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Spatio-temporal responses of Canada lynx (*Lynx canadensis*) to silvicultural treatments in the Northern Rockies, U.S.

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ABSTRACT

Forest managers are often tasked with balancing opposing objectives, such as altering forest structure and conserving forest-dwelling animals. Consequently, to develop holistic strategies managers require information on how forest manipulations influence species of conservation concern, particularly those that are federally threatened or endangered. Here, we characterized how differing silvicultural treatments (n = 1,293 – forest thinnings; removal of small trees, selection cuts; trees harvested in small patches, and regeneration cuts; clearcuts of nearly all trees) influenced the resource use of a threatened forest carnivore, Canada lynx (*Lynx canadensis*), over a temporal gradient of 1–67 years after treatment. To do this, we used an extensive GPS dataset on 66 Canada lynx (i.e., 164,593 locations) collected during 2004–2015 within the Northern Rocky Mountains, U.S. We used univariate analyses and hurdle regression models to evaluate the spatio-temporal factors influencing lynx use of treatments. Our analyses indicated that Canada lynx used treatments, but there was a consistent cost in that lynx use was low up to ~10 years after all silvicultural actions. However, cumulative use (in both winter and summer) by lynx reached 50% at ~20 years after a thinning treatment, whereas it took ~34–40 years after a selection or regeneration cut. This indicated that Canada lynx used thinnings at a faster rate post-treatment than selection or regeneration cuts, and that lynx used selection and regeneration cuts in a similar fashion over time. Further, we discovered that lynx occupancy and intensity of treatment use was influenced by the composition of forest structure in the surrounding neighborhood. In some instances, the existing forest structure surrounding the treatment and the time since treatment interactively influenced lynx use; a pattern characterizing a spatio-temporal functional response in habitat use. This demonstrated that both the recovery time as well as the spatial context of a particular area are important considerations when implementing different silvicultural treatments for Canada lynx at the landscape scale. For example, if a selection cut was implemented with abundant mature, multi-storied forest (i.e., a preferred habitat by lynx) in the surrounding landscape, lynx would use these treatments less over time than if the neighborhood contained less mature forest. Forest managers can apply our spatio-temporal understandings of how lynx respond to forest silviculture to refine expectations and develop strategies aimed at both forest management and the conservation of Canada lynx.

1. Introduction

Forest managers, and in particular those of public lands, are increasingly faced with the challenge of balancing opposing objectives. For instance, in the forests of North America a pervasive challenge is the conservation of threatened and endangered species that rely on complex forest structures, while simultaneously managing disturbance (e.g., wildfire risk, bark beetle outbreaks) or forest products through silviculture (e.g., Zielinski et al., 2013; Stephens et al., 2014; Tempel et al., 2014; Sweitzer et al., 2016). Unfortunately, the difficulty of navigating these issues has only increased in recent decades given the increase in forest disturbances such as wildfire and bark beetle outbreaks (e.g., Westerling et al., 2006; Bentz et al., 2010; Jones et al., 2016). Balancing species conservation and managing forest

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disturbances is a long-term and difficult challenge for land managers. Animal ecologists can help address this challenge by providing information that assists managers in developing strategies aimed at both species conservation and forest management. One question of central importance is, how do animals (particularly those that are threatened or endangered) respond to different silvicultural treatments over time?

Silvicultural activities may impact forest-associated species by modifying their behavior or influencing their ability to survive and reproduce. For example, forest management at the stand-level alters vertical and lateral cover (i.e., trees and shrubs) as well as ground cover (coarse woody debris). Precommercial thinning at the stand-level negatively impacted the abundance of red-backed voles (*Myodes gapperi*) for nearly 20 years post-treatment, but thinning positively influenced the diversity of the greater small mammal community over the same time frame (Sullivan et al., 2013). Further, many studies have demonstrated the negative, short-term (e.g., 1–11 years post-treatment) effects of precommerical thinning on snowshoe hare (*Lepus americanus*) density and behavior (Griffin and Mills, 2007; Homyack et al., 2007; Abele et al., 2013), presumably because of a reduction in security cover (e.g., lateral and vertical cover). At broader spatial extents, mechanical treatments can promote or reduce the configuration and connectivity of different forest structural stages, as well as influence the landscape-level diversity of forest structures. Opening and simplifying forest mosaics through the mechanical reduction of forest fuel has negatively affected the occupancy of fishers (*Pekania pennanti*; Sweitzer et al., 2016) as well as the movement and habitat connectivity of Pacific martens (*Martes caurina*; Moriarty et al., 2016). Collectively, these examples highlight that considering the species-specific and spatio-temporal components of animal responses to forest manipulations is essential. This is particularly true for publicly managed forests inhabited by threatened or endangered species because there is often substantial controversy surrounding the manipulation of forest structure (Stephens et al., 2014).

