely unrealistic to implement. Given modeling results and that control strategies targeting wildlife are unpopular with constituencies, we suggest allocating management resources to strategies that reduce availability of anthropogenic food.

1. Introduction

Human–wildlife interactions, and subsequently conflicts, are increasing worldwide (Conover, 2001; Woodroffe et al., 2005). Human-dominated landscapes offer spatially concentrated, predictable, and reliable food sources, e.g., livestock, crops, or refuse, which can serve as major attractants to wildlife and lead to human–wildlife conflict (Shochat, 2004; Baker et al., 2008). Whether the resultant conflict occurs due to depredation of livestock in South America (e.g., Michalski et al., 2006), raiding of agricultural corps in Europe (e.g., Geisser and Reyer, 2004), or use of refuse in urban centers in North America (e.g., Beckmann and Berger, 2003), a key driver of conflict is the pursuit of food resources by wildlife. Thus, understanding how to best mitigate human–wildlife conflict requires an understanding of how management affects wildlife foraging decisions.

Two major management strategies aimed at humans and wildlife are commonly employed to resolve conflicts. Human-dimensions tools are implemented in conflict communities to change human behavior to reduce the availability of attractants, or foraging benefits, to wildlife. For example, improving husbandry through education reduced livestock depredation by snow leopards (*Panthera uncia*) in India (Jackson and Wangchuk, 2004), and proactively enforcing refuse disposal laws reduced availability of garbage to American black bears (*Ursus americanus*) in Colorado, USA (Baruch-Mordo et al., 2011). Wildlife management tools are also implemented to either eliminate (lethal control) or deter (non-lethal control) wildlife from attractant sites (Fall and Jackson, 2002; Treves and Karanth, 2003). Lethal control can be unpopular with wildlife managers (e.g., Fall and Jackson, 2002; Baker et al., 2005; Spencer et al., 2007), often motivated by the unpopularity of such management actions by the general public (Manfredo, 2008; Messmer, 2009). Therefore, wildlife agencies are increasingly using non-lethal aversive conditioning treatments, including hazing, and chemical or physical deterrents, with the goal of modifying the long-term behavior of wildlife due to the learning

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process of aversive conditioning (Hopkins et al., 2010). Aversive conditioning treatments offer a source of discomfort or pain to wildlife that often invokes a flight response (Shivik et al., 2003; Mazur, 2010) and consequently increases the energetic costs of foraging in human-dominated areas. Examples include hazing of African elephants (*Loxodonta africana*) with fire and noise to reduce crop raiding in Kenya (Sitati et al., 2005), and using chemical repellents to deter badgers (*Meles meles*) from crops in Europe (Baker et al., 2005). Put in the context of foraging decision making by wildlife, conflict management strategies targeting humans and wildlife aim to either decrease wildlife foraging benefits, or conversely, increase wildlife foraging costs that are associated with human-dominated areas.

Conflict management can be expensive and ineffective, and it is generally believed that management cannot successfully eliminate all attractants or deter all individuals (Linnell et al., 1997; Treves and Karanth, 2003; Mazur, 2010; Baruch-Mordo et al., 2011). Consequently, there is a need to determine which management strategy, or which combinations, are most effective in altering wildlife foraging decisions. Patch selection models (Mangel and Clark, 1986) provide a framework to test how benefit reduction and cost increase influence wildlife foraging decisions. Under this approach, patches can be considered as human-dominated or not, and patch selection by wildlife can be optimized based on patch-specific benefits and costs given the energy reserves of the animal (Mangel and Clark, 1986). One can evaluate the effects of conflict management on wildlife foraging decisions by using sensitivity analysis where benefits and costs in human-dominated patches are systematically varied and the impacts on foraging choices are determined. One can also search for thresholds of benefit reduction and cost increase beyond which wildlife no longer select human-dominated patches, thus providing guidelines for conflict mitigation.

