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September 14, 2023

Bitterroot National Forest
Attn: Emmit Pruss
1801 N 1st Street
Hamilton, MT 59804

RE: SCOPING COMMENTS FOR THE PROPOSED SLEEPING CHILD, SULA, RYE CREEK AND SODA BAKER FUELS BREAKS

Hello,

Native Ecosystems Council, the Alliance for the Wild Rockies, the Council on Wildlife and Fish, and the Center for Biological Diversity would like to submit the following scoping comments for 4 fuel break projects currently released for public comment: Sleeping Child, Sula, Rey Creek, and Soda Baker Fuels Projects. Please note we have included 2 papers, one on the Canada lynx, titled "Spatio-temporal responses of Canada lynx (*Lynx canadensis*) to silvicultural treatments in the Northern Rockies, U.S. by Holbrook and others (2018), and another titled "Cal Fire burns next to Bald Eagle nest, eaglets die, by the Defiance Canyon Raptor Rescue 2022. The lynx paper provides clear evidence that the proposed fuel breaks will create long-term resistance and barriers to lynx movement across the landscape, barriers that will in effect be permanent. The paper on prescribed fire impacts on Bald Eagles will apply to all forest birds, including direct mortality if they are in a nest, and long-term losses of health for all birds exposed to toxic smoke. Both of these impacts will clearly have significant adverse impacts to lynx and forest birds.

1. The Forest Service failed to provide reasonable notification of these proposed fuel break projects to the public, even though the agency claims you are interested in public comment; thus the scoping notice provided false information to the public.

Native Ecosystems Council (NEC) and the Alliance for the Wild Rockies (AWR) did not receive a notice that these 4 fuels projects were available for public comment. We have been extensively involved in public opportunities for the Bitterroot National Forest, and would expect to be notified of the release of these 4 fuels projects for public comment. Given there is only a 14-day comment period, which already greatly limits the public opportunity for involvement of these projects, the failure to even notify interested groups of these projects appears to be an agency attempt to reduce public comment, even though the scoping notice says the Forest Service wants to hear from the public. There was also no publication of the projects legal notices on the agency web page. This is also important information to the public, and failure to provide this again demonstrates the agency is not actually interested in obtaining public input even though this is an important function of the National Environmental Policy Act (NEPA).

2. The apparent emergency rationale for these projects indicates that no wildlife surveys will be done for the many thousands of acres of proposed fuel treatments.

Since the agency is using a Categorical Exclusion (CE) for these 4 fuel projects, the claim that no significant adverse impacts will occur to wildlife is questionable since there likely will be no surveys, including to locate and protect numerous forest raptors, including those that are a conservation concern. Please define in the upcoming NEPA analysis for these projects if any wildlife surveys are going to be done for each fuel break, including surveys that are conducted at suitable times to ensure a high detection probability. If no surveys are going to be done, what is the estimated loss of nest sites for forest raptors that may occur in these areas, and why won't population persistence be impacted due to multiple fuels projects? What level of fuels impacts are going to be estimated to have non-significant impacts on forest raptors, and how is this going to be measured?

3. The Bitterroot National Forest needs to complete a Forest Plan amendment to both evaluate the potential impacts of these unlimited fuel break programs, which are to be permanent, as well as to establish wildlife conservation requirements for such.

The new fuel break programs being implemented on the Bitterroot National Forest can create movement barriers to a significant number of forest wildlife, from the pine marten and northern flying squirrel to the threatened Canada lynx. There are no restrictions on the length of these fuels breaks in miles in the current legislation. Nor are there any restrictions on the length of these fuel breaks as per miles in the Bitterroot Forest Plan. The use of a Categorical Exclusion has always been based on adherence to the existing forest plan in effect at the time of the project. Since there is no actual direction in the Bitterroot Forest Plan for the length of fuel breaks, there is no basis for the agency to claim that these CEs will not have significant adverse impacts on wildlife, such as lynx. Miles and miles of barriers to lynx movement will clearly disrupt the ability of lynx to use their home ranges effectively, and thus the fuel breaks can ultimately cause a loss of reproductive potential in the affected home range(s). Without some Forest Plan direction to limit the length and location of these fuel break barriers, the effect of these fuel break programs is at best unknown, and thus would not qualify as a CE as per the NEPA.

As well, there are no requirements in the Bitterroot Forest Plan for the agency to complete valid inventories of these massive fuel break areas, which can occur across at least 3,000 acres of a single landscape area. There are at least 8 forest raptors that are low density species that would be significantly affected if these permanent fuel breaks are constructed within their territory and in particular their nesting areas. The use of a CE without any valid surveys “assumes” that there is an excess of suitable nesting habitat for these low density forest raptors, and hence a reduction of nesting habitat will not reduce their populations of landscape carrying capacity for these birds.

Another potentially severe impact of these massive fuel breaks, almost all of which will include prescribed burning, is the potential for extensive deaths and/or reduced survival potential of forest birds. There are currently no restrictions on the amount of prescribed burning that is allowed in forest bird habitat on the Bitterroot National Forest. There is not even an acknowledgement in the current Forest Plan FEIS that prescribed burning kills and/or reduces the survival potential of forest birds. As such, there is no basis for the agency to claim that prescribed burning of thousands of acres every year in fuel breaks, with repeat treatments every 10 years, will not significantly impact forest birds. Again, without Forest Plan direction to reduce these impacts, there is no basis for claiming that implementation of a Forest Plan will prevent significant adverse impacts to forest birds.

The impact of fuels reduction activities that are noncommercial in nature, where there is heavy removal of understory vegetation through slashing and mastication, is also never evaluated in the Bitterroot Forest Plan. Since there is no analysis in this plan, the agency cannot assume that fuels reduction projects will not adversely impact western forest birds due to habitat alteration. These birds rely on forest vegetation for forage, hiding cover, and thermal cover, and thus vegetation removal impacts all of these birds. As such, without any programmatic analysis of fuels reduction impacts on western forest birds, the agency has no basis for claiming impacts will not be significant. In order to satisfy the requirements of both the NEPA and the National Forest Management Act (NFMA) in regards to forest planning, the Bitterroot National Forest needs to complete a Forest Plan amendment that not only evaluates the impacts of unlimited fuels reduction projects which can have an unlimited length and an unlimited mileage of new roads (roads that will be permanent to retreat fuels areas every 10 years), but establishes "sideboards" that prevent significant local impacts on wildlife.

A Forest Plan amendment is also required so that the agency can demonstrate to the public specifically how "emergency" fuels areas are being identified across the Bitterroot National Forest, and define and map specifically where these areas are on the Forest and how they were determined. Currently, it appears that the agency is claiming that the entire Bitterroot National Forest is an "emergency fire hazard" that needs treatment with fuels reduction. The public has no actual information as to how these emergency fire areas are being identified, or if in fact they are simply considered to be the entire forest landscape. Does all of the forest landscape has the same emergency level of fire risk, and if so, how was this determined? The NEPA requires that the agency provide the data and information supporting a conclusion, and not just providing the conclusion, as is the case with these fuel break proposals. A programmatic amendment is needed so that the agency can display to the public how and where emergency fire areas have been identified, quantified and mapped. Along with this, the agency needs to provide a valid estimate of both the acres expected for emergency treatment, and how these areas were selected with regard to wildlife habitat needs, including the lynx, grizzly bear and wolverine.

4. The agency needs to complete consultation with the U.S. Fish and Wildlife Service on a programmatic amendment to the Bitterroot Forest Plan in regards to the unlimited planned fuels break program.

There is no limit to the 3,000-acre fuel breaks the Bitterroot National Forest can implement with this new program. There is also no limit the mileage of new roads that can be constructed with this new program. The unlimited fuel breaks will create movement barriers for the lynx, while the fuel breaks themselves as well as the new roads and/or trails that are converted to roads permanently to allow repeat fuels treatments will have adverse impacts on the grizzly bear and lynx. These new "temporary" roads are not considered an impact on grizzly bears in the current Bitterroot Forest Plan, which is based on invalid assumptions. Not only will these unlimited miles of new temporary roads, including trails being converted to roads, create direct adverse impacts to the grizzly bear when fuel breaks are being managed, but will also create direct impacts to grizzly bears because temporary roads will be available to hikers, mountain bikers, and hunters. The opening of the landscapes in these fuel breaks, which may be 1,000 feet in width, will clearly greatly increase access of these acres to illegal ATV use. AS such, these fuel breaks are going to significantly increase the mortality risk of grizzly bears in the landscapes along these fuel breaks, which may occur for an unlimited number of miles. The total acreage whereby grizzly bears will have increased mortality risk is thus not directly related to the treatment acres, but more likely related to the miles these treatment acres extend.

It is not clear how the USFWS can provide a biological opinion on this new forest fuel breaks program, since the actual extent of it remains undefined. Until the Forest Service completes a programmatic analysis of this new program, which defines the expected treatment acres and miles during the amendment's planning period, the USFWS cannot reasonably provide a take permit for the increased mortality that is going to occur cumulatively to the grizzly bear from what is currently an unlimited program.

