Living on the edge: the effect of human-created edges on red squirrel (*Tamiasciurus hudsonicus*) abundance and distribution in the Oil Sands Region, Alberta, Canada

INTRODUCTION

Anthropogenic land use is rapidly altering landscape structure, with cascading effects on biodiversity, distribution, and abundance of organisms (Foley et al., 2005). Landscapes are in constant flux — natural disturbances and processes are continuously altering complex matrices of habitat patches — these essential processes diversify habitat patches and can increase biodiversity (Tews et al., 2004). However, the rapid pace and unprecedented extent of anthropogenic landscape change is irreparably changing ecosystems with impacts that differ from natural disturbances. Disturbance leads to changes in the amount of habitat and the spatial arrangement of this habitat, altering species interactions with the landscape and thus their effects on the landscape (Dunning, Danielson & Pulliam, 1992). Wildlife must contend with these complex landscapes; each species may respond differently within a local context and understanding the mechanisms behind these responses is key to effective conservation measures.

Disturbance, whether natural or anthropogenic, drives habitat fragmentation; the process of dividing continuous habitats into many small patches, often isolating habitat patches and causing a matrix of dissimilar patches (Didham, 2010). Physiognomy (spatial arrangement) and composition of habitat types are argued to be two distinct landscape processes (Dunning, Danielson & Pulliam, 1992), whereim the size and isolation of remaining patches is not linearly related to habitat loss and the effects of fragmentation become more intense as remaining habitat decreases (Andrén, 1994; Didham, Kapos & Ewers, 2012). While habitat fragmentation does not occur completely independent of of habitat loss — given that for habitat fragmentation to occur total habitat must also decrease — it describes a change to the configuration of a landscape and is highly interrelated to other landscape attributes such as edges, core area, and patch isolation (Andrén, 1994). Habitat loss and fragmentation are landscape-level processes (Fahrig, 2003), with patch-level processes such as edge effects and habitat isolation occurring and dependent on the landscape context (Didham, 2010). Habitat fragmentation interacts with other changes in the environment, such as climate, invading species, or land use change (Didham, 2010), and the impacts of fragmentation can be both negative and positive on species diversity (Fahrig, 2003).

While natural disturbance, such as wildfire, can open habitat for early seral vegetation and benefit forest communities, anthropogenic disturbance can have complex consequences. Disturbance to contiguous habitat causes edges, characterized by distinct environmental conditions resulting from the biotic and abiotic factors of two separate habitats (Didham, Kapos & Ewers, 2012). There is a complex interplay between configuration of disturbance and type of edge, and the myriad of other factors that influence the extent and magnitude of edge influence (Dabros et al., 2017), such as the shape and size of a habitat patch. Given the stark contrast between edge and interior habitat, there are often differences in species diversity (Slater et al., 2024), composition and abundance in edge habitat (Forman & Gordon 1981; Pfeifer et al., 2017), as edge habitat can both represent increased forage resources and increased risk (Kremsater & Bunnell, 1999).

Within these rapidly changing landscapes, wildlife must contend with altered arrangements of resources and risk. Disturbance introduces new risks and rewards to a landscape, altering how species select habitat in space; patches within a landscape represent varying levels of risks and rewards. Patchy landscapes change how wildlife use habitat; forage availability spatial arrangement alters search time and movement (MacArthur, 1966) and thus rearranges how species interact on a landscape. For example, altered landscape configuration may cause landscape supplementation (resources from nearby habitat of the same or different type) which may allow a species to persist in smaller patches of habitat (Dunning, Danielson & Pulliam, 1992). Optimal foraging theory suggests that an organism will make choices that have the most benefit with the least cost; this has a profound impact on the patch choices, movement, risk aversion on a landscape (Pyke, 1984). The overall habitat abundance impacts occupancy and creates more complex communities (Holt, 2002), but more spatially complex landscapes create more complex responses of wildlife — dictated by a species perception of grain and extent (Kotliar & Weins, 1990). Species experience and influence ecological processes at varying scales, on a landscape where there are multiple processes at varying scales both impacting one another and the species inhabiting the landscape (Levin, 1992). Given this, it is imperative to consider interacting species and scales when disentangling wildlife responses to changing landscapes.

