Nesting ecology of ducks in the boreal forest

by

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Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Matthew Edward Dyson was the sole author for Chapters 1 and 7, which were written under the supervision of Brad Fedy and were not written for publication.

This thesis consists of five (5) manuscripts that have been published or prepared for publication. As lead author of these five chapters, I contributed to conceptualizing study design, applying for funding, applying for research permits, procuring field equipment, organizing field logistics and technician staffing, carrying out data collection and analysis, writing reports for funding and permitting agencies, and drafting and submitting manuscripts. My coauthors provided guidance during each step of the research process and provided feedback on draft analysis and manuscripts.

Exceptions to sole authorship of material are as follows:

Chapter 2 of this thesis was published in 2019 in the Journal of Field Ornithology (citation below). I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthors Stuart Slattery and Brad Fedy.

> Dyson, M. E., S. M. Slattery, and B. C. Fedy (2019). Microhabitat nest-site selection by ducks in the boreal forest. Journal of Field Ornithology 90:348–360.DOI: 10.1111/jofo.12314.

Chapter 3 of this thesis has been submitted to the journal Landscape Ecology. I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthors Stuart Slattery and Brad Fedy.

Chapter 4 of this thesis has been submitted to the journal The Condor: Ornithological Applications. I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthors Stuart Slattery and Brad Fedy.

Chapter 5 of this thesis was published in 2020 in the Wildlife Society Bulletin (citation below). I was responsible for all aspects of manuscript preparation outlined above and received input and feedback from my coauthors Stuart Slattery and Brad Fedy.

Dyson, M. E., S. M. Slattery, B. C. Fedy. 2020. Nest predators of ducks in the boreal forest. Wildlife Society Bulletin. 44:631-639 DOI: 10.1002/wsb.1114.

Chapter 6 of this thesis is being prepared for submission. I was responsible for all aspects of manuscript preparation outlined above and have received input and feedback and editorial comments from Brad Fedy and Stuart Slattery. This manuscript will be submitted for publication to the journal Ecology and Evolution with coauthors Stuart Slattery and Brad Fedy.

In addition to the chapters included in this manuscript, I also submitted a manuscript to the Wilson Journal of Ornithology that is in press at the time of this submission for the pilot telemetry work that I led in 2017 and 2018 as part of field work for this dissertation.

Dyson, M. E., S. M. Slattery, B. C. Fedy. 2020. There and back again: Female mallard (*Anas platyrhynchos*) breeding season movement across the boreal forest and prairie pothole biomes. The Wilson Journal of Ornithology. DOI: 10.1676/19-87.

Throughout the manuscripts I use the pronoun 'we' in the place of 'I' to reflect the collaborative nature of this work. Specifically, the collective 'we' refers to my collaborators and coauthors for each independent manuscript chapter. I followed the American Ornithological Society standard for species common name capitalization for birds but use lower case for mammals and plants to adhere to their common naming convention.

Abstract

The western boreal forest (WBF) is an important breeding area for North American ducks, second only to the prairie pothole region (PPR). The WBF is experiencing intensive industrial development, causing habitat loss and fragmentation. Land use change can have profound effects on predator-prey interactions and influence population dynamics. In most avian species, nest success is critical to population persistence. Therefore, species are under intense selective pressure to choose a safe nest site. Currently, we have limited knowledge of duck nesting ecology in the WBF, including the influence of changing land use practices on how ducks select nest sites, how those decisions influence nest survival, what predators eat duck nests, and how land use change effects predator communities.

To answer these questions, we conducted extensive field research, which involved searching for and monitoring nests of ground nesting boreal ducks, using camera traps to identify predators at real and artificial nests, and using camera traps to monitor predator occupancy across our study area. We located 167 duck nests of 8 different species between 2016 and 2018 by nest searching across a gradient of industrial development. We investigated nest-site selection of ground nesting ducks in the WBF of Alberta at multiple levels and spatial scales using logistic regression-based resource selection functions. We also investigated how land use, landcover, and nest attributes (e.g., nest age, nest initiation date) influenced the daily survival rate of nests using the logistic exposure model. Finally, we evaluated land use and landcover characteristics that predicted predator occupancy using multiscale occupancy models from camera trap data across our study area to understand how predator communities are affected by industrial development.

Our results provide the first descriptive studies of the nesting ecology of boreal ducks from Canada. We identified that ducks selected greater overhead cover and proportion of grass at nest sites, relative to paired-random locations. We also identified that nest-site selection strategies at the microhabitat level were different across nesting guilds and species in relation to vegetation structure and composition, which may facilitate coexistence. At a macrohabitat level, we identified strong selection for marsh habitat, with avoidance of pipelines and seismic lines. We also demonstrated how considering multiple spatial scales while investigating habitat selection is critical by illustrating scale dependent responses to different resources. We then spatially predicted our best model and its error to identify important nesting habitat for boreal ducks, which can be used to help prioritize habitat conservation in the region. Nest survival was relatively low across species (0.212 [85% CI: 0.152 - 0.282]) and increased with nest age and varied annually. At the microhabitat scale, nest survival increased with greater graminoid, forb, and shrub cover at the nest. At the macrohabitat scale, nest survival decreased with greater proportion of fen habitat, and increased with greater lengths of pipelines and roads in proximity to the nest. We did not find evidence that oil and gas development negatively affected duck nest survival.

We identified 8 different species that predated boreal duck nests including American black bear, weasel spp., American marten, Canada lynx, coyote, red squirrel, common raven, and red-tailed hawk. Next, we found that predator species were more likely to use habitats associated with industrial development as opposed to prey species that avoided industrial development. Specifically, coyotes, black bears, and gray wolves had a higher probability of being detected in association with industrial development suggesting they might be more active or abundant in these areas. Considering this evidence with our nesting ecology data, we suggest that ducks appear to be resilient to current levels of development through avoiding predators during nest-site selection. However, continued development combined with climate change has the potential to continue to alter these relationships.

This dissertation represents a first step towards understanding the nesting ecology of ducks in the boreal forest. We provide multiple lines of evidence from our study to help improve our understanding of the effect of industrial development on ducks. The human demand for natural resources is likely to continue to increase the industrial footprint in the boreal forest, a region once considered pristine. To successfully conserve wildlife in this region, continued research is required to deepen our understanding of how the industrial footprint influences habitat selection and space use of predators and prey. The evidence provided herein can be used to revise and adapt our current hypotheses and assumptions to direct further research questions to produce strong inference about ducks and development in the boreal forest.

Acknowledgements

I am incredibly fortunate to have had the opportunity to do this research under the guidance of my primary supervisor, Dr. Brad Fedy. When I arrived at Waterloo in 2015, I wanted to study ducks and I wanted to do field work. I got to do both of those things, but I also learned about how to be a better scientist and critical thinker. Brad provided me with a tremendous amount of autonomy in pursuing my PhD, but also side boards and constructive criticism when I needed it (often). Brad provided support, opportunity, and encouragement in developing a quantitative skill set, which gave me the confidence to engage with complex statistical concepts and approaches that I look forward to continuing to develop over my career. I have greatly benefited from his guidance over the past 5 years, which has allowed me to become a better scientist. I look forward to our continued collaborations.

I was also fortunate to receive guidance and support from Dr. Stuart Slattery from Ducks Unlimited Canada (DUC). Stuart was always supportive of my ideas and appropriately critical to help me think things through. I appreciate him always opening his doors and providing a place to stay while passing through Manitoba. I would also like to thank Dr. Jim Devries, Dr. Vanessa Harriman, and Howie Singer for all the conversations over the years about ducks and the boreal forest. I am also very grateful to Bob Emery, who was instrumental in helping me arrange field logistics and assisting in locating old field equipment that we reused on this project. Bob always provided valuable advice and conversation about decoy trapping, field work, and helping to manage our banding permit. I have also benefitted from conversations with my committee members at Waterloo, Dr. Andrew Trant and Dr. Derek Robinson, who always encouraged me to think about more than just ducks.

This dissertation would not have been possible without the dedication and effort of my field crews. Its not easy slogging through the boreal forest searching for duck nests and collecting field data while being relentlessly attacked by mosquitoes or whatever else the boreal has in store for weather on any given day. Thanks to Alex Meeker, Matt Turnbull, Chris Kahlmeier, Moriah Tanguay, Matt Garrick, Lee Scholl, Aiden Flores, Mya Vanwoudenberg, Josh Bowen, Luke Pletsch, Lucas Short, Nathan (NAJ) Joakim, and Jon Willans. I learned a lot over the years about being a leader, which means that I didn't always make the best decisions at the time. I appreciated your patience and understanding while trying to schedule field work around rain rendering roads inaccessible, moving field camps mid-season, and working out the logistics and challenges of a new field project. It was not always easy. I will cherish the memories of celebratory dinners, guitar by the campfire, fishing, countless Euchre and other card games, good times in the field, and even the memories of water filled waders. I am so proud of what we accomplished together and so pleased to see the success you have all achieved since our time together.

I am confident that I could include a separate chapter, arguably chapters, of this thesis about field logistics planning. I will not do that, but I will thank Carolynn Forsyth and her dogs (Max, Foxy, Bailey, and Zoey) of the ArtisInn where we were primarily based. Carolynn provided hospitality, Sunday dinners, equipment storage, and access to materials and equipment from her "collection". I also want to thank Becky Scott of Northern Lights College in Slave Lake for helping coordinate field camps in 2017. As part of pilot work during this study, we had to procure a flock of farmed "mallard" hens, which proved to be unquestionably one of the most bureaucratically laborious processes of my PhD. Thanks to all the waterfowl ecologists that provided advice from the Afton list serve when I reached out for information on purchasing decoy hens and to all the people who offered help with decoy trapping strategies. Glenn Howe provided temporary space in Ontario and valuable advice on duck husbandry prior to our flock shipping to Alberta. Decoy hens were purchased from Tanjo Farms (Millbank, ON) in 2017 and Juniata River Game Farms (Linwood, PA, USA) in 2018 and I appreciate both farms working with me to allow for procurement of the hens for research purposes, along with the mountains of veterinary paperwork. Finally, I need to thank Sandi Robinson and John Vennnings of Slave Lake for assistance with duck husbandry over the years and equipment storage. I connected with Sandi over a community farm market Facebook group in 2017 and they provided space on their property for our duck pens during trapping, but also for over-winter care. I am so grateful for their assistance and hospitality.

Members of the Fedy Lab helped to keep me sane during my PhD. Thanks to Ryan Watchorn, Marcus Maddalena, Chris Kirol, Natasha Barlow, Jeff Row, Kris Winiarski, Ryan Johnstone, Kelly McLean, Todd Cross, and Marie Raciocoppa. I've learned a lot from my peers in the lab and have enjoyed getting to know you all. When I started at Waterloo, we did not have any ecology focussed seminars or platform to share research, discuss papers, or develop new skills. Courtney Robichaud and I founded the Waterloo Ecology Network in an effort to connect ecologists from across the faculties to provide these opportunities. I am so grateful for Courtney's continued interest and perseverance in helping WEN be successful. I am proud of what we started and hope to see it be a continued success. I also would like to thank Jennifer Nicholson (and also Meaghan Carter) of SERS for continuously helping me navigate the administration at Waterloo for travel and expense claims, hiring technicians, balancing budgets, and purchasing supplies and equipment. I am confident I would not have been able to do it without your guidance and patience.

Completing a PhD involves a lot of ups and downs. I am so fortunate to have had my best friend and wife, Jenn, who has been by my side for this entire endeavour, enduring

4-month field seasons when the dog and I were away, and constantly providing unwavering support through the good and bad times. I know this has not always been easy and I cannot thank you enough for the sacrifices you have made for me while I pursue my PhD, I love you. I can't wait for our next adventure, you are going to be the best mom. Life is so much better with a good dog. I don't know if I could have done this without my trusty sidekick, Paisley, the big red labrador retriever. She always reminds me to appreciate the little things, like good naps in the sun, food, and rolling in dead stuff no matter how long its been decaying (the longer the better). Lastly, I am lucky to have incredibly supportive parents that instilled a work ethic in me that allowed me to succeed in this endeavour and taught me to always give more than you take. I can't think of better virtues to pass on to my kids one day.

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Dedication

To friends, family, and the waterfowl research community.

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Chapter 1

Introduction

Wildlife population persistence is an indicator of ecosystem health and promotes human well-being (Dietsch *et al.* 2016; Manfredo *et al.* 2016). Functioning ecosystems (i.e., balanced energy flows and stable feed-back loops) deliver ecosystem services (e.g., carbon storage, water retention, and fresh water) that can be identified by observing expected populations dynamics of associated wildlife species (Green & Elmberg 2014; Kubiszewski *et al.* 2017). These wildlife species hold cultural and socio-economic value to humans for consumptive (e.g., subsistence or recreational harvest) and non-consumptive use (e.g., aesthetic and cultural beliefs) (Manfredo 2008; Teel & Manfredo 2010). Therefore, in-depth knowledge of how wildlife populations interact with their ecosystems (i.e., ecology) will help to ensure population persistence and promote human well-being now and into the future (Balmford & Bond 2005).

The most pervasive threat to wildlife populations is human induced land use change (Sih *et al.* 2011; Tscharntke *et al.* 2012; Allred *et al.* 2015). Historically, habitat loss due to conversion of land to agricultural production and urbanization was the strongest threat to wildlife (Fahrig 2003; Tscharntke *et al.* 2012). However, recent decades have seen rapid growth in industrial development, such as oil and gas and forestry (Naugle 2011; Butt *et al.* 2013; Allred *et al.* 2015; Pickell *et al.* 2015). Specifically, industrial development is rapidly expanding into previously unaltered landscapes and the resulting effect on wildlife is largely unknown (Naugle 2011; Fisher & Burton 2018). The pervasive and rapid expansion of the human footprint will challenge the adaptive capacity of many species. The persistence of wildlife populations, therefore, will rely on their responses to potential changes in ecosystem regulation and their ability to shift their use of space and resources accordingly. To ensure wildlife persist in these landscapes, we require effective conservation strategies and planning based on a sound understanding of species ecology.

Most ecological inquiry is focused on determining what, where, when, why, and how organisms are distributed across space (MacArthur 1972; Peterson *et al.* 2011; Tucker *et al.* 2018). Traditional approaches have relied on observing, counting, or detecting the location of an organism in geographic space (Aarts *et al.* 2012). Then, to understand why an organism uses a location, we associate environmental space, comprising local site conditions (e.g., forest cover, temperature), with geographic space. The association between geographic and environmental space can reveal patterns leading to improved ecological understanding of species distributions on a landscape (Peterson *et al.* 2011).

Niche theory has been applied as a common framework to help understand these questions (Hirzel & Le Lay 2008; Peterson *et al.* 2011). For example, the fundamental niche represents an n-dimensional hypervolume of abiotic factors that permit species existence or occurrence (Grinnell 1917; Hutchinson 1957). Details related to inter-and-intraspecific species interactions, and their environment, can further shape species distributions (Elton 1927; Hutchinson 1957). Consequently, the realized niche accounts for the biotic interactions that shape distributions (Hutchinson 1957; Soberón 2007). Using this framework to understand the spatial and temporal distribution of species has greatly improved our understanding of species, populations, and community ecology (Elith & Graham 2009). However, interpretation of the ecological niche is fundamentally altered by different assumptions related to the spatial extent and resolution of inquiry, the mechanisms that drive biotic interactions, how resources are represented in the niche, and how the niche changes across time scales (Soberón 2007).

1.1 Predator-Prey Interactions

Predator-prey interactions are fundamental to the structure and function of ecological communities (Sih *et al.* 2011; Gorini *et al.* 2012). Predation shapes life history evolution and influences prey decisions, such as habitat selection (Martin 1995; McLoughlin *et al.* 2005). Theoretically, predators respond to prey densities numerically or functionally (Solomon 1949). A numerical response occurs when the abundance of predators in a population increase as a function of increasing prey densities. Alternatively, a functional response represents an increase in foraging efficiency by the predator (i.e., increased encounter rate) as a result of increased prey density. Therefore, the product of these responses, which most likely falls along some theoretical continuum between a functional and numerical response, will influence the observed predation rate (Messier 1994).

Space use can fundamentally modify predator-prey interactions by influencing a predator's ability to search, encounter, kill, and consume prey (Muhly *et al.* 2011; Gorini *et al.* 2012). Consequently, human induced land use change has strong potential to modify these complex relationships between predator and prey. This could result in cascading effects throughout the food web and alter the stability of predator-prey dynamics and, in turn, the ecosystem as a whole (Sih *et al.* 2011; Gorini *et al.* 2012). Prey try to minimize while predators try to maximize their overlap in geographic space use (Muhly *et al.* 2011). Habitat heterogeneity can, therefore, have a profound effect on this relationship through influencing kill rates and the density of predators or prey (Schneider 2001; Bergström *et al.* 2006; Gorini *et al.* 2012). For example, space use by prey is mediated by direct consumption (Kauffman *et al.* 2007) and the relative influence of trait-mediated mechanisms (e.g., fear) on perceived predation risk (Preisser *et al.* 2005). Research now recognizes the substantial impacts of trait-mediated interactions, because of the potential reduced prey foraging effort, energy income, fitness, and potential increased vulnerability to other predators (Preisser *et al.* 2005; Suraci *et al.* 2016).

Foraging strategies, such as specialist versus generalist, are also important when considering predator-prey interactions (Holt 2002; Ryall & Fahrig 2006; Devictor *et al.* 2008; Clavel *et al.* 2011; Tscharntke *et al.* 2012). Specialist species generally decline with landscape fragmentation and habitat loss, while generalist predators tend to increase, potentially increasing the predation rate on some prey species and altering the availability of prey on the landscape (Clavel *et al.* 2011). Therefore, considering how community, or multi-species, dynamics shape these interactions is critical to understanding predator-prey relationships. For example, apparent competition results when one or more predator species consumes one or more prey species and is often mediated by space use of predator and prey (Holt & Lawton 1994; DeCesare *et al.* 2010).

1.2 Wildlife and Land Use Change

Habitat loss and fragmentation have been identified as major threats to the persistence of wildlife species globally (Fahrig 2003; Tscharntke *et al.* 2012). Habitat loss can be considered as the removal of habitat, while fragmentation can be considered as the breaking apart of habitat (Fahrig 2003). There is overwhelming evidence to suggest that habitat loss results in negative effects on the survival of many species and biodiversity overall (Schneider 2001; Schmiegelow & Mönkkönen 2002; Fahrig 2003; Tucker *et al.* 2018). However, the effects of habitat fragmentation have been less well understood and species responses may change depending on their trophic role, the spatial scale of observation, or the amount of fragmentation on the landscape (Fahrig 2003; 2017; 2019; Ryall & Fahrig 2006; Fletcher *et al.* 2018).

The boreal forest is one of the largest global ecosystems and has vast, but finite, resources imposing a tradeoff between economic growth and ecological integrity (Carlson & Browne 2015). Conserving boreal biodiversity and developing the globally relevant oil and gas industry is a major challenge and, therefore, a global conservation issue (Hebblewhite 2017). The intensity of industrial development and the presence of multiple overlapping industry sectors results in cumulative effects, the combined direct and indirect effects of human activities over time, in the boreal forest (Carlson & Browne 2015; Pickell *et al.* 2015; Johnson *et al.* 2019).

The majority of research on human induced land use change in the boreal forest has focused on large mammal responses to development (Latham *et al.* 2011c;b;a; Tigner *et al.* 2014; Dickie *et al.* 2017; DeMars & Boutin 2018; Scrafford *et al.* 2017; Toews *et al.* 2017). Considerably less research has investigated the response of birds (Bayne *et al.* 2005; Slattery *et al.* 2011; Morissette *et al.* 2019; Mahon *et al.* 2019; Roy *et al.* 2019). This lack of knowledge is particularly concerning for ducks because the boreal forest provides important breeding habitat that supports 12-15 million ducks annually (Slattery *et al.* 2011). Some research suggests that duck species in the boreal have declined in association with development features; however, the mechanisms underlying the declines are unknown (Slattery *et al.* 2011; Singer *et al.* 2020).

1.3 Nesting Ecology

Birds select habitats repeatedly throughout their life cycles at multiple spatial scales due to the mobility provided by flight and migratory behaviour (Eichholz & Elmberg 2014). Nest site selection by females is a major evolutionary driver where decisions affect the survival of their offspring (Refsnider & Janzen 2010). The first decision ducks make in selecting nesting habitat is to migrate to northern latitudes from their southern wintering range to exploit seasonal food resources, avoid predation, reduce exposure to disease and parasites, maximize day lengths, and reduce competition (Eichholz & Elmberg 2014). Females make decisions regarding nest site selection related to maximizing nest and egg survival, maximizing female survival, proximity to suitable habitat for offspring, natal philopatry, and indirect selection via mate-choice (Refsnider & Janzen 2010). The prominent driver of nest site selection related to nest survival is the avoidance of nest predation, which is the dominant source of nest mortality for avifauna (Ricklefs 1969; Refsnider & Janzen 2010). Selecting sites that avoid nest predation involve a tradeoff between concealment of the nest, while also maintaining adequate view of the surroundings to avoid predation (Götmark *et al.* 1995; Refsnider & Janzen 2010). However, in predator dense habitats, safe nest sites may not be achievable. In these systems a generalist strategy to nest site selection is driven more by other ecological factors, such as food availability (Refsnider & Janzen 2010).