5. Will whitebark pine surveys be done for these projects?

Clearly, whitebark pine seedlings and saplings that occur in proposed fuel break areas will be killed by these projects. It is unclear why this destruction of whitebark pikne recruitment is not a significant population impact on this threatened species. Will valid surveys be done so that all whitebark pine trees, both young and old, will be protected, as is required by the ESA?

Regards,

Sara Johnson

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sJJ for

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SJJ for

Steve Kelly, Director, Council on Wildlife and Fish, PO Box 4641, Bozeman, MT 59772; phone 406-920-1381; troutcheeks@gmail.com.

SJJ for

Kristine Akland, Center for Biological Diversity, PO Box 7274, Missoula, MT 59807; phone 406-544-9863. kakland@biodiversity.org.

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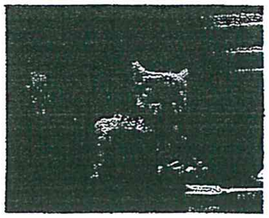

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Liz Cheney: The House Jan. 6 committee has uncovered a 'broad,' 'well-organized' conspiracy
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Tweets of the Week May 29-Jun

Bald eagle chick, dead in nest tree after Cal Fire control burn next to the nest in 2021. Cal Fire has not committed to stop burning by the nest this year. Who would think it would be a problem for public agencies to adhere to laws that protect wildlife?

Climate change impacts have been worsening for years, raising temperatures and exacerbating fire danger in California and the world. In many cases though, trees and other plants are being treated as enemies to be annihilated, rather than as the ecosystems that enable life on earth to exist.

In California, both Cal Fire and PG&E are being given exemptions from any environmental review for their "fuel reduction" or "vegetation management" programs. In this time when thousands of scientists worldwide are screaming and waving red flags about biodiversity and climate catastrophe, the impacts of these projects are being ignored, particularly to wildlife and habitat.

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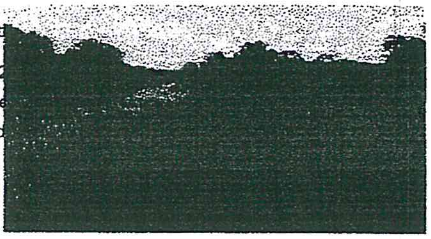
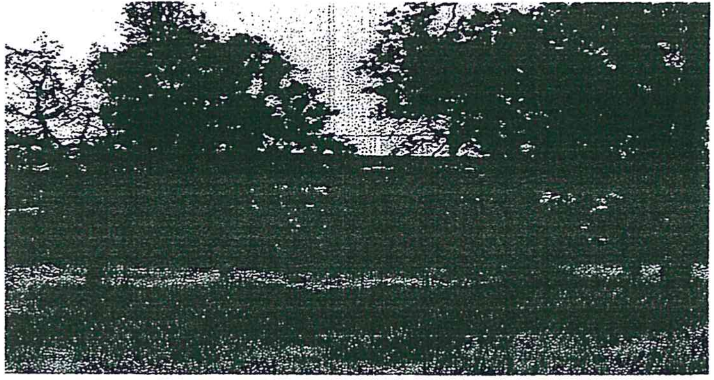
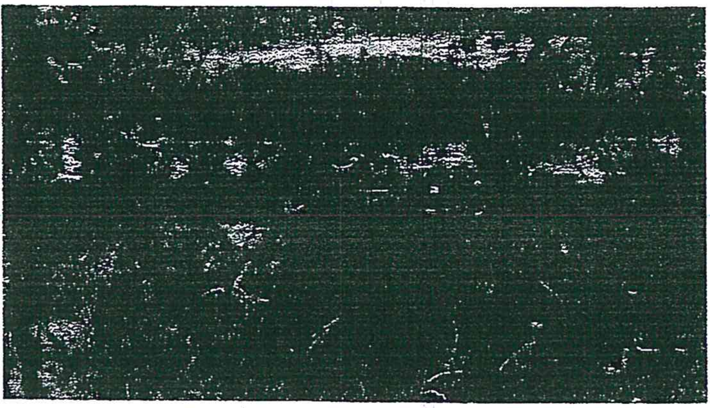
What has happened over the past several years to a bald eagle nest east of Red Bluff, California illustrates what is occurring because of these exemptions from any oversight. The fear of fire is being exploited to the detriment of the natural world, rather than substantive actions being implemented to reduce the emissions which are causing climate disaster.



Hwy 36, east of Red Bluff. The eagle nest is to the right (south side). This is the roadside Cal Fire has burned in 2020 and 2021 when the eagle nest was occupied. There is little reason to burn here, and many reasons not to.



The eagles' nest to the south of the highway, circled in red.



Parent eagle with young eaglet in front (little grey head) in nest tree, April 2022.

Local residents have been watching this nest since 2020. A photographer from Red Bluff was going out to the nest every day in 2021. At the end of May, the photographer saw a notice that there was going to be a control burn by the nest in a few days. She contacted a local eagle group, who

"We are breaking them like nuts."
by annieli
★145 💬59

A Ukrainian military expert confirms much of the analysis you've read here and looks to the future
by Charles Jay
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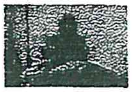

Packard Museum: The 1920s (photo diary)
by Ojibwa
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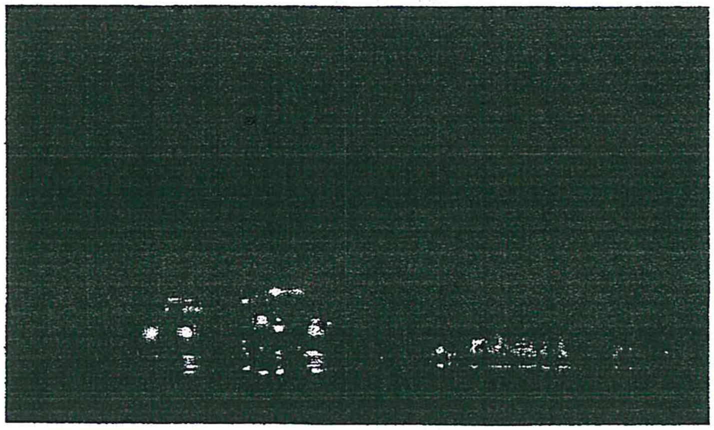
called Cal Fire to tell them about the nest which was occupied by two young eaglets. The eagle group left a message and received a message back from Cal Fire saying their biologist said it was fine to be burning near the nest. The eagle group called back to get the biologist's name, but received no answer then or later. It wasn't "fine".

The burn was done on June 1st. This nest is approximately 100 feet down a ravine from the highway. The eaglets were probably only 6-7 weeks old, 4 or 5 weeks from being able to fly.

The photographer was standing next to the nest during the burn and taking photographs. The Cal Fire people were slightly to the east of the nest. The smoke and flames can be seen on the south side of the highway, on the same side as the nest.



Cal Fire burning next to eagle nest, 2021. How much extra CO2 is being emitted by extra equipment use and burning unnecessarily?

The photographer went to check the nest a few days later and saw one adult perched above the nest, but could see no eaglets.

The next morning, the photographer took a photo which shows a dead eaglet hanging from the nest. The photographer contacted me (Marily Woodhouse from Defiance Canyon Raptor Rescue). We went to search for the other eaglet, in the hope it was still alive.

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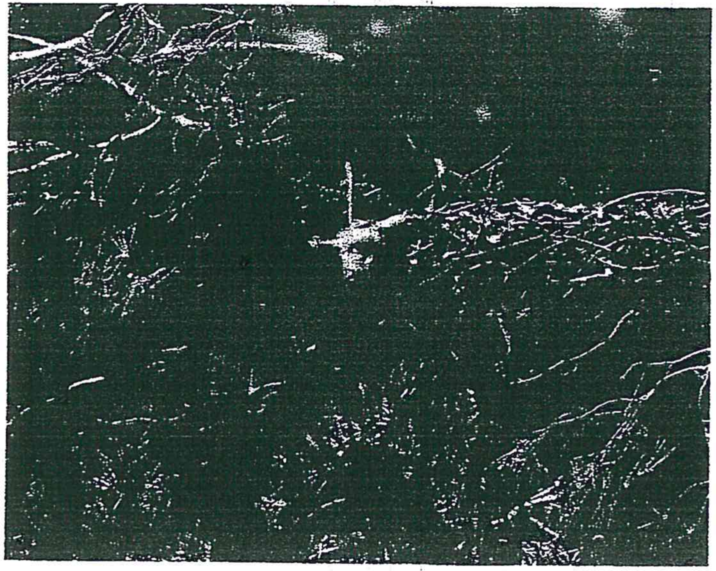

Dead eaglet hanging from the nest.

Both the adults were at the top of the tree, above the nest. I went down the ravine to the nest tree to walk around beneath it to search for the second eaglet and the adults stayed in the tree top. I walked to the southeast side of the tree and looked up and saw the other eaglet hanging dead in the tree, below the nest about 10'.

The second eaglet, dead below the nest.

We reported the deaths to US Fish and Wildlife and CA Department of Fish and Wildlife, but never received any notification of any action taken.