In this paper we demonstrated the application of patch selection models in conservation management. We examined how changes in foraging costs and benefits incurred from the management of human–bear conflicts can influence the foraging decisions of black bears in human-dominated areas. Bears are an ideal organism to use as an example because of the high energetic costs of hibernation, which can lead to conflict with humans over food resources. Bears enter a state of hyperphagia, or intense feeding, in late summer and fall to gain sufficient fat reserves for hibernation (Nelson et al., 1983). If factors such as weather or disease cause the natural food production to fail during hyperphagia, bears will use alternative anthropogenic food sources and forage near human development (Mattson et al., 1992). Consequently, human–bear conflicts increase in poor natural food production years (Zack et al., 2003; Ryan et al., 2007; Baruch-Mordo et al., 2008), and wildlife managers mitigate conflicts by more intensely applying strategies such as education aimed at humans (Baruch-Mordo et al., 2011) or aversive conditioning treatments aimed at bears (Spencer et al., 2007; Honeyman, 2008). We evaluated the effects of such strategies on bear foraging decisions using a patch selection model parameterized from literature and field data. We used the model to search for thresholds of benefit reduction and cost increase beyond which bears would not forage in human-dominated patches to inform the allocation of resources for the management of human–bear conflicts.

2. Materials and methods

2.1. Study system

We used Aspen, Colorado, USA, located in the central mountains of Colorado, as the model system. The human-dominated area of Aspen consists of a downtown business district and high human density residential areas (urban patch) that are surrounded by lower density residential neighborhoods (urban-interface patch; Fig. 1). Residential neighborhoods are dispersed within mountain-shrub and forest communities that are adjacent to large national forest and wilderness areas (wildland patch). Hyperphagia season in Aspen lasts from approximately 1 August–15 October (total of 75 days), a period when fruit ripens providing important local natural food sources for bears including Gambel oak (*Quercus gambelii*), serviceberry (*Amelanchier alnifolia*), and chokecherry (*Prunus virginiana*). From 2005 to 2010 we deployed GPS collars on bears to better understand their movement patterns and resource use in the urban environment (Baruch-Mordo, 2012). Bears used urban and urban-interface areas extensively during hyperphagia season in years of poor natural food production, a time when conflicts with humans flared. We backtracked to GPS locations in Aspen and identified garbage as the main anthropogenic attractant.

Management strategies applied in Aspen to reduce availability of garbage to bears included targeting humans with education, and the enforcement of local refuse disposal laws. We experimentally evaluated both management tools and found proactive enforcement to be most effective in changing human behavior to better secure garbage (Baruch-Mordo et al., 2011). However, despite observing a reduction in garbage availability following treatment, we did not observe a complete elimination of garbage resources, and in fact, found garbage to be readily available to bears throughout Aspen at all times. Alternative management strategies applied in Aspen to prevent bear use of garbage and therefore reduce human–bear conflicts included non-lethal methods of aversive conditioning treatment. While we did not measure bear response to aversive conditioning treatments as applied in Aspen, the most common response by bears is running away from the source of discomfort (Mazur, 2010), a behavior we commonly observed when treatments were applied.

2.2. Patch selection model

Mangel and Clark (1986, 1988) developed a general patch selection model based on optimal foraging theory using a state-dependent modeling approach that is solved by dynamic programming. The patch selection model optimizes a fitness function $F(x, t)$, or the maximum fitness from time step $t = 1$ to terminal time step T given that the organism was alive at time t and had a state variable value of $X(t) = x$. At each time step fitness is updated as detailed in Eq. (1) below, and the selected patch that maximizes fitness is recorded in a patch decision matrix. We applied the patch selection model to our system using two human-dominated patches (urban and urban-interface) and one nonhuman-dominated patch (wildland). We used survival as the fitness currency, body fat reserves (kg fat) as the state variable (Section 2.3), and maximized fitness over the hyperphagia season using day as a discrete time unit ($t = 1, 2, \ldots, 75$).

The dynamic state variable $X(t)$ in patch selection models can be constrained between a critical value of x_c and cap value of C, and the terminal fitness at time T is known and represented by a function $\phi(x)$ such that $F(x, T) = \phi(x)$. We used critical and cap values for kg fat reserves that were converted from minimum and maximum values reported for body mass (M) of Aspen bears, and we quantified survival as a function of body mass at time T based on an allometric relationship (Section 2.3). Once fitness is known at terminal step T, the model can be solved for maximum fitness by backwards iteration using a Markovian decision process (Mangel and Clark, 1986). At each time step fitness is calculated as the probability of survival in period t times the probability of survival from period t to $t + 1$, where the latter is composed of survival when food is found plus survival when food is not found. Fitness is maximized