For many avian species, nest success is the most influential vital rate on population dynamics and for ducks predation is the most common cause of nest failure (Sargeant *et al.* 1993; Sovada *et al.* 2001; Hoekman *et al.* 2002; Pieron & Rohwer 2010; Howerter *et al.* 2014). Research in prairie ecosystems has revealed that landscape change, such as conversion to agriculture, can alter the composition, distribution, abundance, and foraging efficiency of predators, resulting in reduced nest success for ducks (Batt *et al.* 1992; Pasitschniak-Arts & Messier 1995; Pieron & Rohwer 2010). More recently, prairie research has revealed that ducks appear to be relatively resilient to oil and gas development (Ludlow & Davis 2018; Kemink *et al.* 2019; Skaggs *et al.* 2020). However, the community of nest predators and land use and management strategies differ in the boreal forest, raising the question of how transferable knowledge is between these ecosystems. Preliminary results from Ducks Unlimited Canada's boreal research program have indicated some negative associations with industrial development for both pair abundance and productivity (i.e., brood:pair ratios; Ducks Unlimited Canada 2014; Singer *et al.* 2020). These patterns are consistent with a predation limiting hypotheses where predators exert top-down control on prey resulting in reduced prey populations (Terbough & Estes 2010). However, direct empirical data is lacking for the boreal forest in relation to what and where are important nesting areas; what habitat variables effect nest success; who are the important nest predators; and how does land use change effect predators? Answers to these questions would allow us to further test the predation limiting hypothesis and strengthen conservation planning activities. This dissertation fills these knowledge gaps and advances our understanding of boreal ducks, their predators, and the effect of industrial development on the boreal forest to improve conservation and management.

1.4 Dissertation Organization

1.4.1 Scope and Objectives

The scope of my dissertation was to understand how industrial development affects the nesting ecology of boreal ducks. The goal of my research was to understand how industrial development affects nest-site selection and nest success in the western boreal forest. Specifically, I asked:

1. What land use and land cover variables influence nest-site selection of boreal ducks (Chapters 2 and 3);
2. What land use and land cover variables influence nest survival of boreal ducks (Chapter 4);
3. What species eat duck eggs (Chapter 5), and;
4. How does land use influence duck predators (Chapter 6)?

To answer my research questions, we located waterfowl nests and identified predator species across a gradient of industrial development. Using our empirical data in combination with existing spatial data, we produced predictive resource selection functions (RSFs) across multiple spatial scales for nest-site selection. Then, I investigated how nest-site choices influenced nest success to determine variation in habitat-demography relationships. Next, I identified nest predators and investigated predator occupancy dynamics to understand how industrial development might affect predation risk for ducks. Collectively, answering our research questions have provided new information regarding boreal waterfowl ecology that will help guide and support recommendations for conservation policy related to waterfowl management, industrial development, the restoration of developed land (e.g., linear features), and habitat conservation.

1.4.2 Study Design Overview

Study Area

The western boreal forest (WBF) is an expansive ecosystem containing a large diversity of resources, including wildlife and energy (Carlson & Browne 2015). A quarter of Canada's boreal forest occurs in the Mackenzie river watershed and two-thirds of the watershed is intact or undisturbed (Carlson *et al.* 2007). Ecosystem services of the watershed are valued at 483 billion dollars (Carlson & Browne 2015). However, in boreal Alberta, only 38% of the landscape remains intact (Carlson & Browne 2015). The WBF contains one third of the world's proven oil and gas reserves and Alberta's energy industry is responsible for 25% of Canada's GDP, exporting 90% of its oil and gas production to the United States of America (Hebblewhite 2017).

Alberta's provincial policy is to maximize revenue from oil and gas production indicating that provincial support is behind further development (Hebblewhite 2017). Bitumen production has increased ten-fold over the past three decades and timber production has quadrupled in the region (Carlson & Browne 2015). Of concern, the forest industry's rapid expansion has been facilitated by oil and gas access roads, and surpassed the footprint of the oil and gas industry (Pickell *et al.* 2015; ABMI 2017; Hebblewhite 2017)(ABMI 2017, Hebblewhite 2017). The majority (81%) of Alberta's oil and gas reserves are subsurface requiring in-situ extraction techniques (i.e, steam assisted gravity drainage [SAGD]), which represents an area 50 times larger than the Fort MacMurray open pit mining area (Schneider & Dyer 2006).

Our study was located north of the town of Slave Lake, Alberta with study sites distributed to the north and east of Utikuma Lake (Figure 1.1). All sites occur in Canada's boreal plains ecozone and within Alberta's boreal forest natural region (Downing & Pettapiece 2006). Within Alberta's boreal forest natural region, the study sites occur in the dry mixedwood and the central mixedwood natural subregions (Downing & Pettapiece 2006). The region's climate is characterized by short summers with long and cold winters. There is typically only one or two months of the year where the mean daily temperature exceeds 15°C and it falls well below -10°C for at least four months during the winter (Downing & Pettapiece 2006). From 1971 - 2000, the region received approximately 470 mm of precipitation annually, with 70% falling between April and August with the peak occurring in July (Downing & Pettapiece 2006).

The boreal landscape is a combination of deciduous, mixed wood, and coniferous forests interspersed by extensive wetland complexes and industrial development (Downing & Pettapiece 2006). Historically, land cover has been shaped by natural disturbance events, such as insect outbreaks and wildfire. Dominant tree species include trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), and jack pine (*Pinus banksiana*). The main wetland types are black spruce, shrub, or sedge fens. Luvisol soils dominate upland habitats, while mesisols are most common in the wetlands (Downing & Pettapiece 2006). Presently, land cover types have been dramatically changed by not only historical natural drivers (i.e., forest fires), but by increasing pressure from industrial development related to oil and gas exploration and extraction and forestry (Dawe *et al.* 2014; Carlson & Browne 2015; Pickell *et al.* 2015). Industrial development has resulted in the creation of high density linear features (e.g., seismic lines, roads, pipelines) and large block features (e.g., well pads, pumping stations, mines) that did not exist traditionally on the landscape (Pickell *et al.* 2015).

To specifically select study sites, we used a hierarchy of criteria related to project objectives. We considered development intensity, duck density, and accessibility. Additionally, we consider habitat type and exclude recently burned or logged areas to control for their confounding effects. Development intensity and duck density layers used for study site selection were provided and developed by Ducks Unlimited Canada (Barker *et al.* 2014; Ducks Unlimited Canada 2014). Overall, selected sites have the highest probability of encountering duck nests and occur across a gradient of development. I used QGIS and R to select sites with layers developed and provided by Ducks Unlimited Canada (DUC), Altalis, Alberta Environment and Parks (AEP), and the Alberta Biodiversity Monitoring Institute (ABMI).

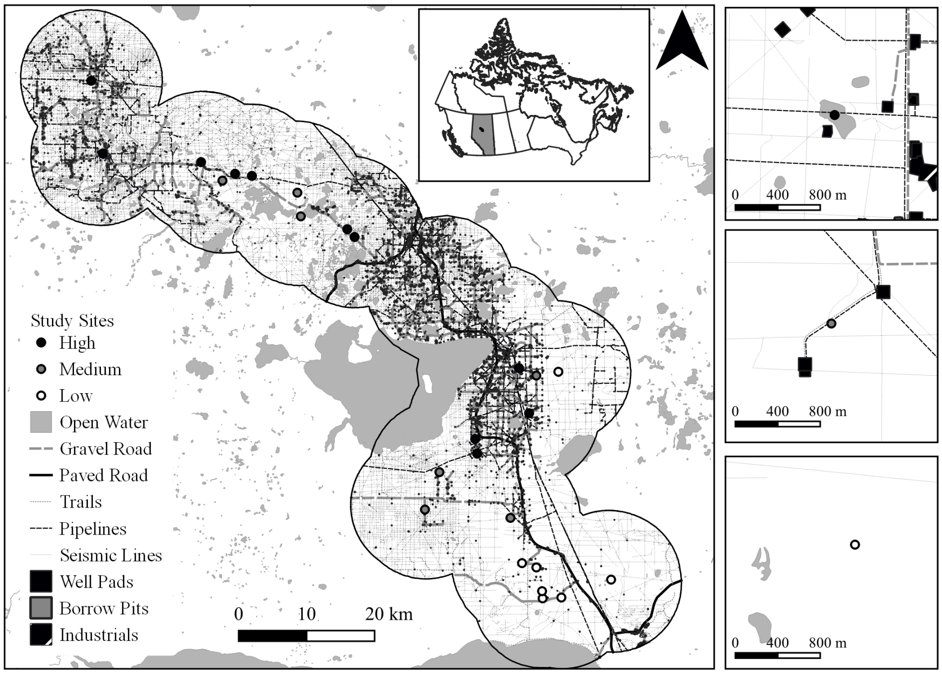

Figure 1.1: Map of the study area near Utikuma Lake, Alberta showing study sites categorized by development intensity. Study extent was produced by buffering all study sites and nest locations by 10 km. Inlay highlights the province of Alberta and a polygon representing the study extent relative to Canada. Panels to the right offer a finer scale example of a high development site (top), medium development site (middle), and low development site (bottom).

Field Sampling

Locating ducks nests in the boreal forest is challenging because of low nest densities and remote, often inaccessible, nesting habitats. Therefore, we used a combination of nest searching for real nests and the placement of artificial nests across the nesting period over multiple nesting seasons (2016-2018) (Klett *et al.* 1986; Gunnarsson & Elmberg 2008). We nest searched on foot by systematically searching around wetland bodies located at study sites (Klett *et al.* 1986). When a nest was found we collected relevant data and monitored it to determine its fate. We also collected fine scale habitat data at all nests and a paired random location following hatch date, including vegetation species identification and cover characteristics to assess microhabitat preferences. For macrohabitat features of each nest we used remote sensing data. To identify predators and understand the effect of development on predator communities we used camera traps (Burton *et al.* 2015; Steenweg *et al.* 2017). We installed camera traps on a subsample of real and artificial nests to identify important nest predators. We also installed camera traps at study sites over the duration of the nesting season to detect terrestrial predators use across the gradient of development. To maximize our probability of detection for terrestrial predators, we combined camera traps with scent lure.

All of the field work conducted for this dissertation was reviewed and approved under the auspices of University of Waterloo Animal Use Protocols (16-04, 17-03), a Canadian Wildlife Service Scientific Research Permit (16-AB-SC004), a Canadian Wildlife Service Migratory Bird Banding Permit (0077AR), and Alberta Environment and Parks Wildlife Research and Collection permits (55236, 55237, 56909, 56910, 18-419). Copies can be found in Appendix C and further detail is available upon request (e.g., standard operating procedures, project outlines). Details regarding our approach are provided in each chapter.

Chapter 2

Microhabitat nest-site selection by ducks in the boreal forest

2.1 Overview

The boreal forest is one of North Americas most important breeding areas for ducks, but information about the nesting ecology of ducks in the region is limited. We collected microhabitat data related to vegetation structure and composition at 157 duck nests and paired random locations in Alberta's boreal forest region from 2016 to 2018. We identified fine-scale vegetation features selected by ducks for all nests, between nesting guilds, and among five species using conditional logistic regression. Ducks in the boreal forest selected nest sites with greater overhead and graminoid cover, but less forb cover than random sites. Characteristics of the nest sites of upland- and overwater-nesting guilds differed, with species nesting in upland habitat selecting nests that provided greater shrub cover and less lateral concealment and species nesting over water selecting nests with less shrub cover.

We examined the characteristics of nest sites of American Wigeon (*Mareca americana*), Blue-winged Teal (*Spatula discors*), Green-winged Teal (*Anas crecca*), Mallards (*Anas platyrhynchos*), and Ring-necked Ducks (*Aythya collaris*), and found differences among species that may facilitate species coexistence at a regional scale. Our results suggest that females of species nesting in upland habitat selected nest sites that optimized concealment from aerial predators while also allowing detection of and escape from terrestrial predators. Consequently, alteration in the composition and heterogeneity of vegetation and predator communities caused by climate change and industrial development in the boreal forest of Canada may affect the nest-site selection strategies of boreal ducks.

2.2 Introduction

The selection of a nest site is one of the most important choices a bird makes and is preceded by decisions at large spatial scales, but ultimately influenced by fine-scale microhabitat characteristics, such as vegetation structure and composition that provide concealment (Johnson 1980; Jones 2001; Eichholz & Elmberg 2014). Nest concealment can reduce the risk of predation for eggs and incubating adults (Martin 1993; Borgmann & Conway 2015). For ground-nesting birds, selecting a nest site is more complex than simply maximizing concealment because of the risk of predation for incubating adults, likely resulting in a tradeoff between nest concealment and predator detection (Wiebe & Martin 1998; Devries *et al.* 2003; Amat & Masero 2004; Miller *et al.* 2007; Fedy & Martin 2011). Therefore, nest-site selection represents a strategy of balancing current (i.e., concealment of eggs) and future (i.e., escaping predation) reproductive success (Lima & Dill 1990; Götmark *et al.* 1995; Martin 1998).

The boreal forest is the second most productive breeding area for ducks in North America and may serve as an important refuge for prairie waterfowl in dry years due to the abundance of permanent wetlands (Derksen & Eldridge 1980; Batt *et al.* 1992; Slattery *et al.* 2011). However, little is known about the nesting ecology of ducks in the boreal forest (Petrula 1994; Walker & Lindberg 2005; Slattery *et al.* 2011). Variation in nest-site selection among species is driven by habitat availability, weather and climate patterns, and predation pressure (Batt *et al.* 1992). All of these variables are different in the boreal forest compared to the prairies (i.e., Prairie Pothole Region and the Canadian Prairie-Parklands), where most studies of North American ducks have been conducted (Keith 1961; Greenwood *et al.* 1995; Drever *et al.* 2012; Baldassarre 2014). The importance of the boreal forest for breeding ducks is likely to increase under most climate-change scenarios that predict distributional shifts north for many species of birds with increasingly warm and dry prairie climates (Drever *et al.* 2012; Cumming *et al.* 2014; Stralberg *et al.* 2015; Zhao *et al.* 2019). As such, additional studies are needed to improve our understanding of the nesting ecology of boreal ducks.

Our objectives, therefore, were to quantify microhabitat nest-site selection by different nesting guilds and five species of ducks in the boreal forest. We predicted a tradeoff between overhead and lateral cover because adults and their eggs are both at risk of predation during incubation. We also predicted that if resource partitioning facilitates coexistence of boreal nesting ducks (Schoener 1974; Rosenzweig 1981; Nudds 1983), we would detect differences in nest-site selection between nesting guilds (upland or overwater nesters) and among species.

2.3 Methods

Our study was conducted north of Slave Lake, Alberta, Canada, near Utikuma Lake in Canada's boreal plains ecozone and Alberta's boreal forest natural region (Fig. 2.1; Downing & Pettapiece 2006). Specifically, our study area included the dry mixedwood and central mixedwood natural subregions of Alberta. The landscape is a mosaic of deciduous, mixed wood, and coniferous forests interspersed with extensive wetland complexes and industrial development (Downing & Pettapiece 2006). Historically, land cover has been shaped by natural disturbance events, such as insect outbreaks and wildfire (Carlson & Browne 2015). Dominant tree species included trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), and jack pine (*Pinus banksiana*). The main wetland types were black spruce, shrub, or sedge fens (Downing & Pettapiece 2006).

We selected sites for nest searching using a hierarchical selection criteria based on spatial layers provided by Ducks Unlimited Canada, the Alberta Government, and the Alberta Biodiversity Monitoring Institute. We considered cumulative energy development, duck density, accessibility, land cover type, and excluded recently burned or logged areas (within 20 years). We selected sites that were representative of the gradient of industrial development density on the landscape, had predicted duck densities greater than the median for the region (4 pairs/2.5 km^2; Ducks Unlimited Canada 2014), were accessible (i.e., within $\approx$3 km of a road or trail), and contained at least one water body ($>$1 ha).

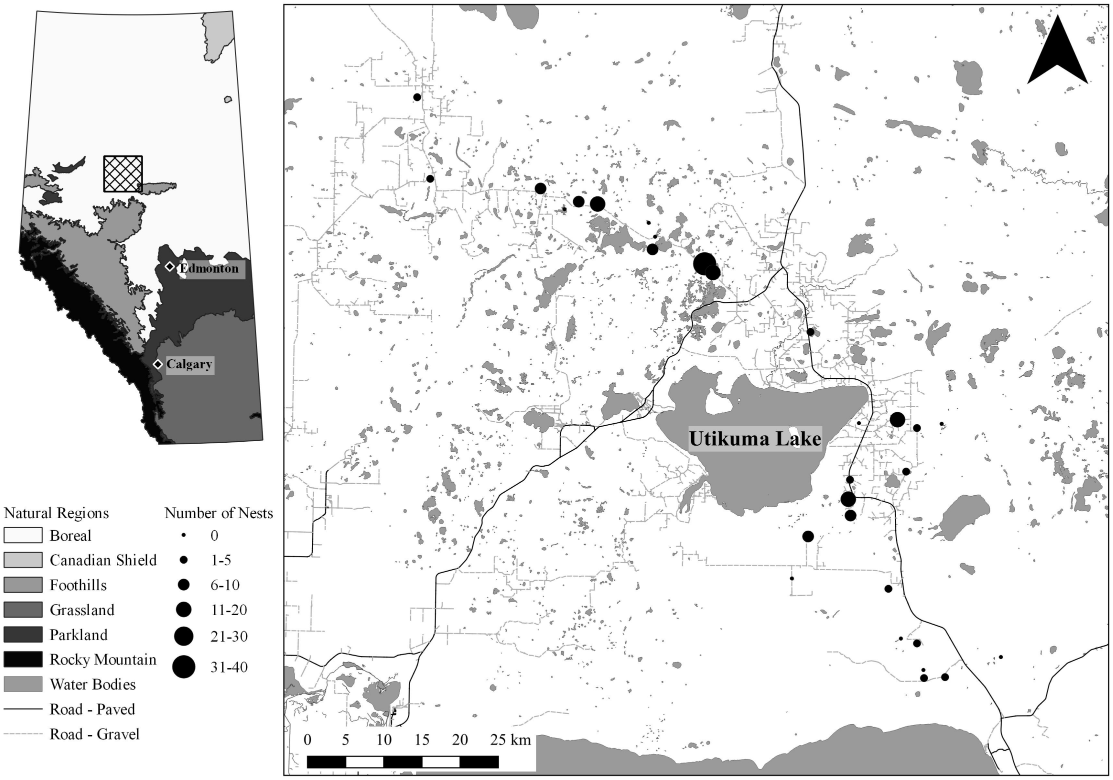

Figure 2.1: Locations of study sites and the number of nests found at each site indicated by point size for ducks nesting in boreal forest near Utikuma Lake, Alberta, Canada. Inlay displays the location of the study area in the boreal forest relative to the province of Alberta, Canada.

2.3.1 Field Methods

We searched 16 sites in 2016, 24 sites in 2017, and 25 sites in 2018. We searched most sites in subsequent years, with the exception of one site that was only searched in 2016 and one site searched in 2016 and 2018. We completed two searches of each site in 2016, two to three searches of each site in 2017, and three searches of each site in 2018 between 10 May and 31 July. Search efforts were separated by 15 to 25 days and were conducted on foot using a 'willow switch' (i.e. ≈1.2 m willow branch) to disturb vegetation and increase the probability of disturbing an incubating female (Klett *et al.* 1986). Nest-searching efforts involved 3 to 6 searchers walking abreast around wetlands ≈5 – 20 m apart and parallel to the shore. We estimated site size by buffering GPS search tracks by 20 m, dissolving the buffers together, and calculating an area, which resulted in sites with a mean size of 27.46 +/− 12.15 (SD) ha. We searched for nests between 08:00 and 16:00 (Gloutney *et al.* 1993). In 2018, as part of a concurrent pilot study, we also located three Mallard nests using radio-telemetry.

At each nest, we identified the duck species, recorded the number of eggs, and estimated the stage of incubation by candling and floating eggs (Weller 1956). We estimated nest-initiation date by subtracting the estimated incubation stage and assuming an interval of one egg laid per day plus one skipped laying day from the day the nest was found (e.g., date found - incubation stage - clutch size - 1; Batt *et al.* 1992; Emery *et al.* 2005). We sampled nest-site vegetation at all nests and paired random locations on the same day once the fate of nests was determined in 2016 and within 5 d of estimated hatch date in 2017 and 2018 to control for temporal variation in vegetation measurements (Gibson *et al.* 2016; McConnell *et al.* 2017; Ringelman & Skaggs 2019).