A State Wildlife Health Lab biologist wrote to us later that:

"A bird's respiratory system is more sensitive to toxins, including smoke, than a mammal's respiratory system. This is because birds have a higher oxygen demand than mammals and a bird's lungs are 10 times more efficient at capturing oxygen. The rapid efficiency of gas exchange in bird lungs makes them more susceptible to inhaled toxic agents, including smoke. Inhaled toxins, such as smoke, can cause irritation and damage the respiratory system. It also can

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Cut for the 'Not-So-Tall' Guy
Peter Manning NYC
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xXRU0dKoPgxdLW7JIFxsShf5nSD-h1gon-XuyrmxNlw)

WFP Scaling Up To Reach 3.1 Million In Ukraine
UN World Food Program USA
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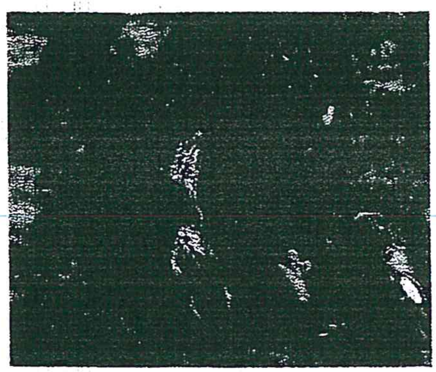
compromise the immune system, making the bird more susceptible to infections. This is especially true in young birds in the nest that are unable to escape the smoke. Smoke inhalation toxicity in birds is caused by irritant gases (aldehydes, hydrogen chloride, and sulfur dioxide), particulate matter, and nonirritant gases (carbon monoxide, carbon dioxide, and hydrogen cyanide) released by combustion."

There was a burn done next to the Dales Station nest in 2020 also. I was called upon to rescue an eaglet who got out of the nest before he could fly that year. It was several days before the burn was done that year, so he was away from the nest when the burn occurred. His sister was still in the nest during the burn. I received a call from Dales Station, less than a mile from the nest, in August, 2020 about an eaglet who had been on the ground for 3 days, standing next to a shallow pool of Paynes Creek. My determination was that it was the female from the nest. She was open-mouthed breathing with a raspy noise. She died a few hours after she was caught and transported. The Wildlife Lab report said: "This was a juvenile female in poor nutritional condition with no fat reserves and minimal pectoral muscle development. Internally, there was evidence of an extensive infection. The visible infection resembled avian tuberculosis which is caused by the bacterium Mycobacterium avium. It's widespread in the environment in soil and dust and is usually an opportunistic infection. Depending on where the lesions are in the bird, gives an idea of how it entered the body. The lesions in this bird were primarily in the air sacs suggesting it was inhaled."

The male who had been in care was released in 2020. A first year eagle was seen back at the nest in 2021. Judging by his and the adults' behavior, it was the male who was in care away from the nest during the burn in 2020.

I had occasion to contact Cal Fire in February 2022 about another issue. I had just been informed that the Dales Station bald eagle nest was occupied, so mentioned it in the hope of preventing another burn next to the nest. Cal Fire and its employees are public servants. It is their job to uphold state and federal laws, which include protection of wildlife, but the answer from a Cal Fire employee contained only dismissive, condescending remarks, clearly refusing to take steps to ensure any protections were implemented.



2020 bald eaglet being released. He was away from the nest in rehab care during Cal Fire's control burn in 2020, which probably saved his life.

Yes we can get gun control passed in the Senate
Daily Kos
(https://www.dailykos.com/story/2022/6/5/2102278/-Yes-we-can-get-gun-control-passed-in-the-Senate)
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Let's start assigning blame for mass shootings where it real...
Daily Kos
(https://www.dailykos.com/story/2022/6/5/2102394/-Let-s-start-assigning-blame-for-mass-shootings-where-it-really-belongs-A-well-regulated-Militia)
(https://www.dailykos.com/story/2022/6/5/2102394/-Let-s-start-assigning-blame-for-mass-shootings-where-it-really-belongs-A-well-regulated-Militia)

Many letters, calls, and emails have ensued since February (most unanswered). I made maps from Cal Fire's own fire database showing how rarely the area around the nest has burned. The ravine area there is extremely rocky and is grazed by cattle. And then there are the State and Federal laws that protect nesting birds. Still, Cal Fire will not commit to refrain from burning by the nest again this year.

Last week a biologist from a PG&E contractor company working in Greenville (a town that burned in the Dixie fire last year) called Raptor Rescue because they wanted us to take eggs from a nest in a tree they wanted to cut down. I explained the multitude of reasons that was a bad idea, along with it being illegal for them to do. The man said "We have an exemption". How many nesting birds are being destroyed in California due to these stupid, thoughtless exemptions and the complete lack of oversight which is occurring?

There have got to be protections enforced. Apparently that won't happen without widespread public outrage.

Here are some state employees to contact if you will help tell them there is a problem with their practices:

George Morris, Cal Fire Northern Region Unit Chief (530) 224-2445 (They would not give out his email address)

Dave Russell, Cal Fire Tehama/Glenn Unit Chief (530) 528-5199 dave.russell@fire.ca.gov

Tina Bartlett, Regional Manager CDFW, (530) 225-2300 tina.bartlett@wildlife.ca.gov

People often focus on individual species, but we believe every species is important, whether it is on a man-made list or not. Habitat fragmentation and loss have significant impacts on wildlife. Defiance Canyon Raptor Rescue works to rescue, rehabilitate, and return raptors to their wild lives, along with our work to protect watersheds and forests of California.

www.thebattlecreekalliance.org (http://www.thebattlecreekalliance.org/)

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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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2.2. Silvicultural treatments, surrounding forest structure, and treatment use by Canada lynx

2.2.1. General overview of analysis

Our main objective was to characterize how time since treatment, treatment type, and surrounding forest structure influenced treatment use by Canada lynx. Given the diversity of silvicultural treatments within lynx home ranges, we first developed an ecologically-based framework to stratify treatments. We used the U.S. Forest Service's FACTS (Forest Activity Tracking System) database and a time-series (1972–2014) of the Normalized Burn Ratio (NBR), a variable created from the Landsat archive using the near infrared (NIR) and shortwave infrared (SWIR) bands (i.e., NBR = NIR − SWIR/NIR + SWIR), to identify distinct silvicultural treatments and evaluate the response of vegetation as a function of time since treatment. The NBR is similar to the Normalized Difference Vegetation Index (NDVI = NIR − Red/NIR + Red), but previous work has demonstrated that NBR outperforms NDVI when assessing differences in vegetation impact (e.g., Escuin et al., 2008; Harris et al., 2011). For instance, the gradient of the NBR was 1.6–2.3 times wider than the gradient of NDVI for the same areas impacted by wildfire (Escuin et al., 2008; Harris et al., 2011), which highlighted the increased resolution of the NBR to discern differences in vegetation responses. Therefore, we used the NBR to validate our treatment stratification from FACTS, which we expected to capture a gradient in vegetation impact. We then used this stratification, along with univariate analyses and hurdle regression models (Mullahy, 1986; Zeileis et al., 2008), to address spatio-temporal questions concerning treatment use (i.e., both occupancy and intensity of use) by Canada lynx. Our application of hurdle models was similar to evaluations of patch occupancy and intensity of use for woodland caribou (*Rangifer tarandus caribou*) in residual forest stands (Lesmerises et al., 2013).

2.2.2. Canada lynx data

We used a dataset of GPS locations (164,593 locations; Fig. 1) from Canada lynx that occupied managed landscapes to assess their use of silvicultural treatments. During 2004–2015, we captured and equipped 66 lynx with store-on-board GPS units (Lotek Wireless, Newmarket, Ontario, Canada or Sirtrack Ltd., Havelock North, New Zealand). Our capture efforts were approved by the Institutional Animal Care and Use Committee (University of Montana IACUC permits 4–2008 and TE053737–1). We programmed GPS collars to collect a location every 30 min for 24 h every other day for the life of the collar (generally 6–8 months). Spatial accuracy of locations averaged 30 m as reported by Squires et al. (2013) and fix rate was approximately 86% (see Holbrook et al., 2017a for additional details on GPS data processing). We assessed occupancy and intensity of use of treated patches across seasons, which we defined as summer (April – October) and winter (November – March).

2.2.3. Stratifying silvicultural treatments with the Normalized Burn Ratio

We used the U.S. Forest Service's FACTS database to identify different silvicultural treatments that occurred within Canada lynx home ranges (home ranges defined in Holbrook et al., 2017a). The FACTS database is a patch-based geospatial layer of silvicultural actions with records going back to the 1920s. Although useful for many research applications (e.g., see applications of FACTS in Zielinski et al., 2013; Tempel et al., 2014; Sweitzer et al., 2016), FACTS data suffers from spatio-temporal errors in terms of treatment extent within polygons and timing of implementation. Therefore, while others have assumed differences among treatment strata derived from FACTS, we implemented a novel assessment to validate our stratification using a time-series of the NBR.