The Canada lynx (*Lynx canadensis*), a forest-dwelling carnivore, is a federally-listed species (USFWS, 2000) that has generated significant challenges concerning the alteration of forests in the contiguous U.S. Previous work determined that the habitat and spatial ecology of Canada lynx is most associated with forest structure or successional stage (e.g., Poole et al., 1996; Fuller et al., 2007; Koehler et al., 2008; Squires et al., 2010; McCann and Moen 2011; Simons-Legaard et al., 2013; Montgomery et al., 2014; Holbrook et al., 2017a). Some lynx populations appear to prefer forests dominated by mid-successional stages with dense understories (e.g., 15–35 years after stand replacing disturbance), for instance in the Midwest and Eastern U.S. (McCann and Moen, 2011; Fuller et al., 2007; Montgomery et al., 2014; but see Simons-Legaard et al., 2013). However, other populations of lynx in the western contiguous U.S. exhibit substantial habitat use and selection of mature, multi-storied structural stages with dense understories (e.g., Squires et al., 2010; Ivan and Shenk, 2016; Holbrook et al., 2017a) that support high densities of snowshoe hares (i.e., primary prey of lynx). Despite the wealth of information concerning Canada lynx habitat relationships, some important questions remain unanswered. To our knowledge, there has been no evaluation of how Canada lynx respond to differing silvicultural treatments. Addressing this question would aid the development of multidisciplinary management strategies that incorporate Canada lynx conservation.

Our research objective was to evaluate the spatial and temporal responses of Canada lynx to differing silvicultural activities. To address this objective, we used an extensive GPS dataset (i.e., 164,593 locations and 66 lynx) collected during 2004–2015 in the Northern Rocky Mountains (hereafter, Northern Rockies), U.S. We hypothesized that the distribution of patch use by lynx would be earlier post-treatment for those treatments that were less severe in terms of vegetation impact (e.g., thinnings), relative to those treatments that were more severe (e.g., clearcuts) because lynx prefer dense and multi-layered forests. In addition, we hypothesized that the composition of forest structure surrounding a treatment would impact how lynx used treatments over time. For instance, Holbrook et al. (2017a) demonstrated that Canada lynx in the Northern Rockies selected mature and advanced regeneration forest structural stages. Thus, if a treated patch was surrounded by these structures, lynx might reduce their use of a silvicultural treatment because of their preference for the surrounding forest structure. Our work represents the first evaluation characterizing how silvicultural treatments influence resource use of Canada lynx and more broadly informs forest management efforts aimed at managing disturbance, harvesting forest products, and conserving habitat for threatened species.

2. Materials and methods

2.1. Study area

Our study occurred in the Northern Rockies of northwestern Montana, U.S., across the known distribution of Canada lynx (Fig. 1; described in more detail within Squires et al., 2013). This area covers approximately 3.6 million ha and is mostly composed of public lands (i.e., ~80%), but with some industrial and private forest lands. Across ownerships there are differing levels of human use and resource extraction permitted; for instance, the mechanical removal of trees is not permitted in the Bob Marshall Wilderness complex and other wilderness areas, nor in Glacier National Park. However, much of the area occupied by Canada lynx, and their primary prey the snowshoe hare, is within publicly managed lands (Holbrook et al., 2017a; Holbrook et al., 2017b), which operate under an umbrella of multiple-use including the extraction of forest products.

Our study area supports a diversity of forest species compositions across an elevational gradient from 550 to nearly 3400 m. Forest stands were generally mixed and included ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), western larch (*Larix occidentalis*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*). However, the predominate tree species in areas used by Canada lynx were subalpine fir, Engelmann spruce, and lodgepole pine (Squires et al., 2010; Holbrook et al., 2017a).

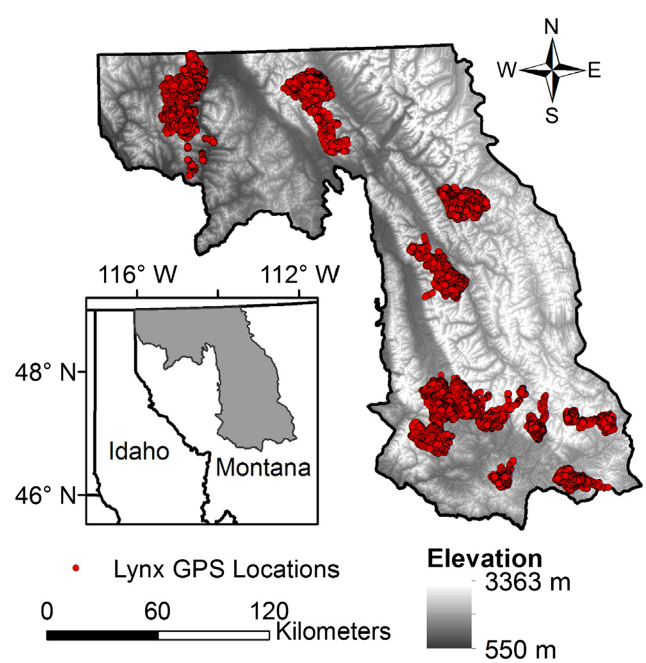

Fig. 1. Study area in northwestern Montana, U.S., where we sampled 66 Canada lynx (*Lynx canadensis*) during 2004–2015 with GPS collars.