We recorded a complete plant species inventory and estimated mean height and percent canopy cover of each species present within a 1 m radius of the nest bowl. Overhead cover centered over the nest bowl was estimated using a 12.5 x 12.5 cm square grid with individual 2.5 x 2.5 cm squares. We estimated the percent cover of each individual square from 120 cm above the nest bowl (Guyn & Clark 1997; Borgo & Conover 2016). We summarized overhead cover by calculating the mean of all estimated cells (25) from the cover grid. We measured lateral cover (i.e., visual obstruction) with a Robel pole that was 120 cm high and marked with alternating black and white bands by decimeter (Robel *et al.* 1970; Nudds 1977; Traylor *et al.* 2004). We summarized lateral cover by scoring each observation as the number of consecutive bands 100% occluded, starting from the bottom of the pole, then calculated the mean of the scores for each plot. In 2016, we estimated percent cover of each band from 1 m from the nest bowl with the observer's eyes level with the top of the pole at 0 and from a random bearing. In 2017 and 2018, we estimated lateral cover at 1 m from each cardinal direction. We identified random locations by generating a random compass bearing (0 – 360) and distance from a nest (2 – 40 m). We chose our confined random distance range to ensure no overlap with the nest site and to keep the random location within a relatively similar habitat classification.

2.3.2 Data Analysis

We evaluated microhabitat nest-site selection by comparing nest sites with paired random locations using conditional logistic regression, where the nest was the grouping variable (Johnson 1980; Hosmer & Lemeshow 2000; Compton *et al.* 2002; Thomas & Taylor 2006). We summarized data on vegetation structure and composition at nests and random sites prior to analysis (Table 2.1). We pooled plant species into functional groups, including graminoids (e.g., grasses, sedges, and rushes), forbs (e.g., herbaceous plants), and shrubs (e.g., shrubs, trees, and woody plants) A, to assess the influence of plant composition (Blondel 2003). We summed the percent cover for species in each group to calculate proportional cover and extracted the mean height of all species among groups for the vegetation height variable (Table 2.1). The sum of proportional cover for groups could exceed 100% when pooled because we estimated species cover in three-dimensional space (i.e., canopy cover). In 2016, we did not collect vegetation height data for early nest attempts (N = 15), so we used the mean value to replace the missing data to retain mean vegetation height as a predictor. As a result, models with vegetation height as a top predictor have corresponding deflated confidence intervals.

We quantified microhabitat nest-site selection at three levels, including 1) all species, 2) nesting guild (upland or overwater nesters), and 3) individual species. We grouped species by guilds consistent with past research from the region (Ducks Unlimited Canada 2014). We standardized all predictor variables prior to analysis (subtracted mean and divided by standard deviation), resulting in the mean for each predictor equalling 0 and the standard deviation equalling 1.

We ran all possible model combinations for all species, guilds, and individual species. To control for multicollinearity, we assessed correlation among all predictor variables and excluded highly correlated predictors (Pearson's r |0.65|) from occurring together in the same model (i.e., treated them as competing models; Doherty *et al.* 2012). We ranked competing models using Akaike's Information Criterion adjusted for small sample sizes (AICc) and selected the top-ranked model with the lowest AICc score (Burnham & Anderson 2002). We removed nested subsets of the top model that contained uninformative parameters from our model sets and present competing models within 4 AICc scores of the top model (Arnold 2010). We did not build species-specific models for species with fewer than 15 nest observations. Marginal effects plots are useful for visualization of model predicted covariates, but developing these plots within a conditional logistic regression framework is not possible. Therefore, to visualize key variables in our top models, we also developed logistic regression models and used them to generate plots. In all cases, we confirmed that coefficient estimates were within confidence intervals of conditional logistic models prior to presenting effects plots. We performed all analyses in program R (version 3.3.2) and used the clogit function from package 'survival' (Therneau 2015).

Table 2.1: Summary (mean (SD)) of microhabitat vegetation measurements at nests and random locations for all species, guilds, and individual species from 2016 to 2018 in the boreal forest of Alberta, Canada.

Species[a]	Plot	Overhead (%)	Lateral	Height (cm)	Graminoid (%)	Forb (%)	Shrub (%)
All	Nest	46.9 (32.7)	2.1 (1.8)	99.9 (71.3)	50.4 (35.6)	22.1 (24.0)	48.7 (48.7)
	Random	29.7 (29.4)	1.8 (1.8)	100.5 (60.2)	39.3 (37.1)	27.3 (30.2)	42.1 (45.8)
Upland	Nest	46.6 (33.6)	1.8 (1.7)	105.8 (77.6)	47.1 (36.2)	21.6 (24.1)	56.2 (49.1)
	Random	30.2 (30.0)	1.7 (1.8)	104.2 (60.3)	40.6 (37.4)	26.4 (30.2)	41.2 (43.5)
Overwater	Nest	48.3 (29.5)	3.2 (1.9)	78.6 (34.1)	63.9 (30.2)	24.4 (23.5)	18.3 (32.8)
	Random	27.8 (26.8)	2.1 (1.9)	87.4 (59.0)	34.0 (35.8)	30.7 (30.2)	45.6 (55.0)
AMWI	Nest	62.1 (35.7)	2.0 (1.6)	126.5 (61.3)	35.5 (33.9)	29.4 (29.8)	76.7 (52.2)
	Random	42.3 (27.2)	1.1 (1.4)	98.4 (59.5)	39.7 (37.4)	46.6 (39.1)	40.0 (43.8)
BWTE	Nest	32.7 (21.8)	1.1 (0.9)	75.6 (35.3)	65.9 (29.2)	16.3 (17.2)	28.6 (29.8)
	Random	25.5 (28.1)	1.5 (1.7)	94.4 (53.8)	47.0 (38.2)	23.2 (27.2)	34.2 (37.4)
CANV	Nest	0 (NA)	4.0 (NA)	190 (NA)	10 (NA)	0 (NA)	75 (NA)
	Random	70.8 (NA)	2.5 (NA)	210 (NA)	0 (NA)	5 (NA)	130 (NA)
GWTE	Nest	61.2 (37.5)	1.9 (1.5)	135.0 (69.9)	36.3 (31.7)	35.7 (26.2)	75.2 (45.9)
	Random	29.9 (36.5)	1.3 (2.0)	97.7 (57.2)	49.5 (38.3)	29.3 (31.3)	35.8 (38.9)
LESC	Nest	53.3 (42.3)	3.9 (2.2)	77.7 (41.3)	26.9 (31.8)	15.0 (17.9)	67.2 (49.3)
	Random	40.0 (27.4)	2.2 (2.3)	143.9 (61.2)	37.2 (42.8)	14.1 (18.9)	46.6 (43.3)
MALL	Nest	53.7 (37.3)	2.4 (2.2)	146.3 (121.8)	29.3 (34.8)	20.8 (28.2)	81.1 (53.6)
	Random	28.5 (31.9)	2.2 (2.0)	114.0 (70.7)	29.1 (34.1)	22.7 (29.4)	50.9 (52.9)
NSHO	Nest	30.2 (34.2)	1.1 (0.9)	120 (NA)	105.0 (21.2)	28.8 (33.6)	12.5 (10.6)
	Random	47.8 (14.7)	2.0 (0.0)	30 (NA)	20.0 (14.1)	38.8 (26.5)	91.3 (30.1)
RNDU	Nest	49.9 (28.6)	3.2 (1.9)	74.9 (27.6)	65.7 (28.9)	25.2 (23.5)	16.4 (31.6)
	Random	26.3 (26.0)	2.1 (1.9)	83.3 (55.4)	35.1 (35.9)	31.6 (30.4)	42.8 (53.6)

[a] AMWI= American Wigeon, BWTE=Blue-winged Teal, CANV=Canvasback, GWTE= Green-winged Teal, LESC=Lesser Scaup, MALL=Mallard, NSHO=Northern Shoveler, RNDU=Ring-necked Duck

2.4 Results

We located 167 nests from 2016 to 2018 and collected vegetation data at 157 nests and paired random sites (Table 2.1, Fig. 2.1). We located 126 nests of upland-nesting species, including 16 American Wigeon (*Mareca americana*), 52 Blue-winged Teal (*Spatula discors*), 15 Green-winged Teal (*Anas crecca*), eight Lesser Scaup (*Aythya affinis*), 33 Mallard (*Anas platyrhynchos*), and two Northern Shoveler (*Anas clypeata*) nests (Table 2.1). We also located 31 nests of overwater-nesting species, including one Canvasback (*Aythya valisineria*) nest and 30 Ring-necked Duck (*Aytha collaris*) nests (Table 2.1).

Our best model that predicted the microhabitat of ducks in our study included overhead, forb, and graminoid cover (Table 2.2, Fig. 2.2). Ducks in the boreal forest selected nest sites with greater overhead (β = 0.65, 85% CI = 0.44 – 0.86) and graminoid cover (β = 0.47, 85% CI = 0.22 – 0.73), but less forb cover (β = -0.38, 85% CI = -0.66 – -0.01) compared to paired random sites (Table 2.2, Figs. 2.2 and 2.3). Upland nesting ducks selected nest sites with greater overhead (β = 0.54, 85% CI = 0.29 – 0.80), graminoid (β = 0.46, 85% CI = 0.14 – 0.77), and shrub cover (β = 0.44, 85% CI = 0.15 – 0.74), but less lateral concealment (β = -0.28, 85% CI = -0.54 – -0.02) and forb cover (β = -0.33, 85% CI = -0.65 – -0.01) (Figs. 2.2 and 2.3). For species nesting over water, the top model included overhead, forb, and shrub cover (Fig. 2.2). Ducks nesting over water selected nest sites with greater overhead (β = 2.47, 85% CI = 0.82 – 4.12) and less forb (β = -1.69, 85% CI = -2.98 – -0.40) and shrub (β = -3.47, 85% CI = -6.13 – -0.81) cover (Table 2.2, Figs. 2.2 and 2.3).

Table 2.2: Model sets for nest-site selection by ducks in boreal forest and by nesting guild in Alberta, Canada, from 2016 to 2018. Model sets represent the competing models within 4 AICc scores of the top model from all possible model combinations.

Model	K	LL	ΔAICc[a]	ωi
All				
Overhead + Forb + Graminoid	3	-89.24	0	0.73
Overhead + Graminoid	2	-91.29	2.02	0.27
Upland				
Overhead + Forb + Graminoid + Shrub + Lateral	5	-72.49	0	0.22
Overhead + Graminoid + Shrub + Lateral	4	-73.7	0.25	0.2
Overhead + Forb + Graminoid + Shrub	4	-73.8	0.43	0.18
Overhead + Graminoid + Shrub	3	-75.01	0.72	0.16
Overhead + Forb + Graminoid	3	-75.54	1.78	0.09
Overhead + Forb	2	-76.62	1.86	0.09
Overhead + Graminoid	2	-77.05	2.71	0.06
Overwater				
Overhead + Forb + Shrub	3	-9.19	0	0.4
Overhead + Graminoid + Shrub	3	-9.49	0.6	0.3
Overhead + Graminoid	2	-10.95	1.05	0.24
Graminoid	1	-13.43	3.72	0.06

[a] Lowest AICc score for all species: 184.64, upland: 155.49, and overwater: 25.27.

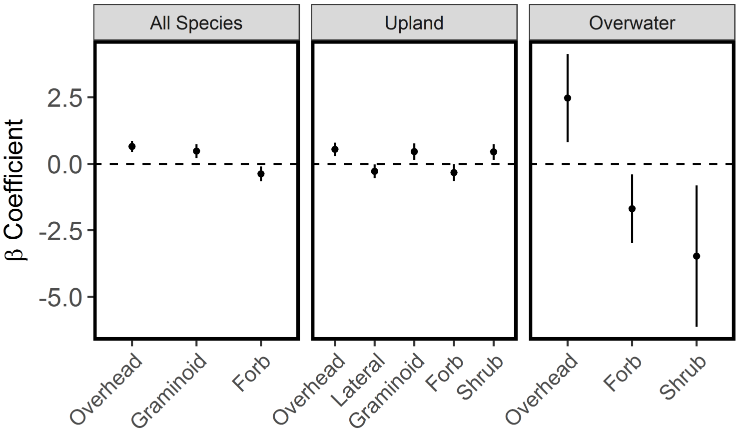

Figure 2.2: Coefficient plot for top-ranked microhabitat nest-site selection models for all species and upland and overwater nesting guilds in the boreal forest, Alberta, Canada, from 2016 to 2018. Error bars represent 85% confidence intervals.

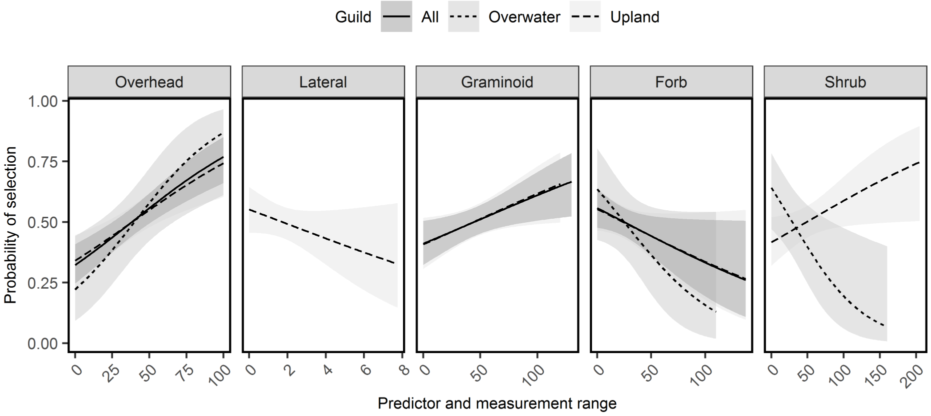

Figure 2.3: Effects plots for microhabitat nest-site selection by all ducks and guilds in the boreal forest in Alberta, Canada from 2016 to 2018. Plots compare and contrast the response of duck species to their respective important predictor variables. Shaded areas represent 85% confidence intervals.

Microhabitat nest-site characteristics also varied among species (Table 2.3, Figs. 2.4 and 2.5). American Wigeon selected nest-sites with greater shrub cover (β = 1.82, 85% CI = 0.23 – 3.41). Blue-winged Teal selected greater overhead (β = 0.74, 85% CI = 0.27 – 1.21) and graminoid (β = 0.71, 85% CI = 0.18 – 1.25) cover, but less lateral concealment (β = -1.02, 85% CI = -1.59 – -0.45), shorter vegetation (β = -0.54, 85% CI = -1.00 – -0.08), and forb cover (β = -1.09, 85% CI = -1.83 – -0.34). Green-winged Teal selected nest-sites with greater overhead cover (β = -1.70, 85% CI = 0.21 – 3.19) and taller vegetation (β = 3.67, 85% CI = 0.76 – 6.59). Mallards selected overhead (β = 1.03, 85% CI = 0.29 – 1.78) and shrub cover (β = 0.80, 85% CI = 0.12 – 1.48). Finally, Ring-necked Ducks selected nest-sites with greater overhead cover (β = 4.38, 85% CI = 1.27 – 7.50), but less forb (β = -2.21, 85% CI = -3.70 – -0.72) and shrub cover (β = -4.43, 85% CI = -8.02 – -0.84).

Table 2.3: Model sets for nest-site selection by ducks in boreal forests in Alberta, Canada, from 2016 to 2018. Model sets represent competing models within 4 AICc scores of the top-ranked model from all possible model combinations.

Model	K	LL	ΔAICc[a]	ωi
American Wigeon				
Forb + Graminoid + Shrub	3	-3.68	0	0.49
Forb + Shrub	2	-5.65	0.85	0.32
Shrub	1	-7.51	1.95	0.19
Blue-winged Teal				
Height + Overhead + Forb + Graminoid + Lateral	5	-21.96	0	0.41
Overhead + Forb + Graminoid + Lateral	4	-23.59	0.81	0.27
Height + Overhead + Forb + Lateral	4	-24.08	1.79	0.17
Forb + Graminoid + Lateral	3	-26	3.29	0.08
Overhead + Graminoid + Lateral	3	-26.12	3.53	0.07
Green-winged Teal				
Height + Overhead	2	-4.34	0	0.64
Shrub	1	-7.16	2.95	0.15
Height + Lateral	2	-6	3.33	0.12
Height	1	-7.62	3.87	0.09
Mallard				
Overhead + Shrub	2	-15.66	0	0.57
Overhead	1	-17.32	1.04	0.34
Shrub	1	-18.61	3.62	0.09
Ring-necked Duck				
Overhead + Forb + Shrub	3	-6.41	0	0.71
Overhead + Graminoid	2	-8.57	1.83	0.29

[a] Lowest AICc score for American Wigeon = 15.36, Blue-winged Teal = 55.22, Green-winged Teal = 13.68, Mallard = 35.73, and Ring-necked Duck = 19.75.

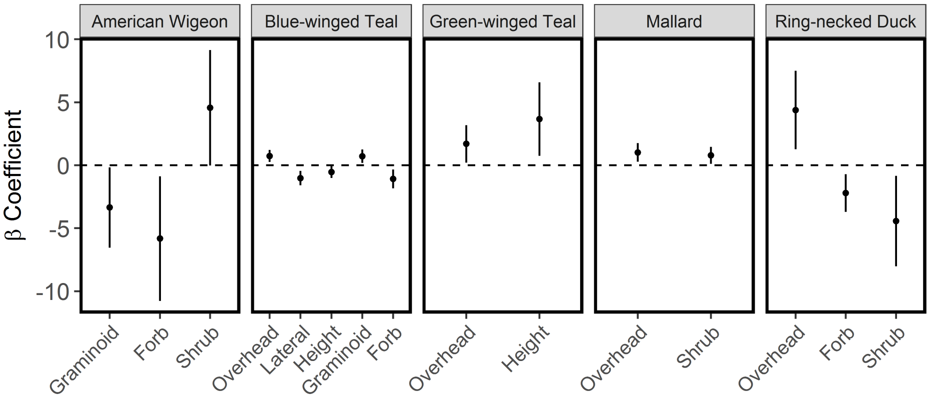

Figure 2.4: Coefficient plots for the top-ranked microhabitat nest-site selection models for duck species in the boreal forest, Alberta, Canada, from 2016 to 2018. Error bars represent 85% confidence intervals.

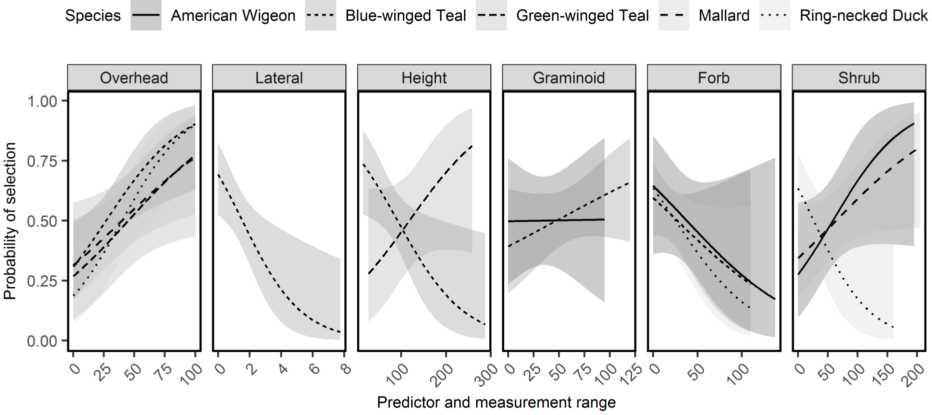

Figure 2.5: Effects plots for microhabitat nest-site selection models for duck species in the boreal forest in Alberta, Canada, from 2016 to 2018. Plots compare and contrast the response of boreal duck species to their respective important predictor variables. Shaded areas represent 85% confidence intervals.

2.5 Discussion

Our results suggest that female ducks nesting in upland habitat selected nest sites that balanced nest concealment from aerial predators with the need to detect approaching terrestrial predators (Götmark *et al.* 1995). Our hierarchical approach of modelling all species, guilds, and individual species provided insights into shifts in selection across these levels of organization. Variation in microhabitat nest-site characteristics between nesting guilds and species in our study is consistent with a strategy to maximize space differentiation between coexisting species through resource partitioning (Lack 1945; Schoener 1974; Nudds 1983; Martin 1996; Marini 1997).

Ducks in our study selected overhead nest concealment across guilds, which is common across many species of birds and likely related to avoiding avian predators (Guyn & Clark 1997; Clark & Shutler 1999; Traylor *et al.* 2004; Dassow *et al.* 2012; Borgo & Conover 2016). Avian predators of both adults and eggs are common in our study region, e.g., Common Ravens (*Corvus corax*), Red-tailed Hawks (*Buteo jamaicensus*), and Great Horned Owls (*Bubo virginianus*) (M. Dyson, pers. obs.). Overhead cover provides visual obstruction from avian predators and likely provides a favorable microclimate for eggs and incubating adults (e.g., protection from sunlight, precipitation, and wind) (Gloutney & Clark 1997; Fogarty *et al.* 2017). Consistent selection across species and guilds for overhead cover suggests this feature may represent an adaptive peak (Latif *et al.* 2012), which could make it difficult to detect an effect of this variable on survival.

