Ecological Complexity 17 (2014) 67–78

Contents lists available at ScienceDirect

Ecological Complexity

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

Identifying non-independent anthropogenic risks using a behavioral individual-based model

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ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form 21 August 2013
Accepted 11 September 2013
Available online 16 November 2013

Keywords:
Agent-based model
Animal movement
Predation risk
Multi-response optimization
Scenario-sensitivity analysis
Caribou

ABSTRACT

Anthropogenic disturbances contribute to an animal's perception of and responses to the predation risk of its environment. Because an animal rarely encounters threatening stimuli in isolation, multiple disturbances can act in non-independent ways to shape an animal's landscape of fear, making it challenging to isolate their effects for effective and targeted management. We present extensions to an existing behavioral agent-based model (ABM) to use as an inverse modeling approach to test, in a scenario-sensitivity analysis, whether threatened Alberta boreal caribou (*Rangifer tarandus caribou*) differentially respond to industrial features (linear features, forest cutblocks, wellsites) and their attributes: presence, density, harvest age, and wellsite activity status. The spatially explicit ABM encapsulates predation risk, heterogeneous resource distribution, and species-specific energetic requirements, and successfully recreates the general behavioral mechanisms driving habitat selection. To create various industry-driven, predation-risk landscape scenarios for the sensitivity analysis, we allowed caribou agents to differentially perceive and respond to industrial features and their attributes. To identify which industry had the greatest relative influence on caribou habitat use and spatial distribution, simulated caribou movement patterns from each of the scenarios were compared with those of actual caribou from the study area, using a pattern-oriented, multi-response optimization approach. Results revealed caribou have incorporated forestry- and oil and gas features into their landscape of fear that distinctly affect their spatial and energetic responses. The presence of roads, pipelines and seismic lines, and, to a minor extent, high-density cutblocks and active wellsites, all contributed to explaining caribou behavioral responses. Our findings also indicated that both industries produced interaction effects, jointly impacting caribou spatial and energetic patterns, as no one feature could adequately explain anti-predator movement responses. We demonstrate that behavior-based ABMs can be applied to understanding, assessing, and isolating non-consumptive anthropogenic impacts, in support of wildlife management.

1. Introduction

Measuring the impacts of anthropogenic activities on the responses of wildlife is crucial for their effective management and population persistence (Leu et al., 2008). Ever-increasing industrial landscape change can lead to consequences beyond habitat loss and amount and arrangement of habitat patches. Anthropogenic features or activities can be perceived by animals as risky habitats or threatening stimuli, respectively, and animals will attempt to minimize their exposure or avoid them (Frid and Dill, 2002; Beale, 2007). To understand underlying processes driving habitat selection and movement of prey species, the 'landscape of fear' concept has been invoked as a behavioral mechanism explaining how *perceived* predation risk in heterogeneous environments could alter an animal's use of an area as it tries to reduce its vulnerability to predation (Laundré et al., 2001, 2010; Willems and Hill, 2009). How animals therefore perceive and respond to anthropogenic features is critical for wildlife management as it will impact their decisions of where to forage, how much energy to expend, and what habitats to use (Johnson et al., 2005; Krausman, 2011).

Prey rarely find themselves in single-predator environments and must accordingly evaluate the relative predation risk from

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http://dx.doi.org/10.1016/j.ecocom.2013.09.004

multiple predators simultaneously (Thaker et al., 2011). With increasing land-use intensification, prey are similarly exposed to multiple anthropogenic features – stressors – that can evoke interactive and/or unpredictable outcomes that aggregate over time and space (Harriman and Noble, 2008). Therefore, an evaluation of how stressors influence an animal's landscape of fear should be examined in an interactive manner. Because multiple anthropogenic effects are characterized by their interdependence between time, space, and activity, this presents a challenging problem in evaluating their relative contributions on wildlife responses (Nitschke, 2008). Studies of this kind are limited by the requisite complexity of experimental designs that often require expert guidance (Frair et al., 2008), and/or use complex statistical analyses for quantifying stressors effects, yet are still unable to adequately quantify interaction terms beyond binary combinations (Glaholt et al., 2012). In addition, studies which examine animal spatial distributions without a behavioral context may also be of limited value, since statistical habitat models parameterized in one area may not be transferable to other areas or conditions in which habitat availability and landscape configuration are different – for example, under future conditions (Beyer et al., 2010). Instead, an integrative modeling framework that allows for the simulation of complex animal movement ecology and behaviors can provide a virtual environment in which to test the interactive effects of multiple stressors on an animal's perception of predation risk and disturbance (Frair et al., 2008; Bennett et al., 2009). Addressing these sources of and pathways to a landscape of fear can resultantly better affect targeted management and mitigation measures should animals respond to anthropogenic effects in graded, interactive, or substitutable fashions (Spaling and Smit, 1993).

