Ecological Modelling 343 (2017) 15–24

Contents lists available at ScienceDirect

Ecological Modelling

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

Does human education reduce conflicts between humans and bears? An agent-based modelling approach

Jessa Marley[c], Andrea Hyde[a], Joseph H. Salkeld[a], Marie-Caroline Prima[a], Lael Parrott[d], Susan E. Senger[b], Rebecca C. Tyson[a,*]

[a] Mathematics, IKBSAS 5 BLDG SCI, University of British Columbia Okanagan Campus, 1177 Research Road, Kelowna, BC, V1V 1V7, Canada
[b] Windwalker Consulting Services, PO Box 436, Lillooet, BC V0K 1V0, Canada
[c] Department of Mathematical and Statistical Sciences, University of Alberta, Edmonton, AB, T6G 2R3, Canada
[d] Biology and Earth, Environmental and Geographic Sciences, 1177 Research Road, University of British Columbia Okanagan Campus, Kelowna, BC, V1V 1V7, Canada

ARTICLE INFO

Article history:
Received 3 February 2016
Received in revised form 14 October 2016
Accepted 15 October 2016
Available online 24 October 2016

Keywords:
Computational ecology
Wildlife interactions
Individual-based modelling
Urban bears
Bear movement
Human–bear interactions

ABSTRACT

As human settlement expands farther into previously uninhabited areas, interactions with wild animals are likely to increase. The nature of these interactions can be detrimental to humans and animals alike. We focus on the relationship between urban areas and bears, and the consequences of a bear's dietary choices. Using an agent-based model we investigated the effects of educating humans about waste management and bear deterrence methods on the number of bears that enter urban areas repeatedly. Variables tested included the percentage of the landscape that is urban, probability of deterrence, percentage of the human population educated about bear safe behaviours, types of bear management strategies (BMSs) implemented in educated urban areas, and the bear management spatial configurations (BMCs). The results indicate that all education methods reduce the number of human–bear conflicts. For each percent of the population that is taught, there is a 5% decrease in the probability that a bear becomes a conflict bear. We also found that the existing residential spatial configuration and the bear management strategies to be implemented are important considerations when creating an education program. Our results suggest that agent-based models can be used to identify viable management strategies and to determine the most effective human education program (BMS and BMC) when trying to reduce the number of conflict bears.

1. Introduction

Human interactions with wild animals and the resulting potential conflicts are a significant concern for wildlife conservationists and the general public alike. Among such animals is the American Black Bear (*Ursus americanus*) in British Columbia, Canada (Carlos et al., 2009; Gore et al., 2006; Herrero and Higgins, 1999; Herrero et al., 2011; Hopkins et al., 2010). Humans tend to settle in valley bottoms, which are also prime bear habitat (Miller, 1989; Aune, 1994). This settlement pattern creates an overlap between bear habitat and urban areas, resulting in problems for both bears and humans. In addition, bears are attracted by human waste and food, such as garbage or fruit trees (Carlos et al., 2009; Gore et al., 2006; Hopkins et al., 2010; Hristienko and Mcdonald, 2007; Peine, 2001). This overlap can be exacerbated during times of limited natural food. During a drought, when the amount of herbaceous food is reduced, bears have been known to expand their home ranges (Peine, 2001) and these expansions can include urban areas where high food quality is maintained. The growth of urban areas also increases the likelihood of overlap with bear territories (Baruch-Mordo et al., 2008). Humans are faced with the issue of dangerous and sometimes aggressive bears wandering through human establishments, as well as potential property damage resulting from bear foraging (Hristienko and Mcdonald, 2007). From an ecological perspective, bears are put at high risk when entering human areas. These risks include dependence on humans as a food source and potential extermination if the bear habituates to people and becomes conditioned to human food (Hebblewhite et al., 2003).

A problem (or conflict) bear is defined as a bear that acts on its learnt behaviour to such an extent that it produces a threat to human safety and property when seeking human food and/or garbage (Ciarniello and Westworth, 1997). If the bear is repeatedly exposed to human contact and loses its wariness towards humans, it can become "habituated", while over-exposure to anthropogenic

* Corresponding author.
E-mail address: rebecca.tyson@ubc.ca (R.C. Tyson).

http://dx.doi.org/10.1016/j.ecolmodel.2016.10.013
0304-3800/

food results in “food-conditioning” (i.e. dependence or reliance of a bear on human rather than wild sources of food) (Peine, 2001; Hopkins et al., 2010). A wild bear becomes a problem bear when it is habituated, food-conditioned, or both habituated and food-conditioned. Every year humans suffer injuries and occasionally fatalities from human–bear interactions (Herrero and Higgins, 1999; Herrero et al., 2011). As communities grow and encroach further on key bear habitat (e.g., valley bottoms), there is a parallel increase in human–bear interactions (Carlos et al., 2009; Herrero and Higgins, 1999; Herrero et al., 2011). Unless steps are taken to mitigate these interactions there will be an increase in human injuries and fatalities, and more dead bears.