Prairie-nesting ducks generally select nest sites with greater lateral cover (Lokemoen *et al.* 1984; Eichholz & Elmberg 2014; Borgo & Conover 2016), but upland species in the boreal forest in our study selected nest sites with less lateral concealment. Although this relationship was primarily driven by Blue-winged Teal, we did not detect selection for lateral cover by our other focal species. These differences may be driven, in part, by different predator communities. Red foxes (*Vulpes vulpes*) are one of the most common predators of duck nests on the prairies, along with increasing numbers of striped skunks (*Mephitis mephitis*) and raccoons (*Procyon lotor*) (Klett *et al.* 1988; Ransom *et al.* 2001; Sovada *et al.* 2001). Olfactory foraging is likely more profitable in landscapes where ducks nest at higher densities (Nams 1997; Larivière & Messier 1998; Ringelman 2014). As such, selecting nest sites with lateral concealment on the prairies may help dissipate scent more effectively and reduce the likelihood of nests being located by olfactory predators (Fogarty *et al.* 2017; 2018; Shutler 2019). Boreal forest predators (e.g., black bear, Canada lynx, and *Mustela* spp.; Chapter 5) may use different foraging strategies or encounter nests opportunistically, which may favor random placement of nests with respect to lateral cover and is more consistent with our observations. Given our paired study design, we are confident that lateral cover is available to ducks (i.e., the resource is present for animals to select). The lower nest densities and different predator communities of the boreal forest may change the associated predation risk to eggs and incubating adults, resulting in different strategies of nest-site selection.

Patterns of nest-site selection by our focal species were generally consistent with observations from the prairies (Klett *et al.* 1988; Higgins *et al.* 1992; Greenwood *et al.* 1995; Baldassarre 2014). Nest sites of American Wigeon have been found to be associated with greater concealment and distances from wetlands in upland habitats (Higgins *et al.* 1992; Kruse & Bowen 1996; Baldassarre 2014) and we observed selection for greater shrub cover at nests. Nest sites of Blue-winged Teal in our study had greater graminoid cover (Glover 1956; Keith 1961; Higgins *et al.* 1992), shorter vegetation, and less lateral concealment, which is consistent with patterns observed in prairie habitat (Livezey 1981; Borgo & Conover 2016). Microhabitat nest-site data for Green-winged Teal are limited, but nests are generally well concealed (Keith 1961; Higgins *et al.* 1992; Baldassarre 2014), and we observed selection for nest sites with overhead cover and tall vegetation. Mallards are considered habitat generalists and select nest sites with overhead and woody cover (Cowardin *et al.* 1985; Hoekman *et al.* 2006; Baldassarre 2014), which is consistent with our results. Finally, nest sites of Ring-necked Ducks are typically associated with open cover and graminoid hummocks/mats or floating vegetation because they nest over water (Maxson & Riggs 1996; Koons & Rotella 2003; Baldassarre 2014), which is consistent with our observation that they avoid shrub and forb cover, but select nest sites with overhead concealment.

The results of previous studies suggest that forb cover is important for ducks nesting in prairies (Higgins *et al.* 1992; Eichholz & Elmberg 2014), but our results suggest that boreal ducks generally selected nest sites with less forb cover. Ducks in our study may have selected shrubs or graminoid cover (including standing dead) early in the season because of the structure it provides. The phenology of forbs may preclude them from being selected by ducks nesting earlier in the spring because many forbs are not fully grown until late spring when most ducks have already selected nest sites in the boreal forest region.

Variation in microhabitat selection strategies among species in our study likely represents a broad niche space that may help limit predation and facilitate species diversity of ducks in the boreal forest region (Schoener 1974; Ricklefs 1989; Martin 1996; Marini 1997). Nest-site selection strategies across duck species have been proposed to occur along a continuum of cover (Safine & Lindberg 2008). In addition, variation in nest placement strategies between regionally coexisting species may hinder development of visual or olfactory search images by predators (Chalfoun & Martin 2009). This variation is consistent with the potential-prey-site hypothesis, where individuals place nests in heterogeneous habitat with numerous potential nest locations to reduce the foraging efficiency of predators (Martin 1993; Chalfoun & Martin 2009). Considering the low density of duck nests in the boreal forest, this hypothesis deserves further study relative to the nesting strategies of boreal ducks.

We focused on patterns of nest-site selection to identify microhabitat characteristics important for ducks in the boreal forest. Our study design allowed us to develop predictive models that quantified selection relative to the availability of nest sites. This provides information that is otherwise not available in studies where investigators only assess habitat characteristics at nest sites either in a qualitative manner or in the context of a survival analysis. Detecting relationships between nest habitat and survival can be difficult if birds are already selecting nest sites in optimal locations (i.e., limited variation in important habitat covariates at nest sites), predation is incidental, or differences between the characteristics of nest sites are subtle (Götmark *et al.* 1995; Clark & Shutler 1999; Latif *et al.* 2012). For example, if ducks select nest sites with overhead cover (as suggested by our data), then modeling efforts to identify factors that influence survival using only known nest sites and associated habitat information may not be able to identify cover as an important covariate because of the limited variation in the covariate across nests or from a limited sample size. Investigating factors that influence survival (i.e., the process) are certainly critical to our understanding of nest-site selection (Clark & Shutler 1999; Chalfoun & Schmidt 2012), but the decision of where to nest relative to what is available should not be overlooked. We can then use our knowledge of these patterns to make predictions about adaptive responses, providing a stronger base to work from in new study systems.

The boreal forest region is currently experiencing changes caused by climate change (Drever *et al.* 2012; Cumming *et al.* 2014) and industrial development (Schneider & Dyer 2006; Slattery *et al.* 2011) that are causing functional and numerical responses in predator communities (DeMars & Boutin 2018; Fisher & Burton 2018) that could ultimately affect nest-site selection strategies by ducks. For example, novel predators (e.g., raccoons and red foxes) may infiltrate the boreal forest, resulting in increased rates of nest predation if selection strategies are not optimized for these predators (Latham 2008). Alternatively, vegetation communities changing as a result of climate change could favor alternative species assemblages of ducks based on their vegetation preferences. For example, more grasslands may develop in the boreal forest as bogs and peatlands dry out (Stralberg *et al.* 2019). Additional research is needed to address landscape-scale influences on nest-site selection and nest survival to help understand demographic consequences of industrial development on predation and predator communities. These efforts will be critical for ensuring effective conservation and management of ducks in the boreal forest.

Chapter 3

Multiscale nest-site selection of ducks in the western boreal forest of Alberta

3.1 Overview

Context – There is limited data regarding the nesting ecology of boreal ducks and their response to industrial development, despite this region being an important North American breeding area.

Objectives – Determine what land cover and industrial features influence third-order nest-site selection of boreal ducks.

Methods – We located duck nests in Alberta's western boreal forest between 2016 and 2018. We used multiscale analysis to identify how scale affects the selection of a resource using general linear models and determined what scale-optimized combination of landscape features were most important in describing where ducks nest. We spatially predicted our best model to identify important duck nesting habitat.

Results – We located 136 nests of 6 species of upland nesting ducks between 2016 and 2018. The magnitude, direction, and best spatial scale varied by resource. For land cover, ducks selected nest-sites associated with marsh at a 300 m scale. For land use variables related to industrial development, ducks responded at scales less than 1000 m; avoiding greater lengths of seismic lines (300 m) and pipelines (300 m), but selecting for nest-sites associated with borrow pits (300 m), primary roads (1000 m) and secondary roads (90 m).

Conclusions – Our predictive maps identify important duck nesting habitat in the boreal forest, which can support conservation and management decisions. We recommend conservation of marsh and associated habitats that have limited seismic line or pipeline development. Further research is necessary to understand the adaptive consequences of nest-site selection and how industrial development influences important nest predators.

3.2 Introduction

Our interpretation of how animals perceive their environment and make decisions about resource use is fundamentally linked to our decisions about spatial scales of investigation (i.e., grain and extent; Wiens 1989; Levin 1992; Boyce 2006; Doherty *et al.* 2016; McGarigal *et al.* 2016; Zeller *et al.* 2017). Scale-dependent selection of a resource by animals is often conceptualized as hierarchical orders of selection (Johnson 1980; Meyer & Thuiller 2006; Decesare *et al.* 2012). Within and across orders of selection, animal responses occur along a continuum and the optimal scale of response is species and resource specific (Meyer & Thuiller 2006; Mayor *et al.* 2007; 2009; Martin & Fahrig 2012; Boyce *et al.* 2017). Termed the functional response (Mysterud & Ims 1998), selection for a given resource will be conditional on its availability (Northrup *et al.* 2013). Critically, how we integrate our perception with the selection process of animals is an important consideration that influences our interpretation (i.e., choice of scale). Multiscale resource selection functions (MRSFs) provide an explicit framework to incorporate and understand an animal's functional response to resources across spatial scales (Laforge *et al.* 2015a; McGarigal *et al.* 2016; Bauder *et al.* 2018).

Investigation of how anthropogenic land use alters resource selection patterns by animals is of imminent conservation relevance (Fahrig 2003; Allred *et al.* 2015; Muhly *et al.* 2019). In the boreal forest, rapid growth of oil and gas development in recent decades has created habitat loss and fragmentation as a result of block (e.g., well pads, industrial facilities) and linear features (LFs; e.g., roads, pipelines, seismic lines) (Schneider & Dyer 2006; Carlson & Browne 2015; Pickell *et al.* 2015; Hebblewhite 2017; Fisher & Burton 2018). Development in these working landscapes (Stewart *et al.* 2019b) has produced a heterogeneous mosaic of natural and anthropogenic features resulting in altered species space use patterns and interactions that have benefitted some species (e.g., generalists) to the detriment of others (e.g., specialists) (Fisher & Burton 2018).

Species-specific responses to development in the boreal forest have been investigated for mammals (Latham *et al.* 2011c; Tigner *et al.* 2014; Dickie *et al.* 2017; Hebblewhite 2017; DeMars & Boutin 2018) and birds (Bayne *et al.* 2016; Shonfield & Bayne 2017; Mahon *et al.* 2019; Morissette *et al.* 2019). In general, mammalian predators (e.g., wolves [*Canis lupus*] and American black bears [*Ursus americanus*]) have benefitted from industrial development as a result of increased access to prey provided by linear features (e.g., roads, pipelines, seismic lines) (Ehlers *et al.* 2014; Tigner *et al.* 2014; Dickie *et al.* 2017; DeMars & Boutin 2018). Conversely, populations of prey species, particularly woodland caribou

(*Rangifer tarandus caribou*), have declined because fragmentation of refugia has increased spatial overlap with predators (Ehlers *et al.* 2014; Mumma *et al.* 2017; 2018; DeMars & Boutin 2018). For song birds, species associated with older, intact forests have declined in association with industrial development, while species associated with more open forests have increased (Bayne *et al.* 2016; Mahon *et al.* 2019). In addition, there is mounting evidence from the boreal forest that species-specific responses to habitat and industrial development are scale dependent (Decesare *et al.* 2012; Bayne *et al.* 2016; Toews *et al.* 2017; Mumma *et al.* 2019; Stewart *et al.* 2019b). For example, wolves, caribou, and moose (*Alces alces*), exhibited scale-dependent resource selection with varying availability in northeastern British Columbia, where selection for seismic lines for wolves tended to increase with expanding available distances (Mumma *et al.* 2019). It is critical to assess the scale dependence of species resource use patterns in response to industrial disturbance to make effective management recommendations that aim to reduce the impacts of disturbance.

Ducks (Family: Anatidae), like many other boreal avian species (Schmiegelow & Mönkkönen 2002), are migratory and rely on the boreal forest for reproduction (Barker *et al.* 2014; Adde *et al.* 2020a). Nest success plays an important role in regulating duck populations and is influenced by predation and environmental conditions (Hoekman *et al.* 2002; Coluccy *et al.* 2008; Howerter *et al.* 2014; Koons *et al.* 2014). The decision of where to nest is one of the most important choices a duck makes, because it influences the probability of hen and nest survival, access to forage during incubation, and options for brood-rearing habitat (Gibson *et al.* 2016; Dyson *et al.* 2018). Therefore, patterns of nest-site selection should represent long-term optima and provide insight into identifying important nesting habitats (Clark & Shutler 1999). There is a lack of empirical data related to the nesting ecology of boreal ducks, despite this region being the second most important breeding area on the continent (Slattery *et al.* 2011). Consequently, understanding how land cover and industrial development affect nest-site selection at various spatial scales will fill key knowledge gaps in both basic life history and conservation and management of boreal ducks.

We previously investigated microhabitat (i.e., fourth order) nest-site selection of boreal ducks, providing fundamental insights into species biology and life history (Dyson *et al.* 2019). However, nest site selection is hierarchical and conservation and management decisions are more consistent with macrohabitat characteristics (Howerter *et al.* 2008; Smith *et al.* 2020) or where ducks choose to nest relative to habitats available within their breeding home range (i.e., third order selection; sensu Johnson 1980). For example, remotely sensed landscape data typically represent macrohabitat characteristics and allow large-scale conservation planning and habitat prioritization efforts (Howerter *et al.* 2008). Importantly, the spatial scales used to quantify biologically-relevant macrohabitat variables are critically important (Stephens *et al.* 2005) and should be constrained within the corresponding selection order of inference (Laforge *et al.* 2015a; Bauder *et al.* 2018). The strongest inference and predictive ability of resource selection functions should occur when the top ranked scale of selection is identified for each variable (Fisher *et al.* 2011; Bauder *et al.* 2018). Therefore, investigating multi-scale responses of nest-site selection of boreal ducks at the third order of selection provides an opportunity to integrate scientific knowledge with management decisions, strengthening the link between research and management (Roberts *et al.* 2017).

We investigated the relationships between nest site selection of upland nesting ducks and land cover and industrial development variables within a single hierarchical order (i.e., third-order). Within the single order, we used a multi-scale (McGarigal *et al.* 2016) analysis to identify how scale affects the selection of a resource and what scale-optimized combination of landscape features were most important in describing where ducks nest. Our application of the multiscale approach to duck nest-site selection is relatively novel and provides a framework for future research on anthropogenic change on duck nesting ecology. We subsequently spatially predicted our models to identify important duck nesting habitat in the boreal forest with the goal of helping inform the conservation and management of boreal ducks.

3.3 Methods

3.3.1 Field Sampling

Our study area was located north of Slave Lake, Alberta, Canada, near Utikuma Lake in Canada's Boreal Plains ecozone and Alberta's boreal forest natural region, hereafter, the western boreal forest (WBF; Fig 3.1). The landscape is a mosaic of deciduous, mixed wood, and coniferous forests interspersed by extensive wetland complexes and industrial development. Historically, land cover has been shaped by natural disturbance events, such as insect outbreaks and wildfire (Carlson & Browne 2015). Presently, land cover types have been dramatically changed by historical natural drivers (i.e., forest fires) and increasing activity from industrial development related to forestry and oil and gas exploration and extraction (Dawe *et al.* 2014; Carlson & Browne 2015). Industrial development has resulted in the creation of high density linear features (e.g., seismic lines, roads, pipelines) and large block features (e.g., well pads, pumping stations, industrial sites) that did not exist traditionally on the landscape (Schneider & Dyer 2006; Fisher & Burton 2018).

We selected sites for nest-searching using a hierarchical selection criteria based on spatial layers provided by Ducks Unlimited Canada (DUC) and the Alberta Biodiversity Monitoring Institute (ABMI; ABMI 2017). We considered cumulative energy development, duck pair density, accessibility, land cover type. We excluded sites that were recently logged or burned (within 20 years) because we were interested in understanding effects of industrial development on ducks and wanted to control other confounding factors such as forestry. We selected sites that were representative of the gradient of industrial development density on the landscape and only considered sites with a predicted duck density greater than the median for the region (4 pairs/2.5 km^2; Barker *et al.* 2014), assuming that would result in a higher probability of locating nests. Finally, all potential sites had to be accessible (i.e., within ≈ 3 km of a vehicle accessible road) and contain at least 1 water body (> 1 ha). A more detailed description of the study area and our process of site selection can be found in (Dyson *et al.* 2019).

We searched 16 sites in 2016, 24 sites in 2017, and 25 sites in 2018 between 01 May and 31 July (Fig. 3.1). We searched most sites in subsequent years, with the exception of one site that was searched in only 2016 and one site that was searched in 2016 and 2018. We completed two searches of each site in 2016, two to three searches of each site in 2017, and three searches of each site in 2018. Search efforts were separated by 15 – 25 days and were performed on foot by teams of 3 – 6 searchers. They systematically searched around wetlands by disturbing vegetation to increase the probability of detecting an incubating female (Klett *et al.* 1986). Our target species were any upland (i.e. ground)-nesting duck. Ducks are often grouped into nesting guilds of upland, overwater, and cavity nesting species (Barker *et al.* 2014). Upland species often nest close to water in graminoid or shrub cover and include species such as Mallard (*Anas platyrhynchos*) or Blue-winged Teal (*Spatula discors*), overwater species nest on floating vegetation such as sedge or cattail mats and include species such as Canvasback (*Aythya valisineria*) or Ring-necked Duck (*Aythya collaris*), and cavity nesting species nest in trees and include Bufflehead (*Bucephala albeola*) and Common Goldeneye (*Bucephala clangula*). We estimated site size by buffering GPS search tracks by 20 m, dissolving the buffers together, and calculating an area, which resulted in sites with a mean size of 27.46 +/− 12.15 (SD) ha. We provide estimates of land cover and land use variables that occurred in our searched areas and how they were related to what was available across the study extent (Table 3.1). We searched for nests between 0800h and 1600h (Gloutney *et al.* 1993) and located an additional 3 radio-tagged Mallard nests in 2018 with VHF telemetry as part of a pilot study. Nests of marked birds were found in similar habitat to unmarked birds, so we combined them with our sample. When a nest was located, we identified the duck species, recorded the number of eggs (i.e., clutch size) and estimated the nest age by candling and floating eggs (Weller 1956; Klett *et al.* 1986; Dyson *et al.* 2019).

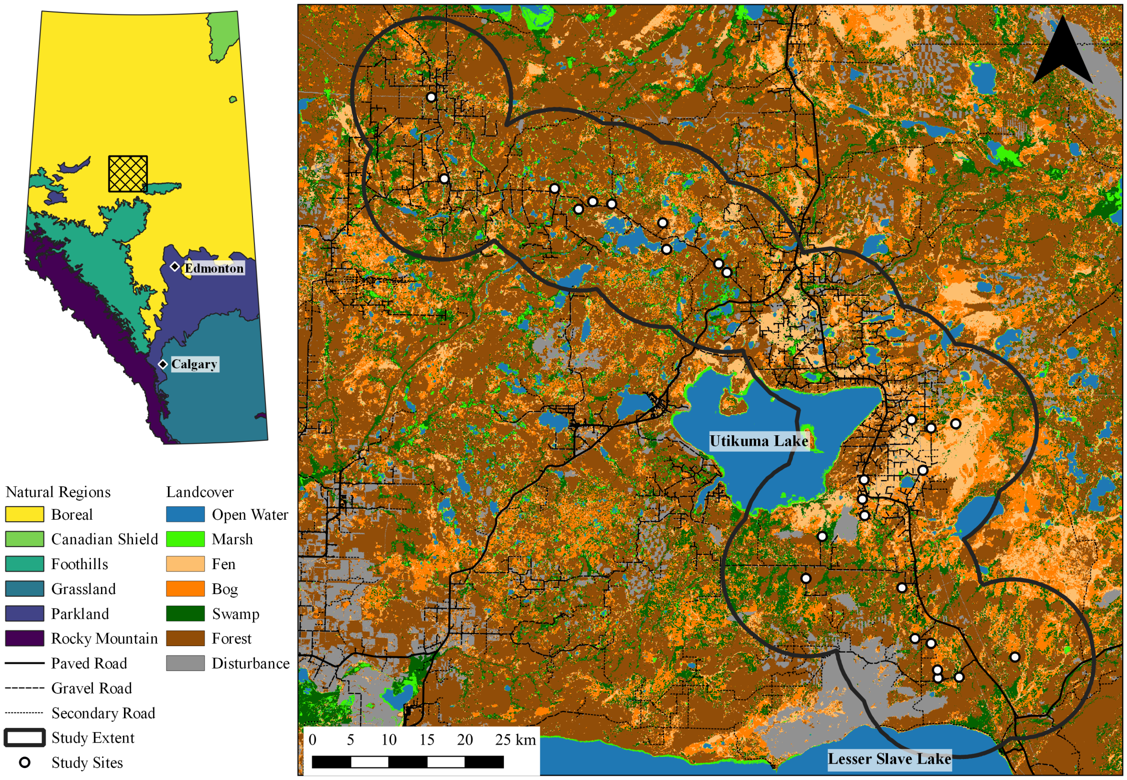

Figure 3.1: Map of study extent and nest searching site locations (n = 26) from 2016 – 2018 with the enhanced wetland classification land cover layer underplayed and the general location of the study area in the boreal forest of Alberta, Canada in the context of the provincial natural regions (inlay; top-left).

