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Incorporating behavioral–ecological strategies in pattern-oriented modeling of caribou habitat use in a highly industrialized landscape

C.A.D. Semeniuk[a,*], M. Musiani[b,2], M. Hebblewhite[c,3], S. Grindal[d,4], D.J. Marceau[a,1]

[a] Department of Geomatics Engineering, University of Calgary, 2500 University Drive, Calgary, Alberta T2N 1N4, Canada
[b] Faculties of Environmental Design and Veterinary Medicine, University of Calgary, Calgary, Alberta, Canada
[c] College of Forestry and Conservation, University of Montana, Missoula, MT 59812, United States
[d] ConocoPhillips Canada, Calgary, Alberta T2P 2H7, Canada

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ABSTRACT

Woodland caribou (*Rangifer tarandus*) are classified as threatened in Canada, and the Little Smoky herd in west-central Alberta is at immediate risk of extirpation due in part, to anthropogenic activities such as oil, gas, and forestry that have altered the ecosystem dynamics. Winter season represents an especially challenging time of year for this Holarctic species as it is characterized by a shortage of basic resources and is when most industrial development occurs, to which caribou can perceive as increased predation risk. To investigate the impact of industrial features on caribou, we developed a spatially explicit, agent-based model (ABM) to simulate the underlying behavioral mechanisms caribou are most likely to employ when navigating their landscape in winter. The ABM model is composed of cognitive caribou agents possessing memory and decision-making heuristics that act to optimize tradeoffs between energy acquisition and predator/disturbance avoidance. A set of environmental data layers was used to develop a virtual grid representing the landscape in terms of forage availability, energy content, and predation-risk. The model was calibrated with caribou bio-energetic values from literature sources, and validated using GPS data from thirteen caribou radio-collars deployed over 6 months from 2004 to 2005. Simulations were conducted on alternative caribou habitat-selection strategies by assigning different fitness-maximizing goals to agents. The model outcomes were evaluated using a pattern-oriented modeling approach with actual caribou data. The scenario in which the caribou agent must trade off the mutually competing goals of obtaining its daily energy requirement, conserving reproductive energy, and minimizing predation risk, was found to be the best-fit scenario. Not recognizing industrial features as risk causes simulated caribou to unrealistically reduce their daily and landscape movements; equally, having risk take precedence results in unrealistic energetic deficits and large-scale movement patterns, unlike those observed in actual caribou. These results elucidate the most likely behavioral strategies caribou use to select their winter habitat, the relative extent to which they perceive industry features as potential predation, and the differential energetic costs associated with each strategy. They can assist future studies of how caribou may respond to continued industrial development and/or mitigation measures.

1. Introduction

Woodland caribou (*Rangifer tarandus caribou*) in Alberta are currently designated as *threatened* under Alberta's *Wildlife Act* due to their reduced distribution, a decrease in the number and size of populations, and threats of continued declines associated with human activities (ASRD, 2010). The Alberta government resultantly recommends the assessment and management of cumulative effects on caribou, as well as the identification and provision of adequate habitat (amount and type) to allow for caribou persistence. A subset of anthropogenic activities, specifically those of resource-extraction industries such as forestry and oil and gas, affect caribou habitat use in three generally accepted ways. First, they remove large tracts of relatively low-productivity mature to old conifer forests and forested peatlands (i.e., cutblocks), which contain lichens, the primary winter food source for caribou. Second, they increase the predation risk via apparent competition (DeCesare et al., 2010a), and by facilitating hunting and/or searching

* Corresponding author. Tel.: +1 403 220 8794; fax: +1 403 284 1980.
E-mail addresses: semeniuc@ucalgary.ca (C.A.D. Semeniuk), mmusiani@ucalgary.ca (M. Musiani), mark.hebblewhite@cfc.umt.edu (M. Hebblewhite), scott.d.grindal@conocophillips.com (S. Grindal), dmarceau@ucalgary.ca (D.J. Marceau).
[1] Tel.: +1 403 220 8794; fax: +1 403 284 1980.
[2] Tel.: +1 403 220 2604; fax: +1 403 284 4399.
[3] Tel.: +1 406 243 6675; fax: +1 406 243 4557.
[4] Tel.: +1 403 233 3261.

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efficiency of predators via linear features such as roads, pipelines, and seismic lines (Dyer et al., 2001). Finally, caribou can perceive human activities and anthropogenic features both as disturbance and predation-risk events, either directly through physical footprint, or indirectly through sensory disturbance (Frid and Dill, 2002; Vistnes and Nellemann, 2008). Caribou respond accordingly by attempting to minimize their exposure to them, similarly as they would to natural predators (Smith et al., 2000; Dyer et al., 2001; Polfus et al., 2011).

Caribou are also susceptible to harsh environmental conditions. Winter represents an especially challenging time of year as over-wintering caribou face the energetic costs of food availability, periodically harsh environmental conditions, predator avoidance, and disturbance. Specifically, the availability of terrestrial lichen, the main winter food source, is constrained to specific habitat requirements (Dzus, 2001) and is energetically costly to access (i.e., cratering through snow). Next, the minimization of energetic costs in winter appears important for caribou, at times at the expense of increased predation risk, as females are willing to use high-risk areas to minimize travel costs (Johnson et al., 2002). Finally, winter is the time of year when most industrial development occurs in the study area (Neufeld, 2006), and as caribou are sensitive to this form of disturbance, they may experience energetic costs in industrial-feature avoidance (Bradshaw et al., 1998). These energetic costs during winter have the ability to affect female caribou reproduction since maternal condition has a direct impact on fetal viability and subsequent calf survival (Post and Klein, 1999). Therefore, caribou, in particular females, need to trade off decisions between energy management, foraging efficiency, and predation risk, and these choices influence their habitat selection, movement, and reproduction.