We used the FACTS database to develop an initial set of six forest treatments, which were composed of 25 unique silvicultural activity types (Appendix A: Table A.1). The six silvicultural treatments included: (1) group selection cut ($n = 11$; trees harvested in small patches usually less than 1 ha and regenerated naturally or by planting), (2) liberation cut ($n = 60$; overstory or competing trees removed moved to liberate subject trees), (3) improvement cut ($n = 85$; removing trees from all size classes as to improve the residual tree quality and growth rates), (4) precommercial thinning ($n = 346$; thinning small trees ~15 cm as to modify species composition and provide growing space for residual trees), (5) regeneration cut with natural regeneration ($n = 360$; clearcut resulting in the remove all or the majority of high forest cover as to regenerate a stand from seed), (6) regeneration cut with planting ($n = 431$; clearcut resulting in the removal of all or the majority of high forest cover and plant trees). We expected regeneration cuts to represent the most severe impact to vegetation followed by selection cut, liberation cut, improvement cut, and precommercial thinning; a total of 1,293 treated patches (i.e. silvicultural cuts or thinnings) were included in this analysis. We only considered patches that were modified through a single action (i.e., we excluded patches with multiple treatment actions) and we discarded any patches that were affected by wildfires.

To evaluate vegetation impact and recovery we assessed how the NBR changed as a function of treatment type and time since treatment. We developed the time-series of NBR for our study area using the Landsat archive as part of the time-series analysis in Savage et al. (2018). We calculated the mean NBR across all treatment patches for each year since treatment (starting at year *t*-1). We then evaluated how mean NBR (± 90% CIs) for each year and treatment changed as a function of time since treatment. For this analysis, our temporal gradient ranged up to 39 years after a treatment. Our premise was that if the silvicultural treatments created distinct vegetation conditions after a harvest, the trajectory of vegetation recovery (indexed via NBR) would differ by treatment type. We used program R (R Core Team, 2017) to complete these analyses.

Our initial assessment of the NBR across time since treatment indicated there were some natural groupings among different treatment types (Fig. 2a). For instance, liberation cuts and group selection cuts, as well as improvement cuts and precommercial thinnings, generated similar NBR trajectories (Fig. 2a). Therefore, we reclassified our treatments into the following strata (Appendix A:Table A.1): (1) regeneration cuts (combined regeneration cut with natural regeneration and regeneration cut with plantings; $n = 791$), (2) selection cuts (combined group selection and liberation cut; $n = 71$), and (3) thinnings (combined improvement cut and precommercial thinning; $n = 431$). We then repeated our NBR analyses with these combined strata, which demonstrated the distinct patterns of vegetation change across these three groups (Fig. 2b). Consequently, we used these three treatments as our final suite of silvicultural actions (regeneration cut, selection cut, and thinning), which captured a low (e.g., thinning) to high (e.g., regeneration cut) gradient in treatment severity.

In order to ensure that our treatment stratification was relevant to Canada lynx ecology, we calculated the range of NBR at GPS locations for all lynx ($n = 64$ lynx, 63,204 locations) sampled during the winter season. We used the winter season because winter is when lynx exhibit more specificity in habitat selection (Squires et al., 2010; Holbrook et al., 2017a). Based on previous work highlighting the disproportionate use of mature forest structures by lynx (Squires et al., 2010; Holbrook et al., 2017a), we expected lynx to use a high value and narrow range of the NBR, indicative of recovered vegetation. We calculated a mean NBR (from 2013) for each lynx and subsequently calculated the interquartile range (IQR). We then evaluated how the IQR related to the NBR trajectories associated with our three silvicultural treatments (Fig. 2b). Consistent with our hypothesis, Canada lynx used a high value and narrow range of the NBR (lynx IQR in Fig. 2b) indicating that our stratification of silvicultural treatments was relevant to lynx.

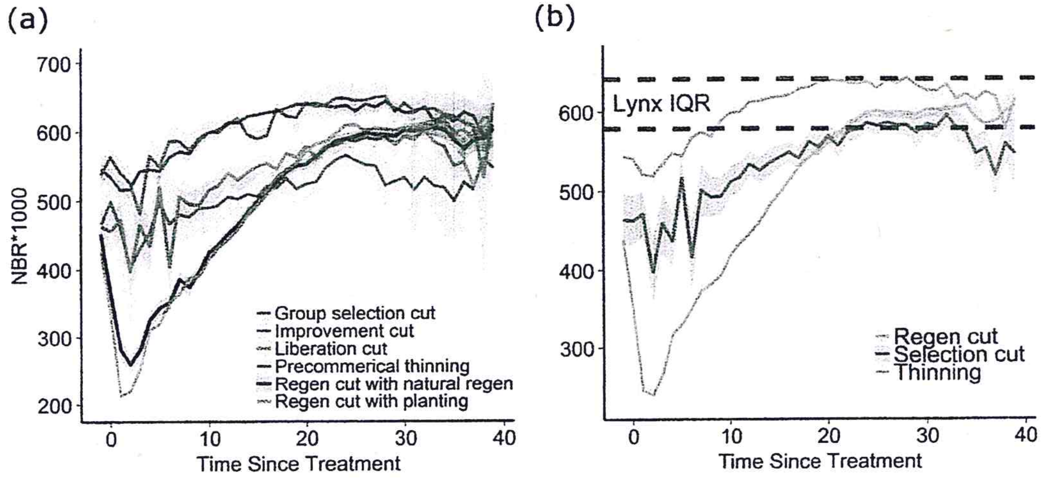

Fig. 2. Mean (± 90% CIs) Normalized Burn Ratio (NBR) * 1000 per year for each treatment type across a gradient in time since treatment (starting at year *t*-1) during 1972–2014 (i.e., 1–39 years post-treatment) for our potential suite (a) as well as our final set of treatments (b). Horizontal lines in (b) represent the interquartile range of NBR at GPS locations averaged for 64 Canada lynx (*Lynx canadensis*) during the winter season. Regen indicates regeneration.

2.2.4. *Evaluating Canada lynx use of silvicultural treatments*

With our silvicultural treatments identified, we then evaluated our main questions concerning how time since treatment and the surrounding forest structure influenced patch occupancy and intensity of use by Canada lynx during winter and summer (see Fig. 3). Patch occupancy was defined as the presence of a GPS location within a silvicultural treatment, while the intensity of use was defined as the number of GPS locations within a silvicultural treatment (i.e., for all patches that were occupied). For each treated patch within Canada lynx home ranges, we calculated the patch size (m^2) and the number of lynx locations within the patch.

We buffered each treatment by 1.5 and 4 km (e.g., Fig. 3), which corresponded to the 95th percentile of hourly movement rates by Canada lynx and the radius of median home range sizes of lynx reported in Holbrook et al. (2017a). We calculated the proportion of forest structural stages (e.g., Fig. 3) within each buffer using the mapped predictions (~80% classification accuracy) from Savage et al. (2018). Forest structural stages included: (1) stand initiation (e.g., ~0–8 years after disturbance with few large trees remaining), (2) sparse forests (e.g., naturally sparse or mechanically thinned, and generally ~9–25 years after modification), (3) advanced regenerating forests (e.g., generally ~25–40 years old with dense horizontal and vertical cover), and (4) mature forests (e.g., multi-storied stands generally ≥ 40–50 years old with dense horizontal and vertical cover). Holbrook et al. (2017a) quantified the differences among these four structural stages in much greater detail using Forest Inventory and Analysis data (see Holbrook et al., 2017a). We used the 1.5 and 4 km buffers simply to identify the scale that fit the data best; the proportion of forest structural stages were highly correlated across scales ($r \geq 0.74$) and thus captured similar variation.

Not all treated patches were sampled equally by lynx throughout a home range. Therefore, we counted the number of GPS locations outside of the treated patch but within the 4 km buffer, which served as an index of treatment-level sampling intensity by lynx. In addition, for every treated patch we developed a time since treatment variable by finding the median year of the lynx GPS locations within the 4 km buffer and subtracting it from the year of treatment. Collectively, these data generated a suite of five explanatory variables (some of which were summarized at two scales; 1.5 and 4 km^2) and two response variables (Table 1). We used ArcGIS (ESRI, 2011) and the Geospatial Modelling Environment (Beyer, 2012) to develop our suite of variables.

The patch size of a treatment as well as the sampling intensity by

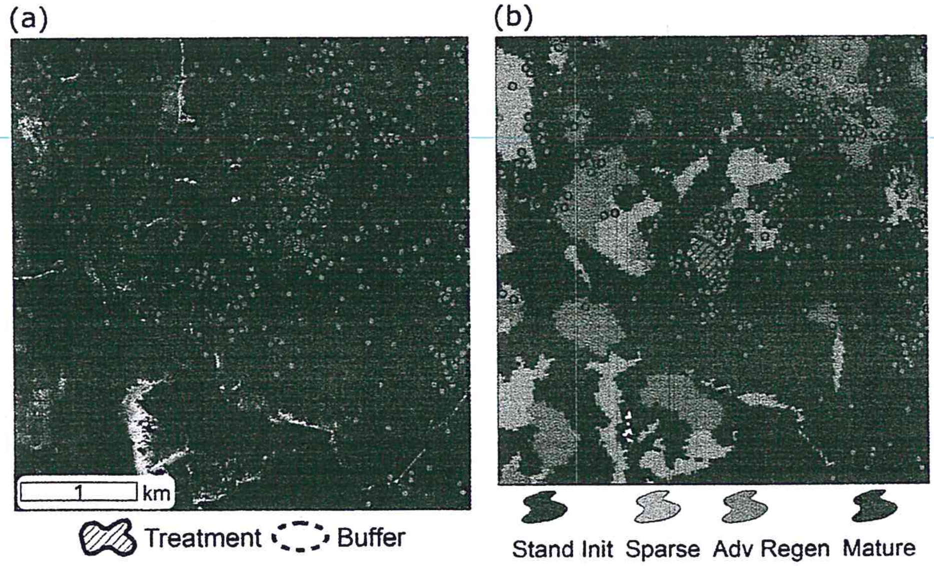

Fig. 3. Example of our sampling scheme to understand how silvicultural treatments, time since treatment, and surrounding forest structure influenced patch occupancy and intensity of use by Canada lynx (*Lynx canadensis*). Dots indicate lynx GPS locations. Panel (a) shows that a regeneration cut from 1979 was occupied (i.e., at least 1 location in treatment) and intensely used (i.e., 17 total locations in treatment) by Canada lynx. Panel (b) shows the distribution of forest structural stages outside of the treatment but inside the buffer or neighborhood. Abbreviations Stand Init and Adv Regen indicate stand initiation and advanced regeneration, respectively.