Table 3.1: Spatial layers included in macrohabitat multi-scale nest-site selection models including their summary statistics of the mean and standard deviation for the study extent, estimated searched area, used, and available calculated at a 30 m resolution (i.e., mean per 30 m pixel).

Name	Units	Study Extent	Searched	Used	Available
Bog	%	0.13 (0.27)	0.13 (0.10)	0.10 (0.22)	0.12 (0.26)
Fen	%	0.10 (0.25)	0.18 (0.14)	0.18 (0.30)	0.11 (0.27)
Swamp	%	0.14 (0.27)	0.17 (0.11)	0.20 (0.29)	0.14 (0.27)
Marsh	%	0.02 (0.08)	0.05 (0.04)	0.06 (0.15)	0.01 (0.08)
Open Water	%	0.07 (0.26)	0.02 (0.04)	0.05 (0.21)	0.05 (0.21)
Forest	%	0.42 (0.41)	0.27 (0.19)	0.19 (0.35)	0.44 (0.45)
Borrow Pits	%	0.0021 (0.0355)	0.0354 (0.0930)	0.0872 (0.2118)	0.0036 (0.0380)
Industrials	%	0.0014 (0.0301)	0.0025 (0.0087)	0.0037 (0.0429)	0.0025 (0.0433)
Pipelines	km	4.77 (25.41)	9.86 (16.77)	10.97 (40.40)	6.98 (30.72)
Primary Roads	km	2.73 (18.43)	10.44 (13.30)	11.48 (31.67)	4.96 (24.67)
Secondary Roads	km	1.27 (12.44)	4.98 (9.69)	4.96 (21.68)	1.20 (12.23)
Seismic	km	29.54 (59.88)	24.68 (15.30)	15.60 (39.35)	32.37 (61.79)
Wells	%	0.0071 (0.0664)	0.0185 (0.0254)	0.0192 (0.1158)	0.0102 (0.0760)

3.3.2 Landscape Definitions

We developed a suite of landscape predictors based on spatial layers that represented land cover and land use features, which we predicted to be important for duck nest-site selection (Table 3.1). Land cover variables were developed from Ducks Unlimited Canada's Enhanced Wetland Classification layer (Ducks Unlimited Canada 2011). This layer was generated from Landsat Thematic Mapper satellite imagery collected from 1999 - 2002 and field truthed from 2000-2002. The raw data included 27 land cover classes that we summarized in 6 thematic groups: bog, fen, marsh, swamp, open water, and forest at a 30 m resolution. Briefly bogs included open, shrubby, and treed bogs; fens included graminoid, shrubby, and treed rich and poor fens; swamp included shrub, hardwood, mixedwood, tamarack, and conifer swamp; marsh included aquatic bed, mudflats, emergent marsh, and meadow marsh; open water included open water; and forest included conifer, deciduous, and mixedwood forests.

Land use layers were developed from the Alberta Biodiversity Monitoring Institute's (ABMI) Human Features Inventory database produced in 2017 (ABMI 2017). These layers were retrieved as individual vector layers for each feature of interest, which we converted to rasters (i.e., pixels; 30 m resolution) to facilitate analysis. We converted polygonal features to rasters by calculating the percent area (i.e., percent cover) within a pixel and line features were converted by calculating the sum of the length of each line feature in a pixel. Specifically we quantified borrow pits, which included all borrow pits, sumps, dugouts, and lagoons; industrials, which included camps, facilities, mills, oil and gas buildings, gas plants, gravel or sand pits, coal mines, oilsands, or peatmines; pipelines, which included any under or overground pipes of substantial length and capacity used for conveyance of petrochemicals and we included transmission lines in this feature because we assumed they were similar to pipeline right of ways and relatively sparse on the landscape; primary roads included all paved and gravel roads; secondary roads included all vegetated roads, winter roads, and trails; seismic lines included all seismic line feature types; and wells included all active and inactive wells. All land cover and land use variables were mapped at a 30 m resolution across our study area. Therefore, we used a constant minimum 30 m resolution in all multiscale analysis described below (Timm *et al.* 2016).

To implicitly incorporate scale in our models, we summarized the landscape predictors at multiple spatial scales using moving windows (Hagen-Zanker 2016). There has been limited application of the multiscale approach for duck nest site selection and because our study was in a novel area, we selected moving window radii sizes based on duck biology and management relevance (Wheatley & Johnson 2009; Ducks Unlimited Canada 2014). Specifically, we limited our investigation to moving window radii sizes of 30, 90, 300, 1000, 2500, and 5000 m. We considered moving windows less than 1000 m to be fine scale and consistent with expected movement of a breeding hen within her nesting home range (Cowardin *et al.* 1995; Howerter 2003; Ducks Unlimited Canada 2014). We chose a 30 m radii to represent the landscape context surrounding a use location (30 m resolution). Next, we chose 90 and 300 m because they were consistent with previous distribution modelling and investigation in this region and they were multiples of the raw data resolution (Ducks Unlimited Canada 2014). We chose 1000 m to approximate the home range or foraging distance that a hen mallard might travel from the nest site during incubation (Howerter 2003). We considered moving windows greater than 1000 m coarse scale and expected variables selected at this scale to be more consistent with predator ecology or avoidance (Tigner *et al.* 2014; Fisher & Burton 2018). For example, the 2500 m radii should approximately capture a bear home range in the spring (Brodeur *et al.* 2008). Finally, we chose a 5000 m radii as our coarsest scale and assumed it approximated the home range of a Common Raven (*Corvus corax*) and a scale more consistent with landscape planning (Bruggers 1988; Burton *et al.* 2014). Moving window analysis calculated the mean resource value within the moving window radius for each pixel with the exception of linear features, which were summarized as the total length of resource within each window for each pixel.

3.3.3 Study Extent and Used and Available Points

We defined the spatial extent of our study for model development by generating a 10 km buffer around all nest locations and the centroids of searched areas (Northrup *et al.* 2013). Prior to generating pseudo-absence points, we generated an exponential decay surface of the form $e^{(\text{-d}/\alpha)}$ where d represents road distances from each pixel centroid and α was fixed to 3 km, because we selected sites to search that were within 3 km of a road (Fedy *et al.* 2014). The resulting layer was a probability surface, where pixels within 3 km of roads had a probability close to 1 and pixels outside of 3 km of roads had probabilities approaching 0. We used the decay surface to generate pseudo-absence locations so that our random sampling of non-nest locations was consistent with our nest searching efforts. We generated pseudo-absence locations at a ratio of 20:1 to ensure we saturated the landscape with available locations to accurately quantify the heterogeneity on the landscape (Northrup *et al.* 2013; Fedy *et al.* 2014).

3.3.4 Statistical Analysis

Prior to extracting landscape predictor data associates with nest and non-nest locations, we standardized (x - $\overline{x}$ /sd) all raster surfaces to improve computation, model fit, and prediction. Next, we extracted data for each nest and non-nest location for all landscape predictors and respective moving window sizes. We then developed multigrain resource selection functions (MRSFs; Laforge *et al.* 2015a;b). We used a weighted general linear model with a logit link as the base form of our MRSF, where the weighting was used to account for the skewed nest to non-nest ratio (1:20), so that nest and non-nest locations contributed equally in the model (Muff *et al.* 2020).

We used a pseudo-optimized multi-scale approach to identify the best scale for each landscape predictor in a univariate modelling framework from 6 spatial scales and used AICc to select the best scale (McGarigal *et al.* 2016; Bauder *et al.* 2018). We then combined all covariates at their best pseudo-optimized spatial scale into a multi-scale global model and tested for collinearity between the covariates using a Pearson's r $> |0.65|$ as the cutoff. When we identified correlated variables, we allowed the individual variables to remain in the model set, but did not allow them to occur in the same model. We then tested all combinations of the fully saturated pseudo-optimized model and used AICc to select the top model (Doherty *et al.* 2012).

We developed predictive surfaces using our top ranked model for nest-site selection to identify important nesting habitats for upland-nesting ducks in the boreal forest. We also spatially predicted the standard error from our top-ranked model to visualize the uncertainty in our model predictions. We evaluated spatial autocorrelation using bubble plots and model fit using area under the curve (AUC; Boyce *et al.* 2002; Hirzel *et al.* 2006; Fedy *et al.* 2018).

3.4 Results

We located 136 nests of upland nesting duck species between 2016 and 2018. We located nests of 16 American Wigeon (*Mareca americana*), 54 Blue-winged Teal, 16 Green-winged Teal (*Anas crecca*), 12 Lesser Scaup (*Aythya affinis*), 36 Mallard, and 2 Northern Shoveler (*Anas clypeata*). For the purpose of our analysis, we modeled upland nesting ducks as an entire guild, because we expected them to exhibit similar patterns of selection in respect to our covariates at our spatial scales of interest.

We observed ducks selecting different resources at different spatial scales and the best spatial scale that predicted nest site selection for each resource varied (Fig 3.2, Fig 3.3).

We also detected changes in the magnitude and direction of selection for resources across spatial scales (Fig 3.2). We observed consistent selection across spatial scales for fen, marsh, pipelines, and primary roads, consistent avoidance of forest, and varying responses across spatial scales for the remaining eight resources (Fig 3.2). For example, swamp, open water, and borrow pits were selected at fine spatial scales (<1000 m), but avoided at coarse spatial scales (>1000 m; Fig 3.2). The most predictive spatial scale for each covariate, determined by AICc, was: fen (5000 m), marsh (300 m), open water (2500 m), swamp (5000 m), forest (90 m), borrow pits (300 m), industrials (1000 m), pipelines (300 m), hard roads (1000 m), soft roads (90 m), and seismic lines (300 m) (Fig 3.3). The next most competitive scale for each variable was greater than $\Delta 22$ AICc scores, with the exception of open water ($\Delta 1$ AICc score) and pipelines ($\Delta 6$ AICc scores); however, the effect size was similar for each competing scale (Fig 3.3).

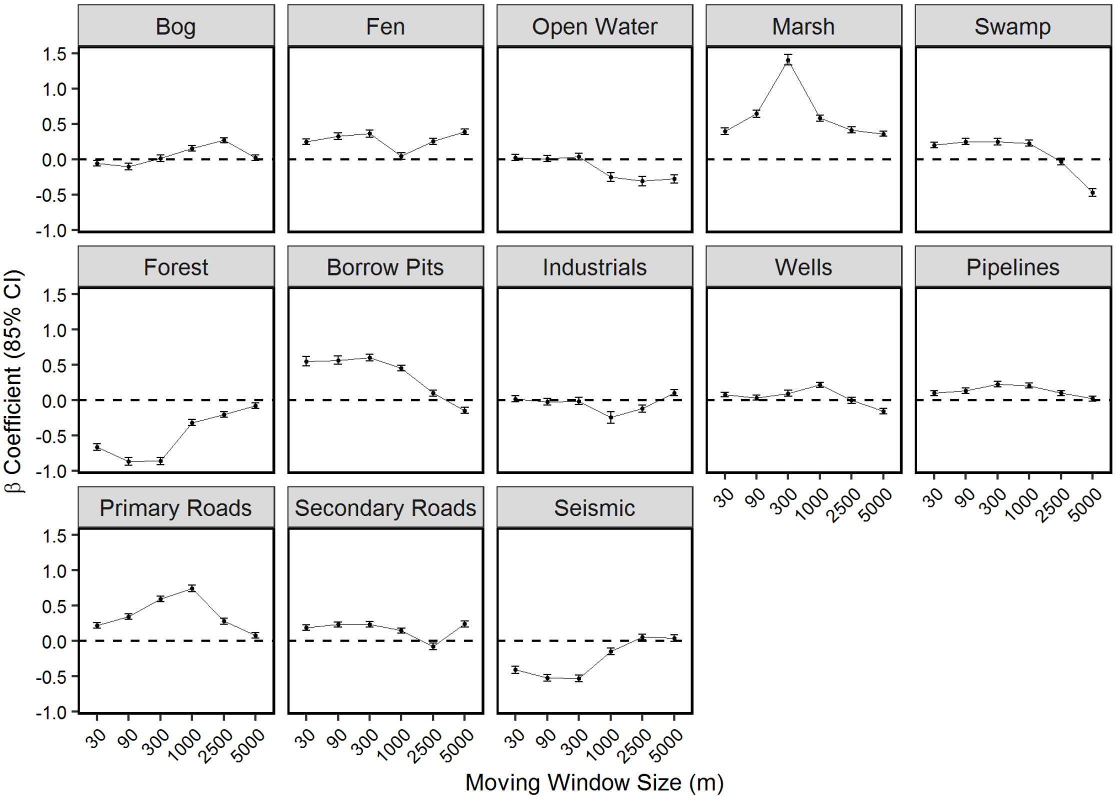

Figure 3.2: Multiscale functional response curves for each covariate considered derived from univariate resource selection functions. Black dots represent beta coefficients with 85% confidence intervals. Line joining points is provided for display only.

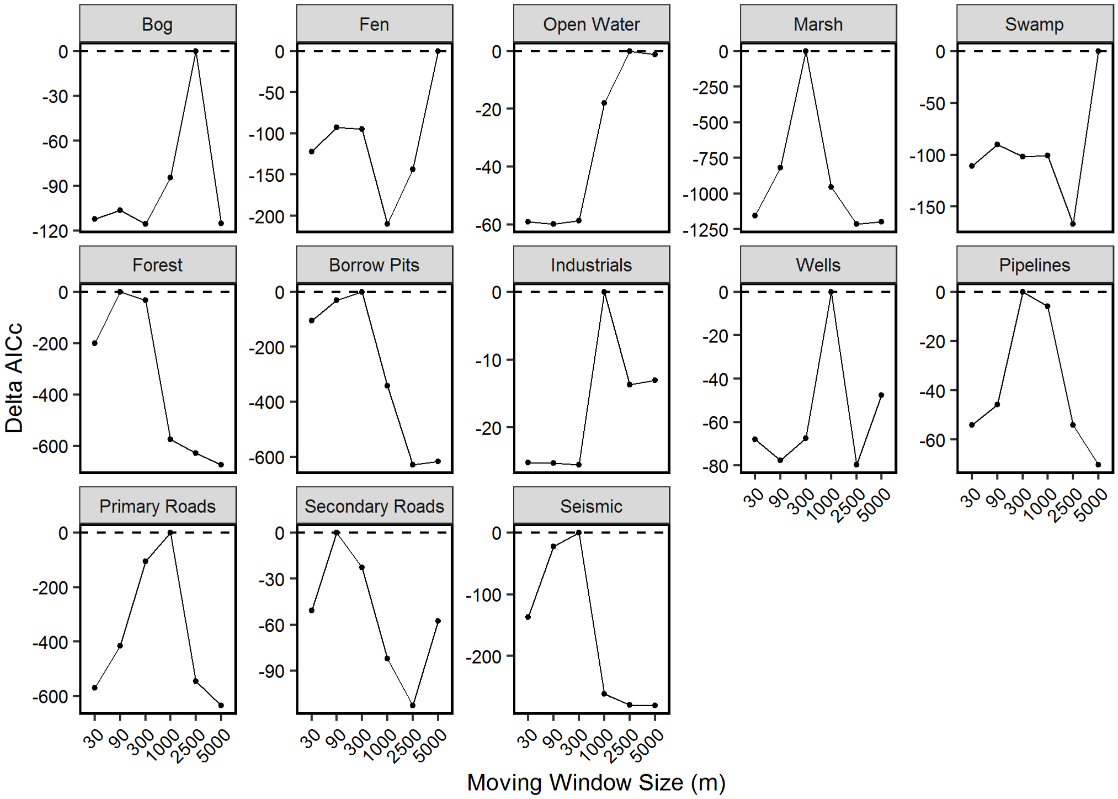

Figure 3.3: AICc ranks for each scale considered from the univariate resource selection functions.

Our best multiscale model for nest-site selection included the land cover variables fen, marsh, open water, swamp, forest, and land use variables borrow pits, primary and secondary roads, industrials, pipelines, and seismic lines (Table 3.2, Fig 3.4). There was only one other competing model within Δ4 AICc scores of our top model and it differed by excluding fen as a variable.

Table 3.2: Model rankings for nest site selection of upland nesting boreal ducks from 2016-2018. Models only shown that composed 0.90 of the cumulative weight.

Model	K	LL	ΔAICc[a]	ωi
Fen_5000 + Marsh_0300 + Open Water_2500 + Swamp_5000 + Forest_0090 + Borrow Pits_0300 + Industrials_1000 + Pipelines_0300 + Hard Roads_1000 + Soft Roads_0090 + Seismic_0300	12	-2467.76	0	0.74
Marsh_0300 + Open Water_2500 + Swamp_5000 + Forest_0090 + Borrow Pits_0300 + Industrials_1000 + Pipelines_0300 + Hard Roads_1000 + Soft Roads_0090 + Seismic_0300	11	-2469.84	2.13	0.26

[a] Lowest AICc score was 4959.64

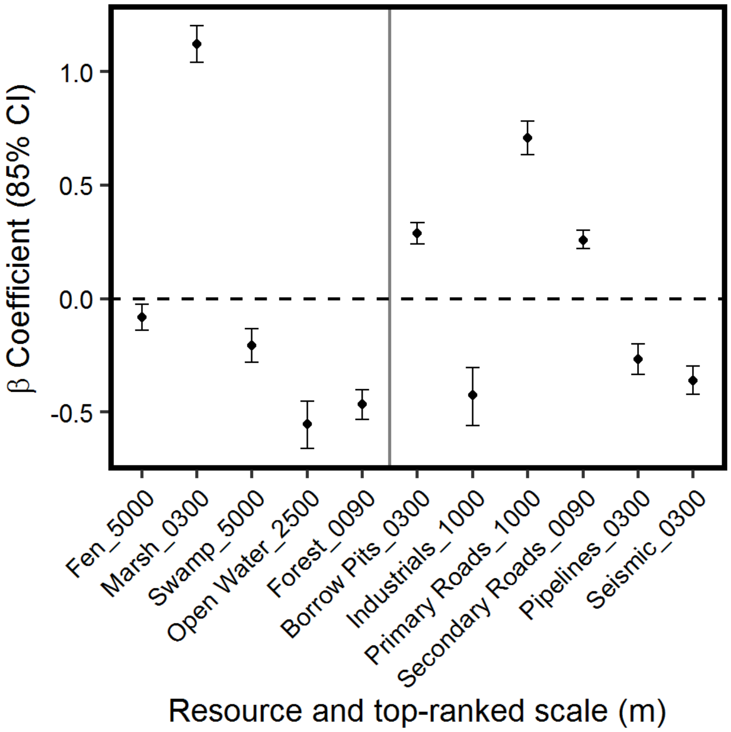

Figure 3.4: Standardized beta coefficients from top multiscale resource selection functions for upland nesting ducks in the western boreal forest of Alberta, Canada. The dashed horizontal line indicates no selection, and everything above is selected for and below is selected against. The vertical line separates land cover from land use variables. The optimized scale can be interpreted from the suffix of the variable name (e.g., Fen_5000 is Fen at 5000 m scale).

Ducks responded to land cover variables at coarse (>1000 m) and fine (<1000 m) spatial scales (Table 3.3). The steepest response was observed for marsh land cover at a fine spatial scale, where less than 20% marsh cover within 300 m resulted in a steep decrease in probability of nest-site selection (Fig 3.5). Fen, swamp, and open water land cover variables all displayed a decreased probability of nest-site selection with increasing proportional area at coarse scales (2500 – 5000 m), while forest cover within 90 m of a nest decreased the probability of nest-site selection at a fine spatial scale (Fig 3.5).

Table 3.3: Coefficient estimates and 85% confidence intervals for the best multiscale resource selection function (MRSF) explaining upland nesting boreal duck nest site selection in Alberta. Canada.

Resource	Estimate	SE	85% LCI	85% UCI
Fen_5000	-0.08	0.04	-0.14	-0.02
Marsh_0300	1.12	0.06	1.04	1.2
Open Water_2500	-0.55	0.07	-0.66	-0.45
Swamp_5000	-0.21	0.05	-0.28	-0.13
Forest_0090	-0.47	0.05	-0.53	-0.4
Borrow Pits_0300	0.29	0.03	0.24	0.33
Industrials_1000	-0.42	0.09	-0.56	-0.3
Pipelines_0300	-0.27	0.05	-0.33	-0.2
Hard Roads_1000	0.71	0.05	0.63	0.78
Soft Roads_0090	0.26	0.03	0.22	0.3
Seismic_0300	-0.36	0.04	-0.42	-0.3

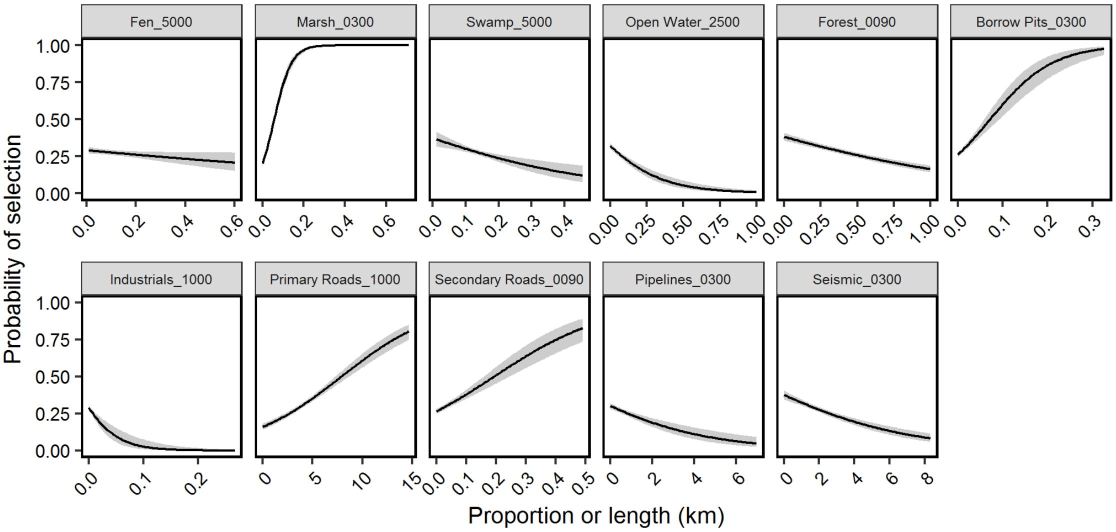

Figure 3.5: Effect plots for resources in the top multiscale nest-site selection model for upland nesting ducks in the western boreal forest of Alberta, Canada from 2016 - 2018.