The large-scale landscape alteration by industry development in the Boreal Plains has no historical analogue (Pickell et al., 2015) and affects all mammals with both benefits and consequences (Fisher & Burton, 2018). While wildlife can be directly displaced due to noise from active areas (Kleist et al, 2021), much of this novel landscape is fragmented with linear features, such as seismic lines — cleared 5 to 10 metre linear strips used for oil and gas exploration (Dabros et al., 2017), with minimal development otherwise. In some areas, the density of linear features can reach up to 10km per km^2 (Pasher, Seed & Duffe, 2013), fragmenting habitat and increasing the amount of edge habitat on the landscape, causing a variety of impacts to vegetation and wildlife. While increased patchiness can increase sunlight and encourage growth, studies have found reduced diversity and cover of herbaceous and nonvascular plants along seismic lines (Dabros et al., 2017). Linear features create a scar in the forest for decades (Lee & Boutin, 2006), and while the overall area impacted might be low in some local contexts, the environmental impact is likely underestimated (Drabos, Pyper & Castilla, 2018), due to the ubiquitous distribution of disturbance features and the cumulative effects from numerous disturbances types (Vernier et al., 2014).

While past research has investigated the response of boreal mammals to disturbance features, relatively little attention has been given to edge effects and landscape configuration (but see Smith et al., 2024). Linear features provide movement subsidies for predator species; research has found linear features increase movement speed (McKenzie et al., 2012; Dickie et al., 2020; Dickie et al., 2017) and change predator habitat selection due to ease of movement (DeMars & Boutin, 2017). For example, these changes to predator-prey interactions have implications in the decline of caribou in landscapes with anthropogenic development — one cited mechanism is increased hunting success due to movement subsidies (Dickie et al., 2017). Disturbance features directly and indirectly impact predator and prey species of the boreal forest, but these effects are context dependent and vary based on the overall level of disturbance (Curveira-Santos et al., 2024).

The red squirrel (*Tamiasciurus hudsonicus*) is a boreal forest small mammal that may be sensitive to changes in landscape structure caused by anthropogenic development. Red squirrels are dependent on coniferous forests, where they consume primarily seeds from cones (Rusch & Reeder, 1978), and the species has been found to be more abundant in mature forests (Larsen, 2009). Both territorial behavior and food supply regulate populations and distribution, and varying habitat types will cause different home range sizes (Rusch & Reeder, 1978). Red squirrel habitat selection and distribution on the landscape is largely governed by resource availability, the amount, size, and isolation of suitable habitat patches, although importance of habitat patches is dependent on the landscape context (Fisher, Boutin & Hannon, 2005; Russel et al., 2010). The effects of edge habitat on red squirrels has been explored in the context of agricultural matrices (Bayne & Hobson, 2000), but the implications for a landscape altered by energy development with a very high edge density remain unknown. Edge habitat may increase survival for the red squirrel (Anderson & Boutin, 2002)and interacting disturbances, such as forestry and fire, have been shown to alter red squirrel habitat selection by altering the available resources and the location of those resources (Fisher, Boutin & Hannon., 2005). Increased edge habitat by industrial disturbance could cause changes to squirrel abundance and distribution through direct effects such as increased resources (Bayne & Hobson, 2000) or changes to distribution or abundance of competing species. Investigating the impact of edge habitat on red squirrel distribution and abundance may yield valuable insights into the influence of landscape composition on an important prey species in a highly altered ecosystem.

In this paper, I will investigate the influence of edge habitat on red squirrel distribution and the effect of scale on this influence. The following research questions will be addressed:

1) Does red squirrel relative abundance or distribution change with the amount of edge habitat?
2) What disturbance features cause edge habitats that are the most impactful to red squirrel relative abundance and distribution?

I hypothesize 1) edge proportions have a nonlinear relationship with red squirrel relative abundance and distribution, whereas moderate edge density will increase habitat use but high edge density will decrease habitat quality (reflected by lower red squirrel abundance, and 2) edge habitat with increase predator presence (reflected by increased predator abundance) will have decreased red squirrel abundance. To answer these questions, data from 450 motion-activated wildlife cameras deployed in the Boreal plains of central and northern Alberta will be used to measure the abundance and distribution of red squirrels across several landscapes with a gradient of oil and gas development. At multiple scales from each camera site, I will extract disturbance metrics (proportion edge, patch isolation, core area index), habitat composition (proportion conifer forest, proportion broadleaf forest), and disturbance composition (proportion of anthropogenic features) within each landscape. There will be both variability within and between landscapes, where some landscapes contain minimal disturbance whereas others have been heavily exploited.

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