Table 1

General summary of variables (across treatment types: regeneration cut, selection cut, and thinning) used to evaluate how silvicultural treatment influenced patch use by Canada lynx (*Lynx canadensis*).

Variable	Description	Extent	Mean (Range)
Response	Presence/Absence of a GPS location	Patch-level	NA; binary variable
	Count of GPS locations	Patch-level	Winter: 5 (0–215) Summer: 7 (0–417)
Offset components	Patch size	Patch-level	12 ha (0.40–167 ha)
	GPS locations in 4 km neighborhood	4 km neighborhood	Winter: 1,149 (1–5,327) Summer: 1,850 (1–8,102)
Explanatory	Time since treatment	Patch-level	32 yrs (1–67 yrs)
	Proportion stand initiation	1.5 and 4 km neighborhood	1.5 km: 0.04 (0.00–0.50)[†] 4 km: 0.05 (0.00–0.40)[†]
	Proportion sparse	1.5 and 4 km neighborhood	1.5 km: 0.21 (0.02–0.78)[†] 4 km: 0.24 (0.07–0.67)[†]
	Proportion advanced regeneration	1.5 and 4 km neighborhood	1.5 km: 0.18 (0.01–0.52)[†] 4 km: 0.16 (0.02–0.67)[†]
	Proportion mature	1.5 and 4 km neighborhood	1.5 km: 0.57 (0.08–0.91)[†] 4 km: 0.54 (0.08–0.79)[†]

[†] Values were similar for summer and winter.

lynx in the 4 km buffer could influence the probability of occupancy and intensity of patch use by Canada lynx (e.g., larger patches sampled more intensely within the 4 km buffer are likely to be used more; Lesmerises et al., 2013). Therefore, we incorporated the sampling intensity and the patch size of a treatment as a correction, or an offset in our regression analyses, for our measures of patch occupancy and intensity of use (Table 1). For our initial assessments of the intensity of use by lynx, we applied the following equation:

$$\mathit{Intensity\ of\ Use} = \frac{\mathit{Number\ of\ GPS\ locations\ in\ a\ patch}}{\log(\mathit{Number\ of\ GPS\ locations\ in\ 4\ km\ buffer} \times \mathit{Patch\ size})}.$$

For all analyses, we only evaluated treated patches that were sampled by lynx (i.e., at least 1 GPS location in the 4 km buffer). Thus, all treatments were generally accessible to lynx and our analyses were approximately at the third-order of resource use (Johnson, 1980).

We initially assessed how the intensity of use by lynx was distributed across our gradient in time since treatment. Because of the heterogeneity in sampling intensity by lynx, we used the maximum intensity of use for each year across our time since harvest gradient. Next, we assessed differences in the temporal distribution of lynx use across the different silvicultural treatments, which only included the patches occupied by Canada lynx (i.e., ≥1 GPS location within a treated patch). We used an analysis of variance (ANOVA) to evaluate if time since treatment for the patches occupied by lynx differed between regeneration cuts, selection cuts, and thinnings ($\alpha = 0.05$). If we documented differences, we calculated 95% confidence intervals of time since treatment to determine the direction and magnitude of the differences. Lastly, we assessed how the cumulative proportion of lynx use varied across time since treatment, which provided a more refined comparison of intensity of lynx use between treatments. We predicted that treatment use by Canada lynx would be distributed earlier after a softer treatment (e.g., thinnings) and later after a harsher treatment (e.g., regeneration and selection cuts).

To evaluate what multivariate factors influenced treatment use by Canada lynx, we used hurdle regression models (Mullahy, 1986; Zeileis et al., 2008) and an information-theoretic approach (Burnham and Anderson, 2002). Similar to Lesmerises et al. (2013), we used hurdle models because they are efficient when dealing with overdispersed data and a large number of zeros. We observed many patches that were sampled by lynx (i.e., GPS locations within the 4 km buffer), but contained no lynx locations within the treated patch itself. In addition, hurdle models account for both a binary process (i.e., patch occupancy) and a count process (i.e., intensity of patch use), which facilitates a more refined assessment of patch use by lynx. Specifically, the zero hurdle model (Binomial distribution with a logit link) considers the entire dataset but censors all counts (i.e., $y \geq 1$) to $y = 1$, while the count model (Negative Binomial distribution with a log link in our case) only considers treated patches with at least 1 lynx location (i.e., left truncated at $y = 1$; Zeileis et al., 2008).

Prior to developing hurdle models, we performed preliminary assessments to ensure appropriate model building. First, as aforementioned, we specified an offset term in our hurdle models: log(number of GPS locations in 4 km buffer × patch size). Second, for each treatment and season we identified the most supported scale (either 1.5 or 4 km) for our neighborhood metrics (Table 1, Fig. 3) using Akaike's Information Criterion corrected for sample size (AIC_c). Finally, we assessed collinearity among the remaining covariates and removed those that were contributing to high correlations ($|r| > 0.60$). This resulted in the removal of sparse forest metrics from all models because it was correlated with mature forest.

We developed our candidate models for each treatment and season to evaluate the following predictions concerning how time since treatment and the surrounding forest structure influenced patch use by Canada lynx:

(1) Time since treatment would be more influential for patch use of severe treatments (e.g., regeneration cuts) relative to softer treatments (e.g., thinning) because Canada lynx avoid forests with mostly open canopies (Malentzke et al., 2008; Squires et al., 2010; Holbrook et al., 2017a). In addition, we expected the influence of time since harvest to be more pronounced during the winter because lynx increase their use of mature, older stands (Squires et al., 2010; Holbrook et al., 2017a).
(2) A neighborhood of largely mature and advanced regenerating forest would likely decrease patch use by Canada lynx because lynx preferentially use mature and advanced regeneration structural stages (Holbrook et al., 2017a). This prediction describes context-dependent patch use, which is a functional response in habitat use (e.g., Mystrud and Ims 1998).
(3) Finally, the influence of forest structure within the neighborhood of a silvicultural treatment could depend on how long ago the treated patch was harvested. In other words, time since treatment could interact with the amount of mature or advanced regenerating forest within the neighborhood to influence patch use by Canada lynx. This prediction describes a spatio-temporal functional response in habitat use by integrating time (i.e., time since treatment) with the spatial composition of forest structure in the neighborhood.

Table 2
Model selection table containing ΔAIC_c values (AIC_c weights) for each hurdle model evaluated characterizing how silvicultural treatment influenced patch use by Canada lynx (*Lynx canadensis*). We evaluated models for regeneration cuts, selection cuts, and thinning during the winter and summer season. Bold values indicate selected models. TST indicates time since treatment, Adv Regen indicates advanced regeneration, and Stand Init indicates stand initiation. As a measure of fit, we calculated the Pearson's *r* correlation between observed and expected counts (for all counts greater than 0) using the top model.

Model description	Regeneration cut		Selection cut		Thinning	
	Winter (n = 1,378)	Summer (n = 1,405)	Winter (n = 223)	Summer (n = 221)	Winter (n = 416)	Summer (n = 422)
Null	92.07 (0.00)	10.93 (0.00)	19.34 (0.00)	5.05 (0.02)	19.68 (0.00)	21.21 (0.00)
TST	**0.00 (0.49)**	8.26 (0.01)	5.13 (0.06)	0.02 (0.27)	21.38 (0.00)	24.12 (0.00)
TST + Adv Regen	2.45 (0.15)	5.28 (0.03)	6.67 (0.03)	**0.00 (0.27)**	15.52 (0.00)	13.51 (0.00)
TST + Adv Regen + TST * Adv Regen	4.44 (0.05)	**0.00 (0.44)**	7.88 (0.01)	3.04 (0.06)	19.07 (0.00)	15.32 (0.00)
TST + Mature	3.37 (0.09)	10.81 (0.00)	3.23 (0.14)	3.36 (0.05)	18.12 (0.00)	16.86 (0.00)
TST + Mature + TST * Mature	7.28 (0.01)	12.37 (0.00)	**0.00 (0.73)**	7.22 (0.01)	20.24 (0.00)	17.57 (0.00)
TST + Adv Regen + Mature	5.08 (0.04)	8.76 (0.01)	7.21 (0.02)	3.83 (0.04)	16.61 (0.00)	0.46 (0.44)
TST + Stand Init	2.61 (0.13)	0.87 (0.29)	8.68 (0.01)	0.65 (0.19)	9.53 (0.01)	9.88 (0.00)
TST + Adv Regen + Mature + Stand Init	5.72 (0.03)	1.37 (0.22)	10.64 (0.00)	2.16 (0.09)	**0.00 (0.99)**	**0.00 (0.55)**
Best model Pearson's *r* validation	0.99	0.99	0.95	0.97	0.97	0.99