For land use variables, ducks responded at fine spatial scales (<1000 m). For block features (i.e., polygonal features), borrow pits exhibited the steepest response, where the probability of nest site selection sharply increased when the proportional area of borrow pits increased from 10 and 20% within 300 m of a nest (Fig 3.5). Ducks strongly avoided potential nest site locations with greater than 10% industrial feature cover within 1000 m (Fig 3.5). Nest-site selection responses also varied with linear feature type. Ducks increased their probability of nest-site selection with increasing lengths of primary and secondary roads within 1000 and 90 km of a nest site, respectively (Fig 3.5). Conversely, the probability of nest-site selection decreased with increased lengths of pipelines and seismic lines within 300 m of a nest (Fig 3.5). From a univariate framework (Figure 3.2), pipelines were consistently selected for; however, in our best multivariate model, pipelines were avoided (Table 3.3).

We spatially predicted (i.e. mapped outputs from) our top model of nest site selection for boreal ducks to identify high probability nesting habitat (Fig 3.6). In addition, we also mapped uncertainty in our spatial predictions of our best model (i.e., standard error; Fig 3.6). We did not observe any spatial autocorrelation in our predictions and our final model had an AUC score of 0.89 indicating strong predictive performance.

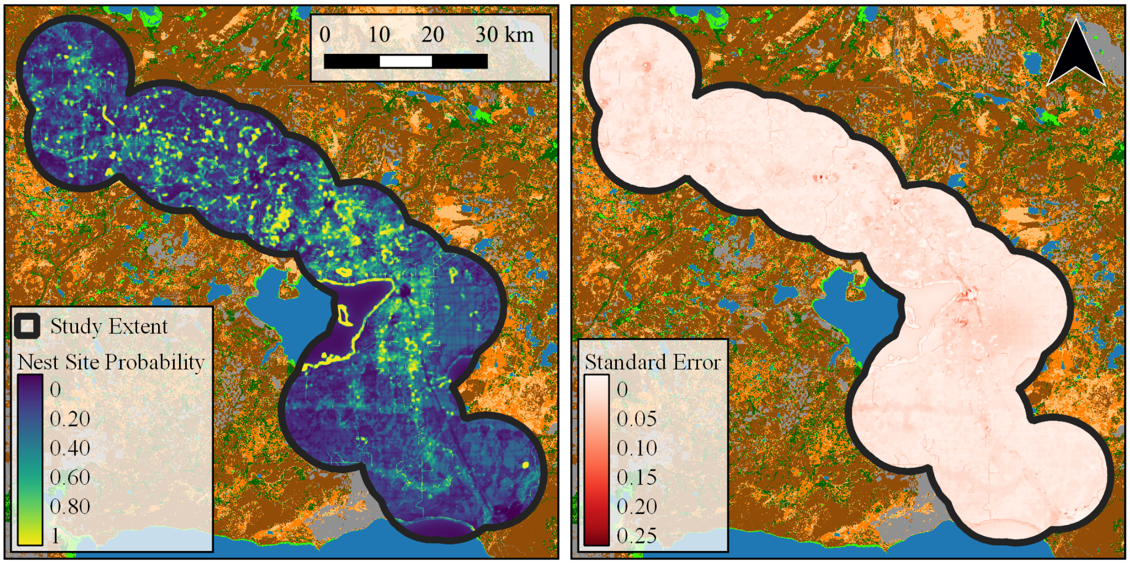

Figure 3.6: Top upland nesting duck multi grain resource selection function predicted across the study extent to highlight critical nesting habitat in the boreal forest (left) and the associated error with that prediction (right).

3.5 Discussion

We identified multiscale macrohabitat nest-site selection strategies of ducks in the boreal forest by simultaneously assessing both habitat and disturbance. By considering multiple spatial scales when quantifying our land cover and land use variables, we were able to identify the most predictive scales of selection for each resource and better understand how ducks might perceive those resources across spatial scales (Figure 3.2). Our results provide novel insights into how ducks respond to development, specifically oil and gas, in the boreal forest and we provide a map that extrapolates our findings to help prioritize conservation of high probability nesting habitats in this region (Figure 3.6). We observed negative associations between nest-site selection and some industrial development features (e.g., pipelines and seismic lines; Figure 3.5) consistent with negative population trends observed for pair settling in this region (Singer *et al.* 2020).

3.5.1 Land cover

The response with the greatest magnitude for nest-site selection was for marsh land cover within 300 m of a nest site. In our study, marsh included aquatic beds, emergent marsh, and meadow marsh, which form the intermediary transition between open water and other wetland types (e.g., swamp, bog, fen) or forest habitats (Smith *et al.* 2007). Importantly, this does not suggest that ducks are only nesting on upland patches in marshes *per se.* Rather it identifies the importance of proximity to marsh for nest sites, likely providing hens easy access to foraging and brood-rearing habitat (Bloom *et al.* 2012). Ducklings hatch precocial but flightless and therefore early brood-rearing habitat close to nests increases survival (Bloom *et al.* 2012; Dyson *et al.* 2018). Additionally, the top-ranked scale of 300 m suggests that within the nesting home range (approximately 1000 m; Cowardin *et al.*

1995) there are other important land cover types, such as open water, peatland, or forest, that may help satisfy nutritional or other cover related requirements during the nesting period and subsequent brood-rearing periods (Krapu 1981; Gurney *et al.* 2016). In North Dakota, wetland size and emergent cover were the strongest predictors of brood abundance in association with oil and gas development at the finest spatial scale of investigation (320 m; Kemink *et al.* 2019). While these authors did not allow different scales to compete in the same model and only investigated scales up to 1510 m, their results are consistent with our findings related to the scale and the importance of marsh habitat to breeding ducks.

Our results suggested variation in the strength and direction of nest site selection across other wetland types found in our study area (Smith *et al.* 2007). Swamp habitats are characterized by a dominance of woody vegetation, including trees (e.g, *Picea mariana*, *Betula* spp.) or shrubs (*Salix* spp. and *Alnus* spp.), and wide variation in nutrient availability (Smith *et al.* 2007). In our study swamp was avoided with increasing coverage within 5000 m of a nest site; however, we did observe that swamp was selected for at smaller spatial scales (Figure 3.2). Fens are peatland wetlands that are level with the surrounding terrain and characterized by short trees, if present (e.g., *P. mariana*, *Larix laricina*), and *Betula* and *Salix* spp. shrubs with wide ranging nutrient variation depending on adjacent habitats (Smith *et al.* 2007). Fen was also avoided after accounting for variation in other land cover and land use variables (Figure 3.4), suggesting that ducks avoided nesting in large patches of fen. We observed variation in selection for fen across spatial scales and the characteristic scale of selection was positive at a univariate scale (Figure 3.2), but including other variables in the models resulted in a coefficient direction instability and ducks appeared to avoid fen (Figure 3.4). Bog land cover, which is relatively similar to fen but with poorer nutrient regimes and greater tree cover (Smith *et al.* 2007), did not receive support for inclusion in our best model. Previous research in the prairies suggested that habitats with perennial woody vegetation can have a negative relationship with Mallard duckling survival (Bloom *et al.* 2013). Overall, swamps and fens may not provide adequate open water resources in proximity to the nest site for foraging or brood-rearing or may be riskier due to the presence of predators.

The presence of open water is an important habitat component for ducks (Pimm 1994). We found that ducks avoided greater open water coverage within 2500 m of a nest site, which we interpret as avoidance of large bodies of water (Figure 3.5). At finer spatial scales, we observed use in proportion to availability of open water, which might indicate that boreal ducks use smaller ponds associated with nesting habitat similar to ducks elsewhere in North America (Gilmer *et al.* 1975; Batt *et al.* 1992; Krapu *et al.* 1997; Baldassarre 2014). We also found that ducks avoided forest land cover within 90 m of a nest site (Figure 3.4, Figure 3.5), which may be a predator avoidance technique if predation is greater in forests or along forest edges (Lahti 2001; Ball *et al.* 2008). In grassland dominated systems, negative effects of woody vegetation were not found in association with nest success (Thompson *et al.* 2012) but forest cover in proximity to brood habitat was found riskier for Mallard ducklings (Bloom *et al.* 2013). Selection away from forest cover, therefore, may be a response to selecting nest sites associated with higher quality brood habitat. Our observation may be explained by our guild approach because some duck species, such as Mallard, American Wigeon, and Green-winged Teal are known to nest in forests; whereas Blue-winged Teal use more open habitats (Keith 1961; Baldassarre 2014; Dyson *et al.* 2019). Alternatively, our nest searching efforts focused on predicted areas of high density nesting ducks and therefore under sampled available forest land cover (Table 3.1) where detection is also predicted to be reduced (Petrula 1994). We are unable to quantify this with our data, but suspect that if ducks were commonly nesting further into the forest away from wetlands, we would have located more nests in these locations than we did given our search efforts

(Table 3.1). We hypothesize that the abundance of marsh and open water land cover in the boreal forest allows ducks to avoid potentially less optimal habitats, such as forest for nesting, particularly if overland travel for ducklings is more risky in the boreal post-hatch.

3.5.2 Land Use: Industrial Development

We found variation in the direction and magnitude of duck nest-site selection relative to industrial disturbance at the macrohabitat scale and identified resource-specific effects on nest-site selection (Figure 3.4). The top-ranked scale of response for industrial development features were all within the approximate home range size of nesting ducks (< 1000 m) suggesting that ducks are actively responding to industrial development for nest-site selection (Figure 3.3; (Moraga *et al.* 2019)). We observed the strongest response to industrial features for borrow pits, which were strongly selected for in close proximity to nests (within 300 m; Figure 3.5). Borrow pits are created during road construction following the removal of the substrate for roadbeds and are generally rectangular (<3 ha) in size (Kuczynski & Paszkowski 2012). These industrial features are often associated with grassy buffers in an otherwise forested landscape that may provide important microhabitat characteristics for nesting ducks (Eichholz & Elmberg 2014; Dyson *et al.* 2019). A previous study of species occurrence on borrow pits in Alberta found that forest cover influenced species composition on borrow pits (Kuczynski & Paszkowski 2012). When borrow pits had less than 33% forest cover, Mallard, Lesser Scaup and American Coot (*Fulica americana*) occurred most often, while borrow pits with greater than 33% forest cover had, Bufflehead, Ring-necked Duck, Green-winged Teal, and American Wigeon (Kuczynski & Paszkowski 2012). In addition, horned grebes (*Podiceps auritus*) were more likely to produce offspring on borrow pits with greater amounts of riparian vegetation (Kuczynski *et al.* 2012). Currently, the quality of borrow pits for breeding ducks warrants investigation, because they are often oligotrophic or mesotrophic, with low levels of dissolved oxygen (Stevens *et al.* 2006), which may represent poor brood habitat if alternative habitat is not available in close proximity. Boreal ducks also avoided nesting in areas that contained greater than 10% cover of industrial sites or mines at a 1000 m scale (Figure 3.5), which may be explained by avoidance of large scale industrial features (e.g., processing stations, camps) in association with industrial noise or human activity at these features (Francis *et al.* 2011; Shonfield & Bayne 2017).

Roads are a common linear feature in the boreal forest and ducks selected nest sites that were associated with primary (i.e., paved or gravel) and secondary roads (vegetated or winter roads; Figure 3.4, Figure 3.5). This pattern was similar to prairie Mallards and Blue-winged Teal, that occupied nest sites close to roads and wells in an oil and gas landscape more than expected (Pasitschniak-Arts *et al.* 1998; Ludlow & Davis 2018). More than half of our sample consisted of Mallard or Blue-winged Teal nests, which may have contributed to this similarity. Roads may act as predator refugia for ducks if dominant predators of nests and adults avoid them thereby increasing nest success (Pasitschniak-Arts *et al.* 1998; Roy 2018). In addition, vegetation associated with road margins often consists of pioneer species, including grasses and other dense exotics (Emery *et al.* 2005), which are beneficial to nesting ducks (Dyson *et al.* 2019).

Ducks avoided nesting in areas associated with increased length of seismic and pipelines within 300 m. Singer et al. (2020) observed a consistent pattern, where population declines of upland nesting ducks occurred in regions with higher density of seismic and pipelines. Linear features, like pipelines and seismic lines, may act as predator corridors (Slattery *et al.* 2011; McKenzie *et al.* 2012), allowing easier access to nesting habitat and an increased probability of nest failure. Previous work has found predators such as wolverines, wolves, and bears use seismic lines for travel supporting the hypothesis that these features act as predator corridors (Tigner *et al.* 2014; Dickie *et al.* 2017; Scrafford *et al.* 2017) with bears, among other predators, being identified as important nest predators in this region (Dyson *et al.* 2020).

Overall, evidence from previous research investigating the effects of habitat loss and fragmentation on the nesting ecology and reproduction of ducks and other precocial birds has been inconsistent. In the prairie-parklands, high proportions of nests were located in right-of-ways and untilled fallow fields suggesting tolerance for disturbance (Greenwood *et al.* 1995). (Skaggs *et al.* 2020) found that nest survival was driven mostly by grassland cover and did not detect an effect of oil and gas development. Other evidence from North Dakota suggests a small negative effect of oil and gas development on brood abundance; however, the effect was only evident for a small percentage of the population (Kemink *et al.* 2019). Sharp-tailed grouse (*Tympanuchus phasianellus*) in North Dakota also experienced greater nest survival in association with oil and gas development (Burr et al. 2017). In Alaska, greater white-fronted geese (*Anser albifrons*) took more incubation breaks in disturbed sites and had greater nest survival with further distance from industrial features (Meixell & Flint 2017). In the context of these findings, our results suggest that industrial development does affect ducks during nest-site selection, but the direction and magnitude of those effects are resource specific, highlighting the value of our approach that evaluated resource specific effects as opposed to lumping all development variables together.

Our approach extends previous multiscale nest-site selection analysis as applied to ducks and supports the hypothesis that multi-scale models are superior (Stephens *et al.* 2005; Howerter *et al.* 2008). We identified the top-ranked scale of response for each independent resource prior to building predictive models that explicitly controlled for ecological context. Understanding the scale effect of the response to different resources can help identify threshold values for habitat quantity and quality, tolerance to perturbations, and cumulative effects (Doherty *et al.* 2016). Importantly, the top-ranked scale of response may vary temporally depending on life history phase (e.g, nesting, brood-rearing, moulting) (Sovada *et al.* 1995; Chalfoun *et al.* 2002; Stephens *et al.* 2005), which will require further investigation in regards to the connection of resource selection across pair settling, nest-site selection, and subsequent use of brood-rearing habitat.

3.5.3 Conservation and Management Implications

We developed a predictive map based on our best model of nest-site selection for upland nesting boreal ducks, which can be used to prioritize conservation efforts in the region for areas most likely to support nesting ducks (Figure 3.6). Our model predicted well (AUC = 0.89), but we caution against extrapolating our predictions outside our study extent without testing its predictive ability against independent data or explicitly accounting for variation in availability at novel sites (Matthiopoulos *et al.* 2011; Barker *et al.* 2014; Smith *et al.* 2020; Adde *et al.* 2020a; Winiarski *et al.* 2020). To assist managers with the inherent uncertainty associated with our modelling approach, we also mapped uncertainty in our estimates (Figure 3.6). Predicting uncertainty provides potential future targets for data collection where sampling may not have been adequate to represent available habitats or allows managers to explicitly incorporate uncertainty into the conservation planning process by potentially exercising addition precaution in areas of greater uncertainty in model predictions (Johnson & Gillingham 2008; Barker *et al.* 2014).

Our research adds to the body of literature aimed at understanding changes to ecosystem structure and function driven by industrial development in the boreal forest by providing novel insights into the effects of industrial development on the nesting ecology of boreal ducks. Our spatial predictions provide a tool that is useful for managers to prioritize key nesting habitats to improve conservation planning in this important breeding region for ducks. Investigating the consequences of nest site selection decisions on survival is the next step for understanding how industrial development affects the nesting ecology of boreal ducks. Given our current findings, greatest short-term benefit to nesting ducks may come from continued efforts that focus on conservation of marsh and nearby habitats that have limited seismic lines and pipelines.

Chapter 4

Duck nest survival in the western boreal forest

4.1 Overview

Nest survival drives population demographics of most avian species. For ducks, researchers and managers have focused studies on investigating nest success in association with climate, land use change (e.g., agriculture), and predators in the Prairie and Arctic biomes. The boreal forest is also a key duck breeding area and some regions have undergone rapid land use change caused by industrial development (e.g., oil and gas; forestry). However, duck nesting ecology has received little attention in this biome. Therefore, we investigated nest survival of upland nesting ducks in the western boreal forest of Alberta, Canada from 2016 – 2018. We specifically evaluated how daily survival rates of nests (N = 96) were affected by a suite of natural and anthropogenic variables measured at the nest-site (microhabitat) and landscape level (macrohabitat). Nest survival was low (0.212 [85%

CI: 0.152 - 0.282]) and comparable to low nest survival estimates for ducks elsewhere in North America, including the Prairies. Nest survival increased with nest age and varied annually. At the microhabitat scale, nest survival increased with greater graminoid, forb, and shrub cover at the nest. At the macrohabitat scale, nest survival decreased with more fen habitat, and increased with greater lengths of pipelines and roads in proximity to the nest. We did not find evidence that oil and gas development negatively affected duck nest survival. However, by comparing to our companion study investigating nest-site selection, we revealed adaptive and maladaptive behaviours associated with nesting ecology and suggest that some resources might be selected at an adaptive peak. Our findings highlight the importance of investigating the effect of anthropogenic disturbance at multiple scales to gain a more nuanced understanding of species responses.

4.2 Introduction

Predator-prey relationships shape ecological communities and strongly influence variation in species life history strategies (Ricklefs 1969; Sih *et al.* 2011). For birds, nesting is a critical life stage under selective pressures to optimize survival. In addition to influencing evolutionary trajectories, nest survival often drives population demographics and predation is the primary cause of nest failure (Ricklefs 1969; Martin 1995). The magnitude and effect of nest predation varies geographically and temporally in association with changing dynamics of nest predator distribution, abundance, and foraging efficiency, all of which are changing in response to human induced landscape change (Rodewald & Kearns 2011; DeGregorio *et al.* 2016). Understanding the causes and consequences of these changing predator-prey dynamics is critical to species evolution, ecology, and avian management and conservation (Chalfoun *et al.* 2002; Sih *et al.* 2011; Hethcoat & Chalfoun 2015a).

Habitat fragmentation and loss from human induced land use change affects predator-prey dynamics across ecosystems (Stephens *et al.* 2003; Tscharntke *et al.* 2012; Northrup *et al.* 2013; Fahrig 2017; 2019; Fletcher *et al.* 2018). It can modify predator-prey interactions by influencing a predator's ability to search, encounter, kill, and consume prey (Muhly *et al.* 2011; Gorini *et al.* 2012; Tucker *et al.* 2018). Changes in predator functional response can cause cascading effects throughout food webs and alter the stability and resilience of ecosystems (Sih *et al.* 2011; Gorini *et al.* 2012; Roos *et al.* 2018). These changes are context dependent and can produce positive outcomes for predators or prey. Predators may use habitat edges created through fragmentation as travel corridors causing an increase in predator abundance, colonization of novel habitats, or predators may experience improved hunting efficiency and access to prey (Salo *et al.* 2010; Latham *et al.* 2011c; Tigner *et al.* 2014; Dickie *et al.* 2017). In general, fragmentation benefits generalist predators and is detrimental to specialists as predicted by niche theory because generalists should benefit from more heterogeneous habitats (Holt 2002; Ryall & Fahrig 2006; Devictor *et al.* 2008; Clavel *et al.* 2011; Tscharntke *et al.* 2012). Additionally, land use change can result in the removal or reduction of top predators resulting in mesopredator release and increased predation risk for numerous prey species, particularly birds (Crooks & Soulé 1999). Changes in vegetation composition and structure due to disturbance may result in increased abundance of prey providing additional alternative prey or possibly resulting in predator swamping (Andrén 1994; Ryall & Fahrig 2006; Fahrig & Rytwinski 2009). Alternatively, if land use change creates predator avoidance then it may create prey refugia resulting in a redistribution of prey on the landscape and effectively reducing a predator's ability to encounter prey (Kauffman *et al.* 2007). Understanding these context-dependent responses requires system, region, and taxon specific evaluation to establish appropriate conservation recommendations.