In view of this, we use a spatially explicit, behavioral agent-based model (ABM) to assess the effects of multiple industrial developments on animal movement, distribution and habitat use by simulating an animal's perception of landscape risk. Agent-based models (ABMs) are computational simulation tools that rely on a bottom-up approach. They explicitly consider the individual components of a system (the agents) and allow the system's properties to emerge from the interactions among these components (Grimm et al., 2005). Agents are goal-driven and try to fulfill specific objectives, they are aware of and can respond to changes in their environment, they can move within that environment, and they can be designed to learn and adapt their state and behavior in response to stimuli from other agents and their environment. This emphasis on interactions between agents and their environment is what distinguishes agent-based models (also referred to as individual-based models) from other systemic modeling approaches (Marceau, 2008).

We parameterized our model for boreal caribou (*Rangifer tarandus caribou*), a useful model species as their populations have been impacted by expanded industrial development over the last few decades (Vors and Boyce, 2009; Environment Canada, 2011). This expansion has resulted in an increased network of seismic exploration, pipelines and roads, and the loss of habitat of older, lichen-bearing forests due to resource-extraction activities of oil and gas and forestry (Peters et al., 2012). Consequently, the decline of woodland caribou is partly based on an indirect interaction between caribou and industry that has increased the caribou's landscape of fear (DeCesare, 2012). Habitat change from forestry has increased predator biomass as ungulate prey (moose, deer) is attracted to early seral forests (Seip, 1992; Wittmer et al., 2005; Peters et al., 2012) thus increasing predation risk and caribou's tendency to avoid open areas (such as cutblocks). In addition, linear features introduced onto the landscape aid in facilitating predator efficiency (either via sight lines or lowered travel costs through dense forests; Latham et al., 2011; DeCesare, 2012). Resultantly, caribou associate these features with increased predation risk (Vistnes and Nellemann, 2008). Caribou can furthermore be disturbed by industrial activity either directly through the physical footprint, or indirectly through sensory disturbance, and respond similarly, minimizing their exposure. Due to these higher levels of predation pressure and disturbance, the evolved predator-defense strategies of caribou – avoidance/separation behaviors – have augmented the allocation of habitat caribou deem as 'risky'/'fearful' (Smith et al., 2000; Dyer et al., 2001; Polfus et al., 2011).

Considering the important impacts of industrial stressors on caribou fitness, empirical studies face a significant challenge disentangling the relative effects of multiple stressors from each other as well as from underlying habitat configuration. Using the ABM as an investigatory tool, we employ a novel scenario-sensitivity analysis to infer knowledge about caribou responses to different existing industrial features based on characteristics that may affect their relative perception: presence and density of linear features, cutblocks and wellsites; age of harvested forest; and activity status of wellsites. In particular, we test whether industrial features all contribute to a caribou agent's landscape of fear and to what extent by allowing agents to differentially perceive and respond to alternate arrangements of industrial features and their attributes in the landscape. The resultant industrial-landscape configuration causing caribou agents to reproduce the most realistic behaviors is determined by comparing simulated caribou movement patterns with actual caribou data using a pattern-oriented, multi-response optimization approach, and its robustness tested against two null models of caribou movement based on random processes (random locations, and undifferentiated responses to industry). The advantages provided by our approach are a mechanistic understanding of the interrelated role of multiple anthropogenic features on processes governing caribou movements and distributions, and the relative impacts of different industrial stressors, offering a foundation on which decisions and future management actions can be evaluated (Nitschke, 2008).

2. Methods

The caribou ABM comprises two main components: (1) caribou agents and their decision-making heuristics and (2) a landscape representation of the caribou herd's habitat preferences. In this section, an introduction of the study area and a brief presentation of the model overview and agent decision-making rules are first provided, followed by a description of the landscape representation (in terms of different predation-risk scenarios), the simulation framework, and the analysis and comparison of agent responses to the different scenarios tested.

2.1. Study area

The area chosen for the study was the range of the Little Smoky (LS) herd demarcated by the Alberta Fish and Wildlife Division (ASRD, 2010), covering 3100 km^2 in the foothills of west-central Alberta. The LSM range is located in the upper foothills ecoregion of west central Alberta, Canada (54° N, 119° W), with the lands primarily managed by the government for multiple uses including forestry, oil, and natural gas industries. Because the Little Smoky is such a dynamically changing landscape due to industrial development, we confined our study to a single time period, during winter 2004–2005. The LS range has a high level of industrial development for a boreal caribou herd in Canada, with 95% of its range in proximity (500 m buffer) of anthropogenic activities (Environment Canada, 2011), and as such provides an ideal case study to evaluate the interactive effects of the caribou's landscape of fear. Specifically, the activities of four forestry management agreements and numerous petroleum-company