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Research article

Salvage logging following fires can minimize boreal caribou habitat loss while maintaining forest quotas: An example of compensatory cumulative effects

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ABSTRACT

Protected area networks are the dominant conservation approach that is used worldwide for protecting biodiversity. Conservation planning in managed forests, however, presents challenges when endangered species use old-growth forests targeted by the forest industry for timber supply. In many ecosystems, this challenge is further complicated by the occurrence of natural disturbance events that disrupt forest attributes at multiple scales. Using spatially explicit landscape simulation experiments, we gather insights into how these large scale, multifaceted processes (fire risk, timber harvesting and the amount of protected area) influenced both the persistence of the threatened boreal caribou and the level of timber supply in the boreal forest of eastern Canada. Our result showed that failure to account explicitly and a priori for fire risk in the calculation of timber supply led to an overestimation of timber harvest volume, which in turn led to rates of cumulative disturbances that threatened both the long-term persistence of boreal caribou and the sustainability of the timber supply itself. Salvage logging, however, allowed some compensatory cumulative effects. It minimised the reductions of timber supply within a range of ~10% while reducing the negative impact of cumulative disturbances caused by fire and logging on caribou. With the global increase of the human footprint on forest ecosystems, our approach and results provide useful tools and insights for managers to resolve what often appear as lose–lose situation between the persistence of species at risk and timber harvest in other forest ecosystems. These tools contribute to bridge the gap between conservation and forest management, two disciplines that remain too often disconnected in practice.

1. Introduction

Protected area networks are the dominant conservation approach that is used worldwide for protecting biodiversity (Millennium Ecosystem Assessment, 2005). Conservation planning in managed forests, however, presents many challenges when species at risk are found in or use old stands ("old-growth") that have been targeted by the forest products industry for their timber supplies. On one hand, prohibition of timber harvesting within protected areas may carry high economic opportunity costs, i.e., the loss of economic gain from timber harvesting when protection is chosen. On the other hand, the absence of regulations for timber harvests may result in unacceptable rates of habitat and species losses (Verkerk et al., 2014). Conservation issues that are related to changes in compositional and structural attributes of old-growth forests caused by forest management operations are recurrent in many ecosystems for a wide range of organisms, including lichens (McMullin et al., 2013), carabid beetles (Paillet et al., 2010), birds (Imbeau et al., 2001), and mammals (Di Marco et al., 2014).

In the boreal forests of North America, conservation of forest-dwelling boreal caribou (*Rangifer tarandus caribou*, hereafter "boreal caribou"), which is a wide-ranging and threatened ecotype that ranges from Labrador to the Northwest Territories in Canada

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(Environment Canada, 2011), is a key challenge for conservationists and forest managers, as both boreal caribou and the forest industry value the same old-growth conifer forests. The sensitivity of boreal caribou to natural and human-induced disturbances is well documented with respect to fire (Beguin et al., 2013), logging (Courtois et al., 2008), roads (Wasser et al., 2011), and petroleum and natural gas infrastructures (Dyer et al., 2001). Furthermore, anthropogenic disturbances are the main cause of range recession in eastern North America (Schaefer, 2003; Vors et al., 2007; Festa-Bianchet et al., 2011). In this context, understanding how conservation and forest management plans are influenced by the interactions among fire, timber harvest, and protected areas is a priority.

Catastrophic wildfire is a key disturbance process shaping the natural dynamics of boreal forest ecosystems (Johnson 1996). Because fires are dynamic spatial processes, they influence the outcomes of forest management and conservation strategies in terms of timber supply and habitat suitability, respectively. For instance, fires can cause timber losses for the industry in the medium-term, but also make a large volume of timber readily available over a very short temporal window through salvage logging, i.e., the logging of burned trees. Costs and benefits of salvage logging, however, may greatly depend upon the spatial characteristics of landscape attributes, such as the development of road networks and the existence of protected areas. Despite its relevance for conservation, the nature and extent to which interactions among fires, conservation areas, and forest management practices influence trade-offs between economics and conservation objectives are still little known (but see Schneider et al., 2012). Several studies have investigated these interactions using a subset of processes or using biological indicators that are not directly related to demographic parameters of focal species (Morgan et al., 2007; Rempel et al., 2007; Hauer et al., 2010), such as the probability of occurrence or habitat suitability indices. Yet it is unclear how changes in these indicators directly relate to risks to species persistence over time. Moreover, we are aware of no study that has evaluated the effect of salvage logging on trade-offs at large spatial scales between forestry and conservation of a wide-ranging species at risk. When long-term conservation objectives (e.g., persistence of species at risk) are at odds with short-term socio-economic goals (e.g., timber supply), a proactive way for improving gains in conservation efficiency would explicitly integrate economic indicators into conservation planning (Polasky et al., 2005; Naidoo et al., 2006).