The effect of industrial development on nest survival of birds can be negative across a range of species (Chalfoun *et al.* 2002; Liebezeit *et al.* 2009; Hethcoat & Chalfoun 2015b). Songbird nest predation increased with habitat loss caused by natural gas development in Wyoming, USA (Hethcoat & Chalfoun 2015a). Nest success for grouse species in this region has been found to decline in association with industrial development (Kirol *et al.* 2015; 2020; Burr *et al.* 2017). In Canada's boreal forest, industrial development has been found to cause the direct loss of nesting habitat or destruction of nests during construction for passerines (Van Wilgenburg *et al.* 2013). However, nest survival was not different between fragmented and non-fragmented forests for ground nesting passerines and nest survival increased near forest edges (Ball *et al.* 2008). If industrial development is affecting predator communities, then it will likely have the most prominent effect on ground nesting birds because they are at a greater risk to predation of both the nest and the incubating female (Wiebe & Martin 1998; Amat & Masero 2004).

For ducks, research in prairie ecosystems has revealed that landscape change, such as conversion to agriculture, can alter the community composition, distribution, abundance, and foraging efficiency of nest predators, resulting in reduced nest success (Batt *et al.* 1992; Pasitschniak-Arts & Messier 1995; Stephens *et al.* 2005; Pieron & Rohwer 2010). However, few studies have investigated the effect of oil and gas on duck nest survival to date. In the prairies of North Dakota, oil and gas extraction activities had no effect on nest survival across species, but nest density declined in association with oil and gas development, suggesting avoidance (Skaggs *et al.* 2020). In southern Alberta's prairies, authors detected variable and weak effects of industrial features on the nest success of ducks (Ludlow & Davis 2018). These results suggest that upland nesting duck nest-site selection and survival may be resilient to current levels of industrial development in those regions; however, in the boreal forest, where landscape, climate, and predator communities differ, the response may be different.

The boreal forest of is one of the most extensive, intact, forests remaining on the globe (Schmiegelow & Mönkkönen 2002; Haddad *et al.* 2015). In Alberta, Canada, it has undergone rapid oil and gas development in recent decades (Schneider & Dyer 2006; Carlson & Browne 2015). Industrial development for oil and gas exploration and extraction results in a footprint from industrial block features, such as well pads and mines, and linear features, including roads, pipelines, and seismic lines (Northrup *et al.* 2013; Pickell *et al.* 2015; Dabros *et al.* 2018). The industrial footprint and associated high density linear features (Dabros *et al.* 2018), has altered predator-prey relationships often resulting in predator species benefitting at the expense of their prey (DeMars & Boutin 2018; Fisher & Burton 2018; Mumma *et al.* 2019; Tattersall *et al.* 2020).

The boreal forest is also an important, but understudied, breeding area for North American ducks supporting 12 – 15 million pairs annually (Slattery *et al.* 2011). Upland nesting ducks were found to be experiencing steeper declines in this region in association with industrial development features, such as wells, pipelines, and seismic lines (Singer *et al.* 2020). While redistribution could explain population declines, declines in association with industrial features might suggest a demographic response is occurring, with decreased nest success being a primary mechanism hypothesized to explain the declines (Slattery *et al.* 2011). We previously found that upland nesting boreal ducks selected greater overhead, graminoid, and shrub cover at a nest site (Dyson *et al.* 2019) and at broader landscape scales, these ducks selected nest sites in areas with marsh, roads, and borrow pits, but avoided open water, fen, swamp, forest, seismic lines, and pipelines refmacrohabitat. Importantly, if we assume nest-site selection is adaptive, we would expect that selected features provide increased nest survival at the scale of the nest (i.e., fourth order) and at broader spatial scales (i.e., third order) related to the distribution and abundance of predator communities (Johnson 1980; Stephens *et al.* 2005).

We investigated how nest-site selection affected nest survival relative to industrial development features (e.g., pipelines and seismic lines) and surrounding land cover. We hypothesized that our observed nest-site selection patterns would be adaptive and; therefore, predicted that industrial development (i.e., pipelines and seismic lines) would have a negative relationship with nest survival (Clark & Shutler 1999; Chalfoun *et al.* 2002). To test our hypothesis, we investigated factors at multiple spatial scales within third and fourth order nest-site selection (Johnson 1980; McGarigal *et al.* 2016). Our study provides novel insights into boreal duck ecology that can help conservation practitioners understand the effect of oil and gas development on duck nest survival and revise current assumptions associated with duck management and conservation.

4.3 Methods

4.3.1 Study Area and Site Selection

We conducted our study north of Slave Lake, Alberta, Canada, near Utikuma Lake in Alberta's boreal forest natural region within Canada's Boreal Plains ecozone; hereafter the western boreal forest (WBF; Figure 4.1). The landscape is a mosaic of deciduous, mixed-wood, and coniferous forests interspersed by extensive wetland complexes and industrial development. Historically, land cover change was driven primarily by natural disturbance events, such as insect outbreaks and wildfire (Downing & Pettapiece 2006; Carlson & Browne 2015). More recently, land cover types have been dramatically changed by increasing pressure from human land use, including industrial development related to forestry practices and oil and gas exploration and extraction (Carlson & Browne 2015; Pickell *et al.* 2015). Industrial development has created high density linear features (e.g., seismic lines, roads, pipelines) and large block features (e.g., well pads, pumping stations, industrial sites) that did not previously exist on the landscape (Schneider & Dyer 2006).

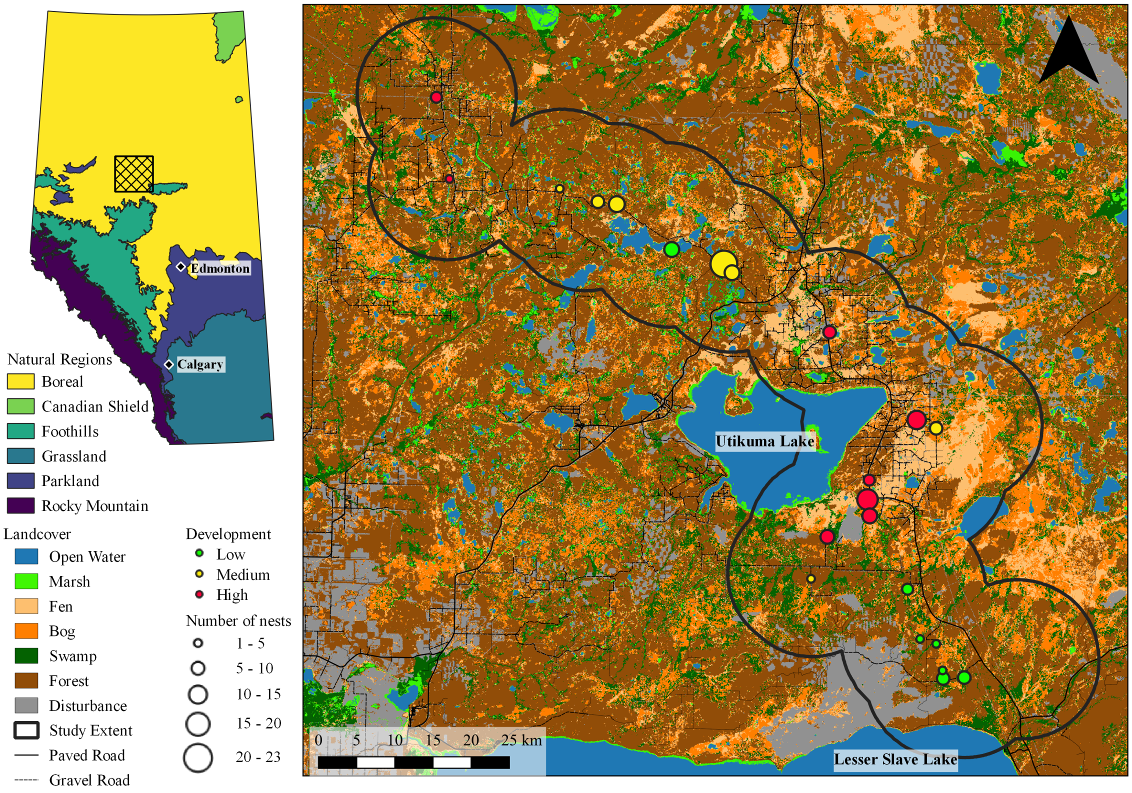

Figure 4.1: Study sites for duck nesting ecology research in the western boreal forest of Alberta, Canada from 2016 – 2018. Dot size for each study site (n = 21) indicates the number of nests found at each site across years included in survival analysis (n = 96) and development class represents the industrial development density used for site selection. Sites where nests were not located are not shown.

We selected study sites using a hierarchical selection criteria guided by spatial layers provided by Ducks Unlimited Canada (DUC) and the Alberta Biodiversity Monitoring Institute (ABMI; ABMI 2017). We considered cumulative energy development, duck pair density, accessibility, land cover type, and excluded recently burned or logged areas (within 20 years). We excluded sites that were recently logged or burned because we were interested in understanding the effects of energy development on ducks and wanted to control for these potentially confounding factors (Chapter 2). We selected sites that were representative of the gradient of industrial development density and had a predicted duck density greater than the median for the region (Ducks Unlimited Canada 2014). Additionally, sites had to be accessible (i.e., within $\approx$ 3 km of a vehicle accessible road) and contain at least 1 water body ($>$ 1 ha). A more detailed description of the study area and our process of site selection can be found in (Dyson *et al.* 2019).

4.3.2 Field Methods

We searched 16 sites in 2016, 24 sites in 2017, and 25 sites in 2018 between 01 May and 31 July (Figure 4.1; (Dyson *et al.* 2019). We searched most sites annually, with the exception of 1 site that was only searched in 2016 and 1 site that was only not searched in 2017. We completed a minimum of two searches of each site in 2016, two to three searches of each site in 2017, and three searches of each site in 2018. We separated searches by 15 – 25 days and searched on foot with teams of 3 – 6 searchers approximately 20 m apart systematically searching around wetlands (Klett *et al.* 1986). Our focal species were upland-nesting ducks (i.e., we did not target overwater or cavity nesting species). We estimated the total area searched at sites as a mean size of 27.46 $+/-$ 12.15 ha (SD). We searched for nests starting at least 3 hours after sunrise ($\approx$ 0800h) until 1600h (Gloutney *et al.* 1993). We located an additional 3 radio-tagged Mallard nests in 2018 with VHF telemetry as part of a pilot study. We included these marked birds in our sample, because nests were found in similar habitat to unmarked birds.

We determined species and estimated the stage of incubation through a combination of egg candling and floating at each nest (Weller 1956; Klett *et al.* 1986). We estimated nest initiation date by subtracting the estimated incubation stage from the date the nest was found and assumed an interval of one egg laid per day plus one skipped day during laying (Batt *et al.* 1992; Emery *et al.* 2005). We monitored nests every 7 – 10 days until fate was determined. In addition, we installed camera traps (n $\approx$ 20 each year; Moultrie 1100i, Moultrie Feeders, Birmingham, AB, USA) at nests suitable for installation (i.e., able to install inconspicuously without disturbing nesting cover) to detect predation events and identify predator species (Dyson *et al.* 2020). We used the presence of egg shell membranes to determine if an egg had hatched and considered a nest successful if $>$ 1 egg hatched (Klett *et al.* 1986). We measured overhead cover using a cover grid placed in the nest bowl, lateral cover using a Robel pole, and estimated vegetation species composition within 1 m of the nest bowl (Guyn & Clark 1997; Dyson *et al.* 2019). We took microhabitat measurements within 5 days of hatch or predicted hatch date (Dyson *et al.* 2019). We did not include nests that were abandoned (e.g., flooded or failed because of investigator disturbance) or were originally found predated or hatched in our sample.

4.3.3 Analytical Approach

Animal habitat use is commonly conceptualized across four orders of selection in which the fourth order represents selection of particular habitat features such as vegetation where a nest is placed and third order represents broader habitat such as selection of a nest-site within an individual's home range (Johnson 1980; Eichholz & Elmberg 2014). Nest survival can be influenced by features associated with the nesting habitat at both the fourth (hereafter microhabitat) and third (hereafter macrohabitat) orders of habitat use (Stephens *et al.* 2005; Howerter *et al.* 2008). Therefore, we evaluated the daily survival rate (DSR) of nests at the microhabitat level with habitat data collected in the field and at the macrohabitat level with land use and land cover data obtained from a GIS. We considered microhabitat and macrohabitat models separately; however, we accounted for the effect of the nonhabitat variables (e.g., nest age, year) with a baseline model consistent across both hierarchical levels of selection. To accommodate for the affect of scale on variation in macrohabitat survival, we first investigated the affect of variables at multiple spatial scales and identified the top-ranked scale for each variable (Fisher *et al.* 2011) prior to developing a multi-scale macrohabitat model explaining nest DSR.

Model Variables

We considered a suite of variables that have been previously found important for duck nest survival and additional variables relevant to our specific hypotheses about industrial land use. Variables that were not captured by micro or macrohabitat were treated as baseline variables (e.g., site, year, nest age). We investigated the effect of site and year to account for spatial and annual variation in predation pressure or environmental conditions (Ringelman *et al.* 2018). We considered the effect of species to account for potential differences in survival related to species-specific variation in nest-site selection strategies (Dyson *et al.* 2019) or other behaviours. We tested for the effect of nest camera presence, because previous studies have shown a positive association of cameras with nest survival, potentially due to predator neophobia (Richardson *et al.* 2009). Next, we considered variables associated with nesting phenology, which included age of nest when found and nest initiation date

(Shaffer 2004; Pieron *et al.* 2012). Nest vulnerability can change with age as a function of hen attendance and nests initiated earlier often experience a greater probability of success because they are initiated by more experienced hens (Klett & Johnson 1982; Stephens *et al.* 2005; Devries *et al.* 2008). We also considered the quadratic effect of initiation and nest age to account for nonlinear responses (Webb *et al.* 2012; Setash *et al.* 2020; Skaggs *et al.* 2020). We did not include any variables related to nest density (Ringelman 2014; Skaggs *et al.* 2020) because nest density is low in the boreal forest and our relatively small sample size precluded us from conducting the analysis.

We predicted the direction of each effect for microhabitat and macrohabitat variables would be similar to our previously reported nest-site selection analyses (Chapter 2, Chapter 3), because nest-site selection should be adaptive (Clark & Shutler 1999; Chalfoun & Schmidt 2012; Setash *et al.* 2020). These microhabitat variables and their measurements were previously described in Chapter 2. Briefly, we investigated the influence of overhead and lateral cover, vegetation height, and the proportion of graminoid, forb, and shrub cover. We predicted that upland nesting ducks would have greater nest DSR at nests with greater overhead and graminoid cover, and lower nest DSR at nests with greater forb cover consistent with our microhabitat nest-site selection analysis (Dyson *et al.* 2019).

At the macrohabitat scale, we previously described and quantified a suite of land cover and land use variables hypothesized to affect nest-site selection of boreal ducks (Chapter 3). These land cover variables represent the surface cover related to vegetation on the ground and we included emergent marsh, fen, bog, swamp, upland forest, and open water, which were derived from Ducks Unlimited Canada's Enhanced Wetland Classification layer (Ducks Unlimited Canada 2011). We also included land use variables related to anthropogenic modification of the landscape derived from the 2016 Alberta Biodiversity Monitoring Institute's Human Features Inventory (ABMI 2017), and quantified the area of block features, such as borrow pits, industrials, and well pads, and the length of linear features, such as primary roads, secondary roads, pipelines, and seismic lines (Chapter 3). As a brief description, borrow pits are small excavated areas of soil and substrate to create roads and well pads and often become flooded; industrials include any block feature not captured by our other categories (e.g., gravel pit, processing plant); and well pads include both active and abandoned wells. Linear features included primary roads, which were any paved or gravel road in the study area, secondary roads were any vegetated road or trail, pipelines included above and below ground infrastructure and were maintained (i.e., vegetation removed) at a variety of widths across the study area, and seismic lines were relatively thin lines (2- 5 m, but up to 10 m) and were created at high densities for oil deposit exploration purposes and exist across the landscape at various levels of regeneration (Lee & Boutin 2006). We created 30 m resolution rasters for our land cover and land use variables and developed spatial covariates by summarizing the landscape using moving windows at six spatial scales (radii: 30, 90, 300, 1000, 2500, 5000 m) associated with species biology or management relevance (Chapter 3; Hagen-Zanker 2016). Consistent with our observations from nest-site selection patterns (Chapter 3), we predicted that DSR would be greater at nests with a greater proportion of marsh, borrow pits, and greater lengths of roads in the surrounding landscape; and lower at nests with greater proportions of fens, swamps, open water, upland, industrials, and greater lengths of pipelines and seismic lines.

Model Structure and Construction

We modeled nest DSR with the logistic exposure model in a generalized linear model framework (Shaffer 2004) and defined the exposure period to contain both laying and incubation (Blomberg *et al.* 2015). We used a two-step variable inclusion approach to evaluate microhabitat and macrohabitat nest survival models (Webb *et al.* 2012). The first step involved evaluation of the top baseline model, which we then carried forward for analysis of microhabitat and macrohabitat additive affects on nest survival. We included site as a random intercept, but we did not consider year as a random effect because we only had 3 years of data and random effects perform better with greater than 5 levels. Therefore, we retained it as a fixed effect (Stephens *et al.* 2005; Bolker *et al.* 2009). We screened variables for the baseline model by first testing them in a univariate framework and used AICc to include only variables that performed better than the intercept-only model in our candidate set. Next, we considered all combinations of the baseline variables and used the top-ranked model to move forward to the next step. We built a global microhabitat model using the baseline model in addition to all microhabitat variables. For macrohabitat, we used pseudo-optimization (*sensu* McGarigal *et al.* 2016) to determine the top-ranked scale (Fisher *et al.* 2011; Stuber & Gruber 2020) for each variable. We included the baseline model during the pseudo-optimization procedure to account for variation in nest DSR not explained by macrohabitat features (Chapter 3). Variables were removed from further consideration in our analysis if the baseline model performed better than any variable scale we considered based on AICc rank. We then moved the top-ranked scale for each variable forward in an additive framework with the baseline model to create a global multi-scale macrohabitat model for nest survival.

We standardized continuous covariates to promote convergence and comparison across covariates measured on different scales. We then used AICc on all combinations of our global models for each step to select the best combination of predictor variables that explained nest survival. We present candidate model sets for each step with more complex variants of the top ranked model removed because these models create unnecessary model selection uncertainty in association with an all combinations approach by including uninformative parameters (Richards 2008; Arnold 2010; Doherty *et al.* 2012). We present estimates of nest DSR and nest success rate by species across years with 85% confidence intervals. We calculated nest success for each species by raising the DSR to the power of the average age of the nest at hatch, which we drew from previous literature (Klett *et al.* 1986; Skaggs *et al.* 2020). For species specific estimates of nest survival, we used exposure periods of 35 days for Mallard (*Anas platyrhynchos*) and Lesser Scaup (*Aythya affinis*), 34 days for Blue-winged Teal (*Spatula discors*), and 33 days for American Wigeon (*Mareca americana*) and American Green-winged Teal (*Anas crecca*). For effects plots, we used a 35 day exposure period to derive nest survival curves. We performed all analysis in R version 3.6.2 “Dark and Stormy Night” (R Core Team 2019).

4.4 Results

We located a total of 136 active nests of upland nesting ducks and removed nests not suitable for survival analysis, which included 2 Northern Shoveler (*Anas clypeata*) nests eliminated due to small sample size. Our final sample for survival analysis included 96 nests of 5 different species, including 14 American Green-winged Teal, 11 American Wigeon, 39 Blue-winged Teal, 8 Lesser Scaup, and 24 Mallard (Table 4.1). We also removed two nests for microhabitat analysis because of missing habitat data (n = 94); but we retained all nests for macrohabitat analysis (n = 96).

Table 4.1: Summary of nests found by species and their fate from the western boreal forest of Alberta, Canada across 2016 - 2018.