Critical habitat for caribou in Canada has been defined as the percentage of range needed to maintain or return that herd at or to a self-sustaining rate (Environment Canada, 2011a). While the impacts of habitat change and industrial features and activities on caribou have been studied in terms of spatial distribution (Fortin et al., 2008), physiological stress (Wasser et al., 2011), energetic costs (Bradshaw et al., 1997), and population viability (Weclaw and Hudson, 2004), the behavioral mechanisms and strategies caribou use when navigating their landscape, and how these are influenced by resource-extraction industries are less clear. Most studies have not explicitly incorporated how caribou concurrently make behavioral tradeoff decisions that are motivated by both the animal's internal state and external environs. Indeed, the Canadian government's determination of critical habitat is not restricted simply to an explicit geographical delineation, but instead ties the designation of critical habitat to a geographic *state* that has a likely probability of supporting a local self-sustaining population (Environment Canada, 2011a).

Traditional approaches to studying wildlife-human-environment interactions do not typically consider individual-level information, account for complexities, or integrate cross-scale and cross-discipline data and methods, resulting in a great loss in predictive or explanatory power (Semeniuk et al., 2011). By considering the actions of the individual, such information aids in quantifying animal–habitat relationships, describing and predicting differential space use by animals, and ultimately identifying habitat that is important to an animal (Beyer et al., 2010). To address the issue of understanding caribou habitat selection in the face of high-density industrial development, we have developed a spatially explicit, agent-based model (ABM) to simulate winter habitat selection and use of caribou in west-central Alberta. The use of an ABM for our research is advantageous since dynamic interplay between agents and their environment is readily accommodated, realistic conditions can be approximated (such as movement costs across the landscape), and hypothetical scenarios can be simulated. These models are also amenable to tests of robustness and sensitivity (Grimm and Railsback, 2005). Our caribou ABM incorporates two critical ecological theories involved in habitat selection: animal movement ecology and behavioral ecology. Agents are given fitness-maximizing goals (i.e., survive to reproduce) allowing the model to be used to understand the processes that govern animals' movement, distribution, and selection, and therefore to predict how they might respond to habitat alteration and the presence of industrial features.

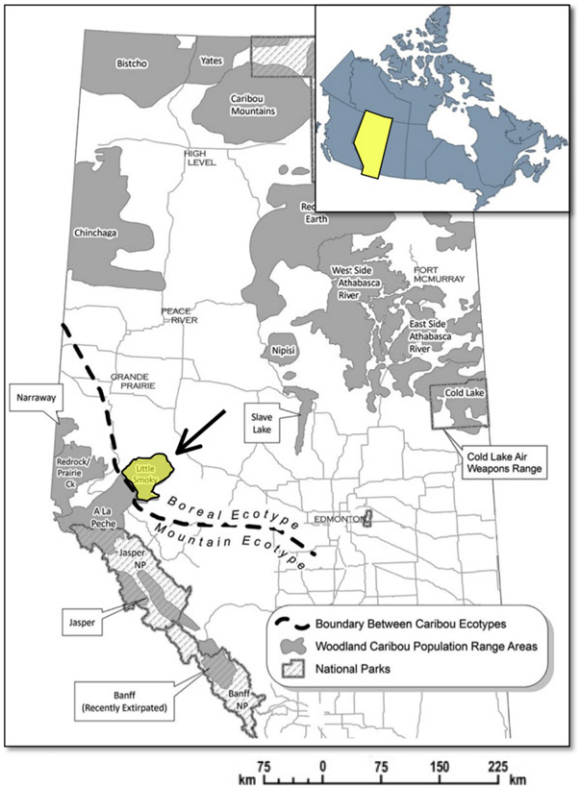

Fig. 1. Little Smoky caribou range (indicated by the arrow) situated amongst other Albertan herds (shaded grey) within the province of Alberta, Canada (ASRD, 2010).

2. Methodology

The caribou ABM comprises two main components: (1) a landscape representation of the caribou herd, and (2) caribou agents and their decision-making heuristics. In this section, a description of the study area and datasets is first provided, followed by a presentation of the model parameterization, the simulation framework, and the validation approach.

2.1. Description of the study area and datasets

The Little Smoky (LSM) herd is located in the foothills of west-central Alberta, east of Grande Cache. Its range covers an approximate area of 3100 km^2 (Fig. 1). The LSM range has the highest level of industrial development of any caribou herd in Canada, with 95% of its range in proximity (500 m buffer) of anthropogenic activities (Environment Canada, 2011b). The site of four forestry management agreements and numerous petroleum-company operations, a proportion of the Little Smoky herd range (8.6%) is composed of 30 year-old (or younger) cutblocks; it also has the highest road and pipeline density of any caribou range in Alberta and contains substantial industrial infrastructure (e.g. well site, compressor, processing plant, battery) facilities (WCCLPT, 2008). At present, there is considerable development pressure from