Our main objective, therefore, was to quantify how interactions among fires, protected areas and forest management shape the population dynamics of boreal caribou (a conservation objective) and the annual timber supply for the forest industry (an economic objective) in order to identify possible trade-offs between caribou conservation and forest management. We first assessed how conservation areas affected levels of sustainable timber supply under fire risk in three forest management units of $> 10^4$ km^2 each, hereafter referred to as FMUs. This assessment allowed us to quantify the relative effect of the current conservation strategy on a key economic indicator for the forest industry. Second, we assessed the separate and joint impacts of fire, (salvage) logging, and road networks on the annual population growth rate of boreal caribou under various levels of protection. This allowed us to quantify the ecological consequences of timber harvesting and fire on the probability of persistence of boreal caribou under various conservation schemes. We controlled the amount and spatial configuration of protected areas, (salvage) logging, fire, and roads using a spatially explicit landscape simulation model in which each of these processes interacts annually in space and time over a time horizon of 150 years. Based on existing empirical disturbance-population growth equations (Environment Canada, 2011), we used these simulated disturbance events as inputs in caribou population viability analyses (ecological indicator). Using yield tables, we also calculated the amount of timber volume that can be harvested (economic indicator) following the sustainable principles of forest management. We designed a series of experiments to uncover the influence of disturbance types and the amount of protected area on both economic and ecological indicators.

2. Material & methods

2.1. Study area

The study region (38 844 km^2) is located in the southeastern continuous range of boreal caribou and is part of the Côte-Nord (North Shore) administrative region, which is located in the eastern part of the Province of Quebec, Canada (Fig. 1A). Forested areas represent 76% of the study region and are dominated by coniferous

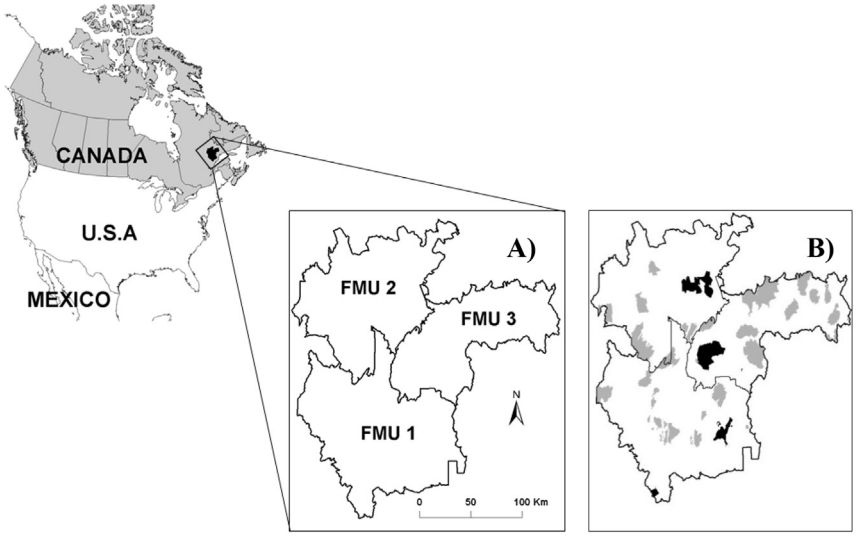

Fig. 1. Location of the study area, with delineation of A) the three Forest Management Units (FMUs) used in this study, and B) conservation areas (IUCN protected areas in black and caribou protection blocks in light grey). See Table A.1. in Appendix 1 for further details on initial conditions in each FMU.