We evaluated model support using AIC_c and selected the top model when several models received similar support (i.e., $\Delta AIC_c < 2$). We then calculated standardized regression coefficients (by standardizing explanatory variables: $(x_i - \bar{x})/SD$) and evaluated the strength of relationships ($\alpha \leq 0.10$). In addition, we evaluated the fit of our top models by assessing hanging rootograms (Kleiber and Zeileis, 2016), which characterize a model's tendencies to over- or under-predict across the gradient of the response variable (intensity of patch use in our case). As a final measure of model fit, we also computed the Pearson's correlation coefficient between observed and expected counts > 0; we used values > 0 because hurdle models (by design) predict exactly the number of zeros observed within the fitted dataset (Kleiber and Zeileis, 2016). Lastly, we evaluated if there was evidence of spatial autocorrelation in the residuals from our top models using Moran's *I* (Moran, 1950) correlograms across 20 lag distances. Moran's *I* ranges between -1 and 1, which indicates perfect dispersion and perfect correlation, respectively. Positive autocorrelation in the residuals would indicate our models did not capture an important environmental gradient. We conducted all analyses in program R (R Core Team, 2017) and used the 'countreg' (Kleiber and Zeileis, 2016), 'pscl' (Zeileis et al., 2008), and 'pgirmess' (Giraudoux, 2017) packages.

3. Results

Our initial assessment indicated that the intensity of use by Canada lynx was distributed similarly across seasons (winter and summer) and that there was little use by lynx up to ~10 years after a silvicultural treatment regardless of type (Fig. 4a). Our ANOVA indicated differences in time since treatment for patches occupied by lynx across regeneration cuts, selection cuts, and thinnings (winter: $F_{2,1030} = 161.59$, $p < 0.001$, $R^2 = 0.24$; summer: $F_{2,1231} = 176.54$, $p < 0.001$, $R^2 = 0.22$). On average, Canada lynx used thinning treatments 14–20 years faster (winter: $\bar{x} = 20$ years since treatment, 95% CI = 19–21 years since treatment; summer: $\bar{x} = 20$ since treatment, 95% CI = 19–21 years since treatment) than regeneration cuts (winter: $\bar{x} = 34$ years since treatment, 95% CI = 33–35 years since treatment; summer: $\bar{x} = 34$ years since treatment, 95% CI = 33–34 years since treatment) or selection cuts (winter: $\bar{x} = 39$ years since treatment, 95% CI = 38–41 years since treatment; summer: $\bar{x} = 41$ years since treatment, 95% CI = 40–42 years since treatment; Fig. 4b). Although we observed statistical differences among all treatments, the largest effect was associated with thinnings relative to regeneration and selection cuts (Fig. 4b). Consistent with these statistical differences, cumulative use (in both winter and summer) by Canada lynx reached 50% (i.e., half) at ~20 years after a thinning treatment (Fig. 4c), whereas it took ~34–40 years after a selection or regeneration cut to reach 50% use. The cumulative proportion of use by lynx was distributed similarly for regeneration and selection cuts (Fig. 4c) despite the differing levels of vegetation impact associated with tree harvest as measured by the NBR (Fig. 2b). Overall, these univariate assessments indicated that Canada lynx exhibit temporal differences in their use across silvicultural treatments (i.e., thinning versus regeneration or selection cuts).

Results from our multivariate hurdle models provided additional detail concerning how Canada lynx used differing silvicultural treatments over time (Table 2). Lynx use of regeneration cuts in the winter (n = 1,378) was best explained by only time since treatment; no other models were supported (i.e., < 2 ΔAIC_c). The effect of time since treatment was statistically positive, which indicated that both the probability of occupancy and the intensity of lynx use increased with time since treatment (Table 3). In the summer (n = 1,405), lynx use of regeneration cuts was best characterized by time since treatment, the proportion of advanced regeneration in the neighborhood, and their interaction (Table 2; although, there was some evidence stand initiation positively influenced patch occupancy by lynx). The only statistical effect from our top model was the interaction between time since treatment and advanced regeneration for the intensity of lynx use (Fig. 5a, Table 3), which indicated that lynx use was relatively static with a low amount of advanced regeneration in the neighborhood, but increased with time when advanced regeneration was abundant in the neighborhood (Fig. 5a). This pattern suggested that abundant advanced regeneration had a negative effect on lynx use early (e.g., 0–30 years after treatment), but facilitated more use of regeneration cuts later in time (e.g., > 40 years after treatment); that is, a spatio-temporal functional response in patch use by Canada lynx. Collectively, these results indicated that (1) time since treatment was important for lynx use of harsh regeneration cuts (particularly in the winter), and (2) the structural composition in the neighborhood surrounding a treated patch influenced lynx use over time.

Similar to regeneration cuts, our top models characterizing lynx use of selection cuts varied by season (Table 2). During winter (n = 223), patch use was best explained by time since treatment, the proportion of mature forest within the neighborhood, and their interaction (Table 3). However, the interaction was only significant for intensity of lynx use and indicated that the effect of time since treatment depended on the amount of mature forest in the neighborhood (Fig. 5b). When mature forest was abundant, lynx were less inclined to use the selection cut over time; however, when mature forest was low, lynx increasingly used the selection cut after ~40 years (Fig. 5b). This was consistent with lynx preferentially using mature forest over selection cuts when the former was abundant in the neighborhood of a treated patch. In the summer (n = 221), our top model included time since treatment and the proportion of advanced regeneration in the neighborhood (Table 2;

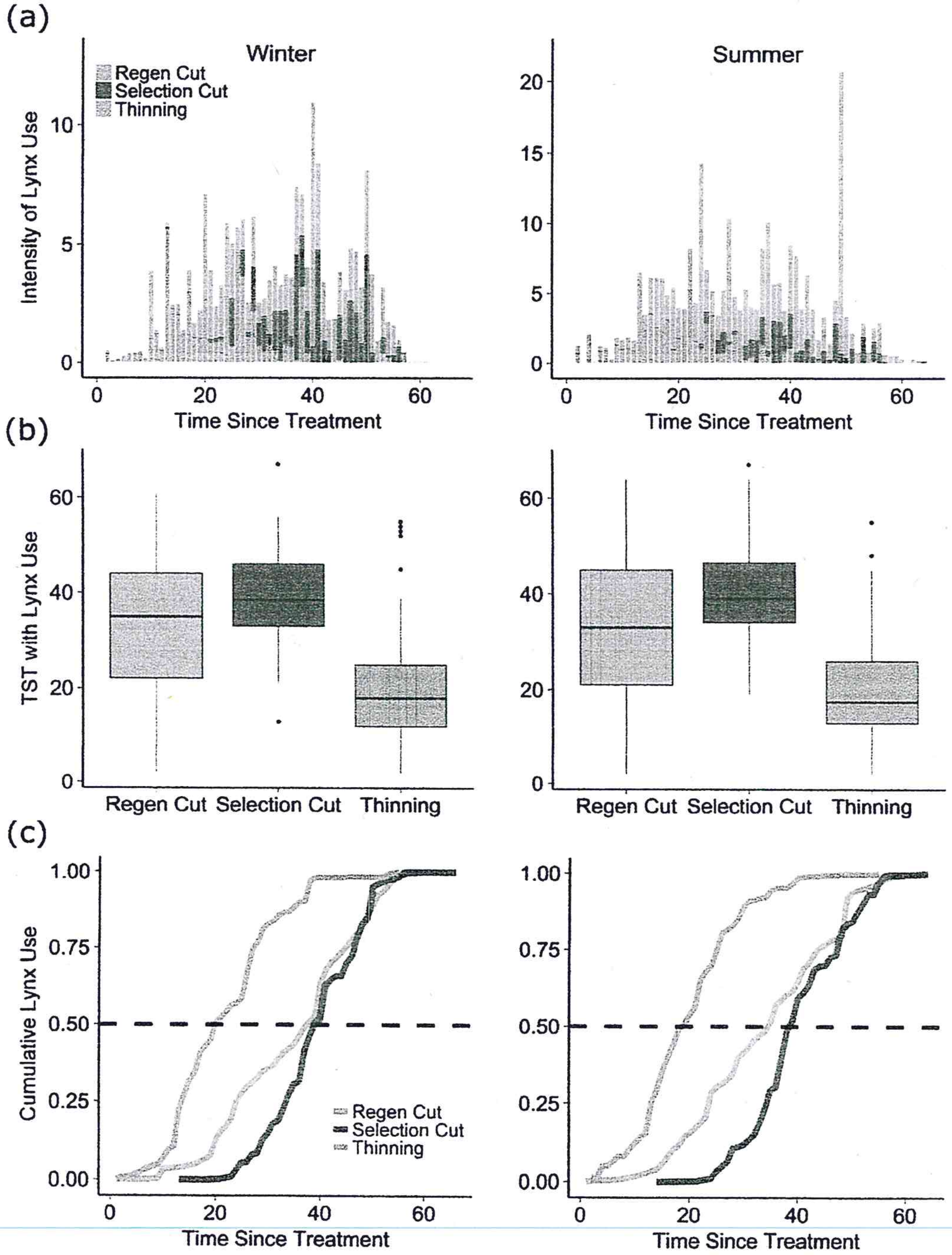

Fig. 4. Temporal distribution of habitat use by Canada lynx (*Lynx canadensis*) associated with different silvicultural treatments. (a) Standardized intensity of patch use by treatment and across a gradient in time since treatment (TST; 1–67 years post-treatment). (b) Boxplots of TST by strata for all patches that were used by lynx (i.e., ≥1 lynx location). (c) Cumulative intensity of lynx use by treatment and across a gradient in TST (1–67 years post-treatment). The dashed lines in (c) indicate 50% of the cumulative use, which is approximately equal to the median value in (b). Regen indicates regeneration.