Today there are many methods in use for managing bears in order to avoid large numbers of conflict bears in an area. These include, but are not limited to, aversive conditioning, translocation, land management, and extermination (Carlos et al., 2009; Riley et al., 1994; Hopkins et al., 2010; Herrero, 1985; Gunther, 1994; Thompson and McCurdy, 1995; Gniadek and Kendall, 1998; Honeyman, 2008; Ciarniello and Westworth, 1997). Aversive conditioning includes any vigilance reaction from a human that does not harm the well-being of the bear, such as the use of sound makers or rubber bullets, and that is used repeatedly to condition a bear (Hopkins et al., 2010; Mazur, 2010). Aversive conditioning helps the bear associate humans with pain or unsettling noises, and, if effective, results in the bear moving away from human areas. However, unless the procedure is timed appropriately with the moment when a bear first finds human food, the food reward trumps the inconvenience of vigilance responses, and aversive conditioning is no longer effective (Mazur, 2010). Bear extermination is mostly used when other options are not viable or no longer effective. Unfortunately, exterminations are much too frequent and there is concern that this strategy will eventually be detrimental to bear populations as a whole (Hopkins et al., 2010; Hristienko and Mcdonald, 2007). More importantly, as conflicts between humans and bears persist in spite of the continued use of extermination, it appears that this strategy is a destructive stop-gap measure that does not provide a lasting solution to the problem.

Solutions need to be found that optimize the trade-off between bear conservation and human safety. There is a need for prevention programs that reduce the negative impacts of bear encounters with human settlement, and studies to determine the effectiveness of such programs (Carlos et al., 2009; Mazur, 2010; Peine, 2001; Merkle et al., 2011). One approach is to implement education programs that teach humans how to keep their properties free of attractants and how to behave when encountering a bear (Gore et al., 2008).

Several different education programs have been implemented in communities across British Columbia. Empirical studies have been carried out to evaluate the effectiveness of each of these programs, but the evaluations have been done differently, and comparison across programs is difficult. In particular, the outcome of each education program depends on the interaction between community structure and the way the program is implemented. Consequently, each community represents one realisation of a single education program, essentially a single data point, making it difficult to draw general conclusions (Dunn et al., 2008; Gore et al., 2006, 2008).

We are thus left with the question: To what extent does educating the human population about bear safety reduce the number of conflict bears in an urban landscape at the community scale? We approached this question using an agent-based model. A modelling framework makes it possible to run hundreds of realisations of each education program, and to closely investigate the effect of model parameters by varying them over the entire plausible range for each individual factor. Furthermore, we can control variables (such as population size) that can be difficult or impossible to control empirically, and we can manipulate each factor separately. Finally, we can allow bears to become conflict bears in the model, giving us more freedom to investigate a wide range of management scenarios. There is a great deal of expert knowledge available, but there are also a great number of variables for the experts to keep track of, and so a modelling approach is very helpful, particularly in generating predictions and guiding later empirical work.

Our model includes a single foraging bear as the agent, and humans as part of the landscape. We first define the model in Sections 2–8 using the Overview, Design concepts, and Details (ODD) protocol outlined by Grimm et al. (2006). We then present our simulation results in Section 11, and discuss the implications of our results in Section 12.

2. Purpose

The main purpose of this model is to explore the suitability and potential of agent-based models as tools to investigate the effectiveness of human education on human–bear interactions, and to determine if the bear management strategy (BMS) taught, as well as the spatial configuration (BMC) of educated humans affect the number of conflict bears on a theoretical landscape. We apply the model to explore the effects of bear awareness education on the expected number of conflict bears, specifically black bears (*Ursus americanus*), in a theoretical urban landscape within and at the interface of bear habitat. We focus on the effect of education within a single summer season and we do not consider bear population dynamics. The environment has dynamic and static components. The model is simple and not designed to represent a real landscape, however, by gaining a base understanding of how the model works, we can justify further investigation of these types of models and their application.

3. State variables and scales

We have two types of variables, environmental variables and agent or bear variables. The environmental variables are the landscape matrix (L_n^m), the food matrix (F_n^m), the bear memory matrix (M_n^m), the vigilance (V_n^m), and the garbage matrix (G_n^m). The bear variables are habituation (HBI_{hab}), food conditioning (HBI_{fc}) and deterrence (HBI_{det}).

The landscape is a grid of urban and wilderness cells, each containing food resources and habitat information about the area. The habitat information available for a cell is dependent on whether a cell is urban or wilderness. Bears are simulated on the landscape one at a time, which means the bear forages independently, ignoring any other bears that may be on the landscape. The bear's food consumption is tracked for both anthropogenic and wild food in order to determine the bear's status with respect to humans, as outlined in Section 4.1. Any human bear interactions that occur are counted, and the nature of each interaction is recorded, as there is also influence on the bear's status. Each time step represents 12 h of foraging behaviour. The cells represent approximately the size of an average urban neighbourhood, or approximately 0.5 sq. km.

To describe the model in detail, we will need to introduce several indices. We use i and j to denote cell position, n for simulation run number, and m for the group of simulation runs. Every matrix in the model is thus written as $A_{n_{i,j}}^m$ where $A_{n_{i,j}}^m$ is the value of the matrix A in cell i,j in the nth iteration of group m. In Sections 3.1.1–3.1.4 we describe the state variables for the environment variables of the model (Table 1), and then describe the bear variables of the model for the remainder of Section 3. The area modelled is comprised of several matrices that are layered together to give various values to