although, there was evidence that the intensity of lynx use was positively related to stand initiation). However, the only statistical effects were associated with the intensity of lynx use (Tables 2 and 3). The intensity of lynx use was positively related to both time since treatment and advanced regeneration in the neighborhood. These results further emphasized that (1) time since treatment was important for lynx use of harsher treatments (e.g., selection cuts), and (2) the structural composition in the neighborhood surrounding a treated patch influenced lynx use.

Finally, use of thinning treatments by Canada lynx was generally driven by the same factors during winter ($n = 416$) and summer ($n = 422$). Lynx use was influenced by the proportion of stand initiation, advanced regeneration, and mature forest in the neighborhood, but the effect of time since treatment was only significant during the winter (Table 2). The standardized regression coefficients characterizing lynx use of thinning treatments indicated that (1) the surrounding neighborhood was more important than time since treatment, and (2) that the neighborhood effects varied in direction and magnitude across

Table 3
Standardized regression coefficients for covariates within the selected hurdle models characterizing how silvicultural treatment influenced patch occupancy and intensity of use by Canada lynx (*Lynx canadensis*). Coefficients are shown for both the binomial and negative binomial regressions, characterizing occupancy and intensity of use, respectively. Bold indicates support for a spatio-temporal functional response in patch use by lynx. TST indicates time since treatment, Adv Regen indicates advanced regeneration, and Stand Init indicates stand initiation.

Covariate	Regeneration cut		Selection cut		Thinning	
	Winter	Summer	Winter	Summer	Winter	Summer
TST						
Occupancy	0.442^{***}	0.051	0.381^{**}	0.138	0.054	−0.040
Intensity of use	0.614^{***}	0.079	0.298^{**}	0.267^{**}	0.158^{*}	-0.096
Mature						
Occupancy	–	–	$-0.346^{\gamma,**}$	–	$-0.335^{\dagger,***}$	$0.267^{\gamma,*}$
Intensity of use	–	–	$-0.314^{\gamma,***}$	–	$0.256^{\gamma,**}$	$-0.161^{\gamma,*}$
Adv regen						
Occupancy	–	-0.093^{γ}	–	$0.002^{\dagger}$	-0.207^{γ}	$0.570^{\gamma,***}$
Intensity of use	–	-0.064^{γ}	–	$0.221^{\gamma,***}$	-0.029^{γ}	$-0.133^{\gamma,*}$
Stand Init						
Occupancy	–	–	–	–	$-0.285^{\gamma,**}$	0.095^{γ}
Intensity of use	–	–	–	–	$0.389^{\gamma,***}$	$0.194^{\gamma,**}$
*TST*mature*						
Occupancy	–	–	−0.126	–	–	–
Intensity of use	–	–	$\mathbf{-0.409}^{***}$	–	–	–
*TST*Adv Regen*						
Occupancy	–	0.057		–	–	–
Intensity of use	–	$\mathbf{0.145}^{***}$		–	–	–

† 1.5 km neighborhood.
$^{\gamma}$ 4 km neighborhood.
* $\alpha < 0.10$.
** $\alpha < 0.05$.
*** $\alpha < 0.01$.

seasons and lynx responses (i.e., occupancy and intensity of use; Table 3). The probability of lynx occupancy during winter was negatively related to the amount of stand initiation and mature forest in the neighborhood, whereas the intensity of lynx use was positively related to these two variables (Table 3). During summer, lynx occupancy was positively related to the amount of advanced regeneration and mature forest in the neighborhood, but contrastingly the intensity of lynx use was negatively related to these factors (Table 3). The intensity of lynx use was also positively related to the amount of stand initiation in the neighborhood (Table 3). In contrast to regeneration and selection cuts, the forest structure surrounding a thinning treatment was consistently more important for lynx use than the effect of time since treatment.

All model evaluations provided evidence of appropriate model fit. The correlations between observed and expected counts > 0 were consistently high, which suggested strong model performance (Table 2; $r \geq 0.95$). In addition, we observed no consistent spatial autocorrelation in the residuals (all Moran's I values ≤ 0.10) across all lag distances.

4. Discussion

Relatively few studies have evaluated the effect of different silvicultural actions on the resource use of forest carnivores (e.g., Cushman et al., 2011; Tigner et al., 2015; Scrafford et al., 2017), despite the management controversy associated with manipulating forests occupied by these sensitive species (e.g., Howard, 2016). To our knowledge, our work is the first to assess the effect of silvicultural actions on Canada lynx. Importantly, we discovered that lynx use silvicultural treatments. However, use of any treatment (i.e., regeneration cut, selection cut, or thinning) was low up to ~10 years post-treatment. This suggests there is a cost regardless of treatment type, which is consistent with previous work highlighting a ~10 year negative impact of precommercial thinning on snowshoe hare densities (Homyack et al., 2007). The alignment of these ~10 year responses for lynx and snowshoe hares is consistent with ecological predictions because Canada lynx rely heavily on snowshoe hares as a prey resource (e.g., Mowat et al., 1996; Squires and Ruggiero, 2007; Ivan and Shenk, 2016). In addition, we found that Canada lynx use thinning treatments at a faster rate over time than either selection or regeneration harvests (Fig. 4). Contrary to our expectations, lynx used selection and regeneration cuts similarly over time despite the differences we observed in vegetation impact as measured via NBR (Fig. 2). Moreover, the composition and abundance of forest structural stages surrounding a particular treatment (e.g., Fig. 3) influences how lynx use that treatment. In some cases, both the probability of occupancy and the intensity of patch use by Canada lynx was influenced by the surrounding forest structure, which exemplified a spatial functional response in habitat use (*sensu* Mysterud and Ims, 1998). This was similar to previous work demonstrating the importance of the surrounding landscape for the patch use of woodland caribou (Lesmerises et al., 2013) and pygmy rabbits (*Brachylagus idahoensis*; McMahon et al., 2017). However, patch use by Canada lynx was also characterized by an interaction between time since treatment and the composition of forest structure in the neighborhood, which indicated a spatio-temporal functional response (Fig. 5). In other words, vegetation recovery after a silvicultural treatment and the existing forest structure surrounding a treatment interactively influenced the behavior of Canada lynx. Collectively, this work fills an important knowledge gap in Canada lynx spatial ecology. Forest managers can apply our spatio-temporal understandings to develop refined strategies aimed at both forest management and lynx habitat conservation.

The relationship between time since treatment and patch use by Canada lynx was generally similar across our univariate and regression analyses. For instance, our univariate assessments indicated lynx use thinnings sooner after a harvest than selection or regeneration cuts (Fig. 4), which aligned with our index of treatment severity based on the NBR (Fig. 2). Our regression analyses indicated that the effect of time since treatment was always positive for lynx use, but the effect was

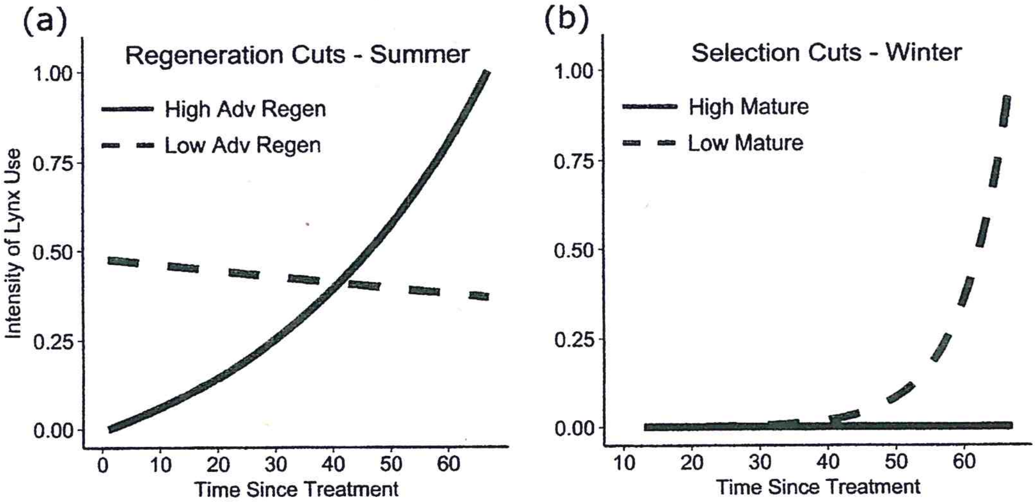

Fig. 5. Spatio-temporal interactions (i.e., a spatio-temporal functional response) predicted from our selected hurdle models characterizing the intensity of Canada lynx (*Lynx canadensis*) use (scaled between 0 and 1) for regeneration and selection cuts. In other words, the intensity of lynx use within a patch depends on the amount of advanced regeneration or mature forest in the 4 km and 1.5 km neighborhood (respectively) surrounding the patch as well as the time since treatment. Predicted intensity of use was generated from the negative binomial regression within the hurdle model. (a) Indicates the predicted intensity of lynx use during summer for patches that received a regeneration cut. (b) Indicates predicted intensity of lynx use during winter for patches that received a selection cut. The proportion for 'High Adv Regen' was 0.30 and 'Low Adv Regen' was 0.10, while the proportion for 'High Mature' was 0.80 and 'Low Mature' was 0.30. Adv Regen indicates advanced regeneration.

stronger for regeneration cuts followed by selection cuts and thinnings, respectively (Tables 2 and 3; again, aligning with treatment severity). Finally, as predicted, time since harvest generally exhibited a stronger effect on lynx use during the winter as compared to the summer (Table 3), but this was only apparent in our regression analyses.

These temporal patterns were consistent with habitat selection by Canada lynx in the Rocky Mountains, U.S. For example, Canada lynx exhibit strong multi-scale selection for advanced regeneration and mature forest likely because of abundant and accessible snowshoe hares (Squires et al., 2010; Ivan et al., 2014; Ivan and Shenk, 2016; Holbrook et al., 2017b). In our study area, the stage of advanced regeneration takes at least ~25 years to develop (Holbrook et al., 2017a), which aligns with the initial use of regeneration and selection cuts by lynx (Fig. 4a and 4c). Further, Canada lynx increasingly use mature structural stages during the winter months (Squires et al., 2010; Holbrook et al., 2017a), suggesting more time might be needed to develop winter habitat as compared to summer habitat. Heterogeneous disturbances such as thinnings, however, seemingly facilitate the development of advanced regeneration and mature forests at a faster rate than selection or regeneration harvests given the earlier use by lynx (Fig. 4c). These results have implications concerning the temporal dimensions of forest treatments aimed at improving Canada lynx habitat.

Furthermore, lynx exhibited different responses to the composition of forest structural stages in the neighborhood surrounding thinnings based on the hierarchical level of behavior; that is, the probability of lynx occupancy (first level) and the intensity of lynx use (second level). Many studies have demonstrated the hierarchical habitat relationships (e.g., Johnson, 1980; Rettie and Messier, 2000; DeCesare et al., 2012; Holbrook et al., 2017a; McMahon et al., 2017), and our insights build on this work. For instance, increasing stand initiation in the neighborhood negatively influenced lynx occupancy of thinnings during the winter. This is likely because Canada lynx strongly avoid stand initiation (Holbrook et al., 2017a), and particularly so in the winter, thus decreasing the probability of patch use when stand initiation is abundant in the surrounding area. In contrast, stand initiation positively influenced the intensity of lynx use within a thinned patch during the winter and summer. This was conceivable because once a lynx occupies a thinning, they might then chose to remain within the patch versus moving out into an avoided structural stage (i.e., stand initiation). Other studies using analytical procedures similar to ours have demonstrated differential responses depending on the hierarchical level of the response (e.g., occupancy or intensity of use) for woodland caribou and pygmy rabbits (Lesmerises et al., 2013; McMahon et al., 2017).

We also observed situations where the effect of forest structure in the surrounding neighborhood was similar across the hierarchical levels of behavior. For example, Canada lynx exhibited a reduced probability of occupancy and intensity of use for treated patches when the neighborhood contained abundant mature forest (Table 3). In fact, when mature forest was abundant in the neighborhood of selection cuts, the intensity of use by Canada lynx remained low regardless of time since treatment (Fig. 5b). The negative influence of mature forest on lynx resource use was likely associated with the benefits provided by mature forests resulting in lynx selecting this stage and avoiding the treated patches nearby. A similar mechanism was suggested to explain the fast and direct movement of Pacific marten through resource-poor stands (i.e., open areas) versus the slow, more deliberate movements in resource-rich stands (Moriarty et al., 2016). Mature forests provide abundant, temporally stable, and accessible snowshoe hares within the Rocky Mountains (Griffin and Mills, 2009; Ivan et al., 2014; Ivan and Shenk, 2016; Holbrook et al., 2017b), and therefore lynx spend a substantial amount of time within this structural stage (Squires et al., 2010; Holbrook et al., 2017a).

Our suite of insights concerning the spatio-temporal responses of Canada lynx to silvicultural actions were in part a result of our novel approach to stratifying silvicultural treatments. We retroactively evaluated vegetation responses over time using the NBR, which ensured our treatment stratification was ecologically relevant. We then demonstrated that this approach related to Canada lynx, with lynx using a high value and narrow range of NBR (Fig. 2). Future work examining animal responses to forest manipulations could apply our approach to characterize ecologically distinct treatments through time. This is an important contribution because often it is assumed that different database labels, such as classifications of silvicultural actions (e.g., with the FACTS database), represent ecological differences, which we demonstrated to be a false assumption (e.g., Fig. 2a).

5. Conclusion

A difficult challenge within publically managed forests lies at the intersection of silvicultural actions and the management of forest-dwelling species that are of conservation concern (e.g., Stephens et al., 2014; Howard, 2016). To assist in narrowing the gap between silviculture and species conservation, we evaluated how forest treatments influence resource use of Canada lynx, a threatened carnivore in the contiguous U.S. (USFWS, 2000). First, we demonstrated that lynx clearly use silviculture treatments, but there is a ~10 year cost of implementing any treatment (thinning, selection cut, or regeneration cut) in terms of resource use by Canada lynx. This temporal cost is associated with lynx preferring advanced regenerating and mature structural stages (Squires et al., 2010; Holbrook et al., 2017a) and is consistent with previous work demonstrating a negative effect of precommerical thinning on snowshoe hare densities for ~10 years (Homyack et al., 2007). Second, if a treatment is implemented, Canada lynx used thinnings at a faster rate post-treatment (e.g., ~20 years post-treatment to reach 50% lynx use) than either selection or regeneration cuts (e.g., ~34–40 years post-treatment to reach 50% lynx use). Lynx appear to use regeneration and selection cuts similarly over time suggesting the difference in vegetation impact between these treatments made little difference concerning the potential impacts to lynx (Fig. 4c). Third, Canada lynx tend to avoid silvicultural treatments when a preferred structural stage (e.g., mature, multi-storied forest or advanced regeneration) is abundant in the surrounding landscape, which highlights the importance of considering landscape-level composition as well as recovery time. For instance, in an area with low amounts of mature forest in the neighborhood, lynx use of recovering silvicultural treatments would be higher versus treatments surrounded by an abundance of mature forest (e.g., Fig. 3b). This scenario captures the importance of post-treatment recovery for Canada lynx when the landscape context is generally composed of lower quality habitat. Overall, these three items emphasize that both the spatial arrangement and composition as well as recovery time are central to balancing silvicultural actions and Canada lynx conservation. Our work here represents an important step in filling knowledge gaps at the intersection of disciplines, such as silviculture and animal ecology, which is essential for the future development of pragmatic solutions.

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Appendix A.

Silvicultural treatment stratification from the U.S. Forest Service's FACTS database.

Table A.1
Reclassification table showing the raw classification from the U.S. Forest Service's FACTS database to our first and final set of silvicultural treatments.

FACTS labels	First set of potential treatments	Final set of treatments
Group selection cut	Group selection cut	Selection cut
Single-tree selection cut	Group selection cut	Selection cut
Liberation cut	Liberation cut	Selection cut
Shelterwood preparatory cut	Improvement cut	Thinning
Improvement cut	Improvement cut	Thinning
Seed-tree preparatory cut	Improvement cut	Thinning
Commercial thin	Improvement cut	Thinning
Stand clearcut	Regen cut	Regen cut
Patch clearcut (w/leave trees)	Regen cut	Regen cut
Stand clearcut (w/leave trees)	Regen cut	Regen cut
Patch clearcut	Regen cut	Regen cut
Seed-tree final cut	Regen cut	Regen cut
Seed-tree seed cut (with and without leave trees)	Regen cut	Regen cut
Shelterwood establishment cut (with or without leave trees)	Regen cut	Regen cut
Two-aged seed-tree seed and removal Cut (w/res)	Regen cut	Regen cut
Two-aged shelterwood establishment and removal Cut (w/ res)	Regen cut	Regen cut
Two-aged shelterwood establishment Cut (w/res)	Regen cut	Regen cut
Certification of natural regeneration with site prep	Natural regen	NA
Certification of natural regeneration without site prep	Natural regen	NA
Initiate natural regeneration	Natural regen	NA
Fill-in or Replant Trees	Planted	NA
Plant Trees	Planted	NA
Planting propagules and cuttings	Planted	NA
Wildlife habitat seeding and planting	Planted	NA
Precommercial thin	Precommercial thin	Thinning

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