Species	Number of Nests				Successful				Predated				Removed			
	2016	2017	2018	Total	2016	2017	2018	Total	2016	2017	2018	Total	2016	2017	2018	Total
AGWT	8	9	1	18	4	4	0	8	3	3	0	6	1	2	1	4
AMWI	6	4	7	17	1	2	3	6	3	1	1	5	2	1	3	6
BWTE	17	15	19	51	2	5	9	16	9	8	6	23	6	2	4	12
LESC	5	5	3	13	3	0	0	3	1	3	1	5	1	2	2	5
MALL	16	9	10	35	1	3	5	9	8	5	2	15	7	1	3	11
Total	52	42	40	134	11	14	17	42	24	20	10	54	17	8	13	38

AGWT = American Green-winged Teal, AMWI = American Wigeon, BWTE = Blue-winged Teal, LESC = Lesser Scaup, MALL = Mallard

We did not find any support for site as a random effect and therefore, proceeded to only consider fixed effects using general linear models (Stephens *et al.* 2005). We also did not detect any variation in nest DSR across species (Figure 4.2). American Green-winged Teal had a DSR of 0.974 (85% CI: 0.945 to 0.988) and an estimated nest success rate of 0.425 (85% CI: 0.155 to 0.677). American Wigeon had a DSR of 0.963 (85% CI: 0.916 to 0.984) and an estimated nest success rate of 0.284 (85% CI: 0.055 to 0.584). Blue-winged Teal had a DSR of 0.955 (85% CI: 0.934 to 0.969) and an estimated nest success rate of 0.209 (85% CI: 0.098 to 0.348). Lesser Scaup had a DSR of 0.943 (85% CI: 0.863 to 0.977) and an estimated nest success of 0.128 (85% CI: 0.006 to 0.450). Finally, Mallard had a DSR of 0.945 (85% CI: 0.911 to 0.966) and an estimated nest success rate of 0.137 (85% CI: 0.039 to 0.297; Figure 4.2).

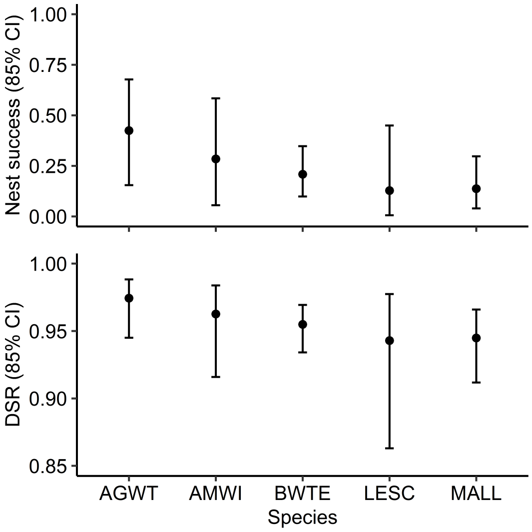

Figure 4.2: Estimated nest success (top) and daily survival rate (DSR; bottom) for species of upland nesting ducks with 85% confidence intervals from the western boreal forest of Alberta, Canada across 2016 – 2018. See Table 4.1 for definitions of species codes.

Our top baseline model explaining nest DSR included the age of the nest when found (AgeFound) and year (Table 4.2). Nests that were older when found had a greater DSR and we observed an increasing trend in DSR across years (Table 4.3, Figure 4.3). We used this model structure to carry forward to account for unexplained variation not related to habitat for the microhabitat and macrohabitat models.

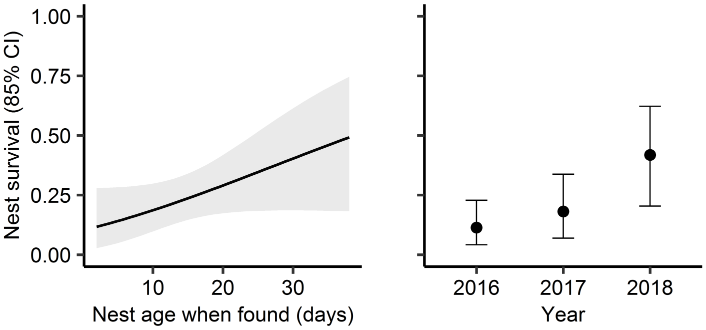

Figure 4.3: Effects plots for top nest characteristics model of nest success for nests of upland nesting ducks in the Western boreal forest of Alberta, Canada across 2016 – 2018. Nest age (in days) when found and year effects with 85% confidence intervals. Nest success

Our top microhabitat DSR model included proportion of graminoid, forb, and shrub cover in addition to the baseline model (Table 4.2). We observed a positive association for vegetation cover and DSR for graminoid, forb, and shrub species at a nest (Table 4.3, Figure 4.4). Structural cover variables including lateral and overhead cover at the nest also received some support for inclusion (Table 4.2); however, we considered the data was best supported by the top-ranked model. Consistent with our predictions, we observed a positive effect on survival for greater proportions of graminoid and shrub cover at nests; however, forb cover was avoided during nest site selection but provided increased survival (Chapter 3).

Table 4.2: Competitive candidate models for baseline, microhabitat, and macrohabitat variables for explained variation in daily survival rate (DSR) for nests of upland nesting ducks in the western boreal forest of Alberta, Canada from 2016 – 2018. Candidate sets are reduced to remove more complex models of top model that occurred in the model set following the all subsets procedure and the macrohabitat models are further trimmed to only include models that account for the cumulative sum of 0.90 of model weight.

Model	K	LL	ΔAICc[b]	ωi
Baseline				
AgeFound + Year[a]	4	-98.39	0	0.32
Year	2	-99.87	0.95	0.20
AgeFound	3	-101.69	2.57	0.09
(.)	1	-103.28	3.73	0.05
Microhabitat				
Forb + Graminoid + Shrub + BASE	7	-91.70	0	0.23
Graminoid + Shrub + BASE	6	-92.80	0.16	0.21
Graminoid + Lateral + BASE	6	-93.20	0.96	0.14
Forb + Graminoid + BASE	6	-93.47	1.50	0.11
Overhead + Graminoid + BASE	6	-93.53	1.62	0.1
Graminoid + BASE	5	-94.65	1.82	0.09
Lateral + BASE	5	-95.10	2.73	0.06
BASE	4	-96.30	3.09	0.05
Macrohabitat				
Fen_0090 + Pipelines_0090 + Primary Roads_0030 + Secondary Roads_2500 + BASE	8	-86.82	0	0.32
Forest_5000 + Borrow Pits_0300 + Pipelines_0090 + Primary Roads_0030 + Secondary Roads_2500 + BASE	9	-86.71	1.84	0.13
Forest_5000 + Pipelines_0090 + Primary Roads_0030 + Secondary Roads_2500 + BASE	8	-87.81	1.98	0.12
Fen_0090 + Primary Roads_0030 + Secondary Roads_2500 + BASE	7	-89.09	2.51	0.09
Forest_5000 + Borrow Pits_0300 + Primary Roads_0030 + Secondary Roads_2500 + BASE	8	-88.42	3.2	0.06

[a] Top baseline model forms the BASE model in subsequent steps

[b] Lowest AICc score for Baseline = 204.83, Microhabitat = 197.56, Macrohabitat = 189.84

Table 4.3: Beta coefficients and 85% confidence intervals for top models of nest characteristics, microhabitat, and macrohabitat effects on nest daily survival rate (DSR) of upland nesting ducks in the Western boreal forest of Alberta, Canada across 2016 – 2018.

	Nest Characteristics		Microhabitat		Macrohabitat	
	β	85% CI	β	85% CI	β	85% CI
Intercept	2.75	2.45 to 3.07	3.33	2.89 to 3.81	2.80	2.48 to 3.14
AgeFound	0.23	0.04 to 0.44	0.32	0.11 to 0.55	0.50	0.26 to 0.78
Year (2017)	0.25	-0.22 to 0.73	-0.47	-1.11 to 0.17	0.04	-0.48 to 0.56
Year (2018)	0.93	0.40 to 1.51	0.21	-0.43 to 0.88	1.74	1.11 to 2.41
Graminoid	.	.	0.54	0.27 to 0.83	.	.
Forb	.	.	0.24	0.01 to 0.48	.	.
Shrub	.	.	0.37	0.08 to 0.66	.	.
Fen (90m)	.	.	.	.	-0.41	-0.64 to -0.19
Pipelines (90 m)	.	.	.	.	0.41	0.12 to 0.77
Primary Roads (30 m)	.	.	.	.	0.46	0.20 to 0.77
Secondary Roads (2500 m)	.	.	.	.	0.54	0.31 to 0.80

The pseudo-optimization procedure identified non-zero scales of effect for bog, fen, swamp, and forest land cover variables and borrow pits, pipelines, and primary and secondary road land use variables to affect nest DSR (Figure 4.5 and 4.6). The remaining variables had confidence intervals that overlapped zero across scales suggesting that inclusion of those variables did not improve upon the baseline model (Figure 4.5); however, we did observe some general trends in the data. For example, seismic lines had a consistent negative effect; however, 85% confidence intervals overlapped zero (Figure 4.5). For most variables, all the confidence intervals overlapped zero (Figure 4.5) and the majority of spatial scales for each variable ranked within 3 AICc scores of the top ranked scale, or baseline model, suggesting some uncertainty in scale selection (Figure 4.6).

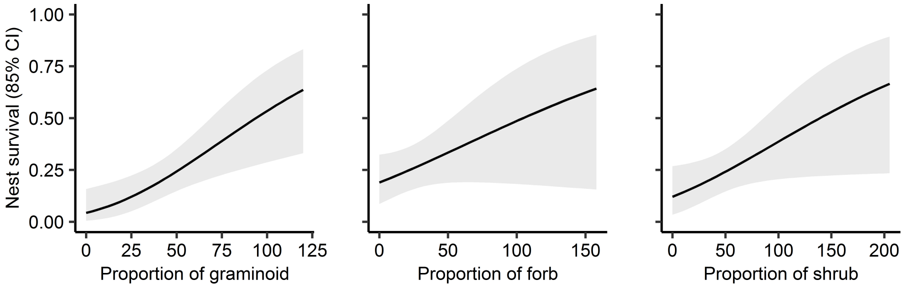

Figure 4.4: Effects plots with 85% confidence intervals for top microhabitat model of nest survival for nests of ducks in the western boreal forest of Alberta, Canada across 2016 – 2018. Effect plots are only shown for proportion of graminoid, forb, and shrub cover because effects of nest age when found and year are shown previously.

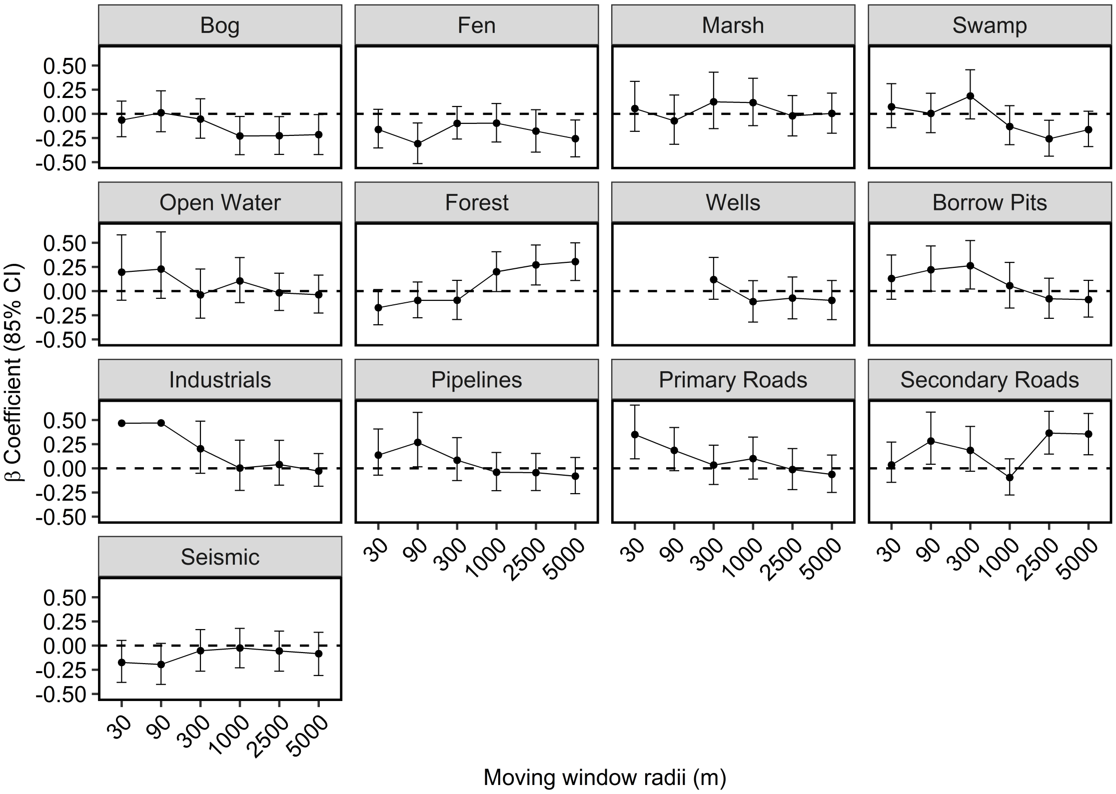

Figure 4.5: Functional response curves of daily survival rate (DSR) to land cover and land use variables in addition to the baseline model for nests of ducks in the western boreal forest of Alberta, Canada from 2016 – 2018 . Moving window sizes without coefficient estimates failed to converge due to a lack of data and estimates without confidence intervals exceeded the plot space and overlapped zero.

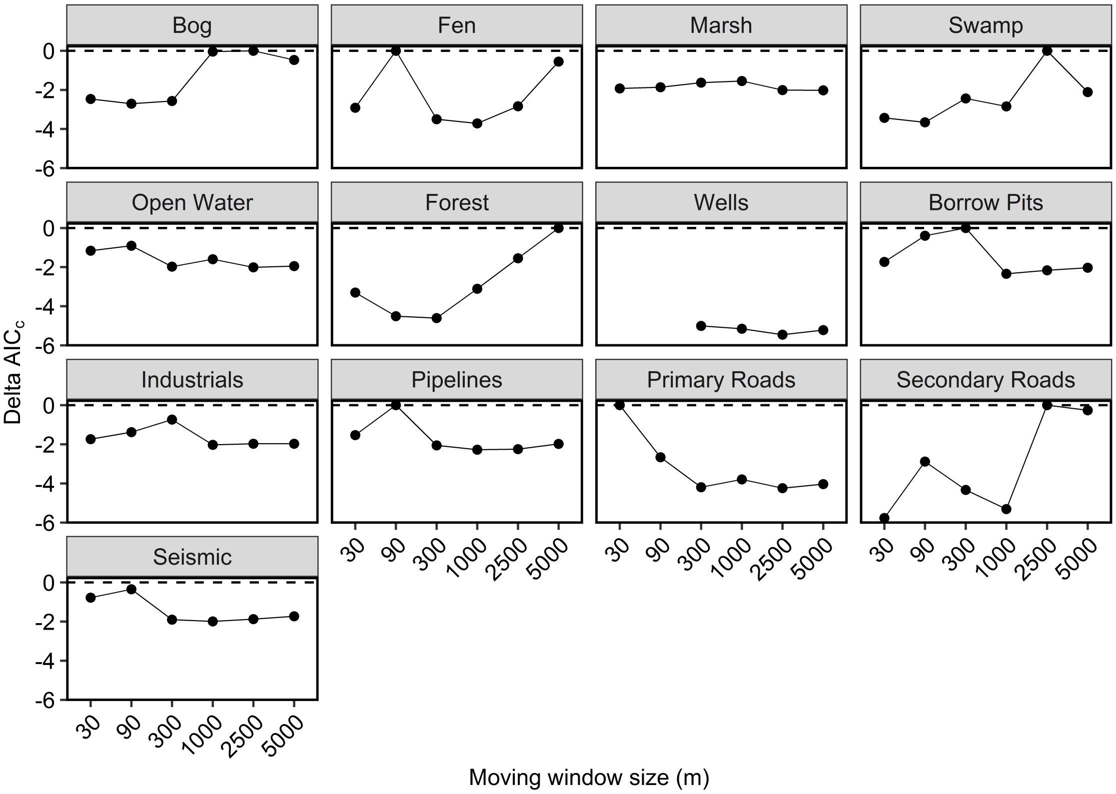

Figure 4.6: Delta AICc score for the baseline model plus the functional response of daily survival rate (DSR) for nests to land cover and land use resources of ducks in the western boreal forest of Alberta, Canada from 2016 – 2018. The baseline model performed best for variables where points along the line for moving window size do not intersect 0.

We identified the top-ranked scale for variables affecting nest survival for bog at 2500 m, fen at 90 m, swamp at 2500 m, upland forest at 5000 m, borrow pits at 300 m, pipelines at 90 m, primary roads at 30 m, and secondary roads at 2500 m (Figure 4.7), which we added to the baseline model for our global model for macrohabitat survival. Subsequently, the top-ranked multi-scale model explaining macrohabitat variation in nest DSR included fen, pipelines, primary, and secondary road variables in addition to the baseline model (Table 4.2; Figure 4.7). Nest DSR decreased with increasing proportion of fen habitat at the 90 m scale and increased with greater lengths of pipelines within 90 m of the nest, primary roads within 30 m of the nest, and secondary roads within 2500 m of the nest (Table 4.3; Figure 4.7).

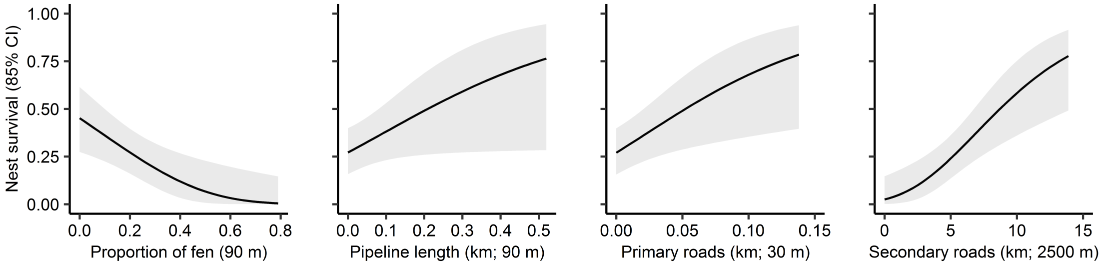

Figure 4.7: Effects plots for top macrohabitat model of nest survival for nests of ducks in the western boreal forest of Alberta, Canada between 2016 – 2018 as a function of proportion of fen habitat, and length of pipelines, and primary and secondary roads in addition to the baseline model, with 85% confidence intervals.

4.5 Discussion

We provide nest survival estimates of upland nesting ducks from Canada's western boreal forest. Based on the suite of variables we considered over the duration of our study and our sample size, we did not find any negative effects of oil and gas development on nest survival. Nest survival was influenced by annual variation and the age of the nest when found. Nest-site selection was adaptive for graminoid and shrub cover at the microhabitat scale and roads at a landscape scale (Chapter 3; Dyson *et al.* 2019). Our estimates suggest that boreal duck populations have similar nest survival estimates to ducks elsewhere in North America, including the Prairie Potholes, and currently exceed an estimate of 15% needed to sustain populations (Cowardin *et al.* 1985; Hoekman *et al.* 2002). Our assessment of nest survival across a gradient of industrial development essentially substituted space for time and, therefore, it is difficult to make inference to whether our survival estimates accurately predict pre-development survival rates in the region because we lacked a baseline (i.e., a non-developed control site was nonexistent).

4.5.1 Baseline Model

We found support for variables not associated with habitat for nest survival including the age of the nest when found and annual variation. Nest survival increasing with nest age is ubiquitous for waterfowl across their breeding range and was further supported from our study (Stephens *et al.* 2005; Ludlow & Davis 2018; Setash *et al.* 2020). Older nests have a higher probability of hatching (less exposure time remaining) and nest defense should increase for older nests (Forbes *et al.* 1994; Gunness & Weatherhead 2002). Our nest searching approach precluded us from detecting an adequate number of nests in the laying stage because there is a lower probability of detecting nests while searching when hens may be absent from nests. If nest survival during laying differs from incubation, then our estimates are likely biased high. Annual conditions can affect nest survival through variation in water availability, temperature, or changing predator populations. In a long-term study on nest success of prairie ducks, large-scale environmental variables often outperformed more local variables suggesting that annual environmental conditions can have a relatively larger effect on nest survival than variables specific to the nest site (Ringelman *et al.* 2018).

We only considered nests that failed because of predation in our study; however, the number of nests that were not successful as a result of flooding (10 nests) or abandonment due to other reasons (28 nests; Table 4.1) was not negligible. We did not include flooded nests in our sample because we expected flooding to be a separate process from predation and during data exploration we detected no difference in DSR when we included nests that flooded in our sample (M. Dyson, unpublished data). Flooding was also a prominent source of nest failure in a study of nest survival in the boreal forest of Alaska and was suggested to affect predator accessibility to nest sites (Petrula 1994; Walker & Lindberg 2005). In our study area, we observed flooding events midseason (M. Dyson, pers. obs.). We suspect that environmental variation in precipitation, beaver activity (Nummi *et al.* 2013; Lapointe St-Pierre *et al.* 2017), and industrial development interact in the boreal forest to create a dynamic hydrological landscape that requires further investigation in the context of duck demography. In addition, understanding if flooding is compensatory or additive to the predation process presents an opportunity for future inquiry in this system.

4.5.2 Microhabitat

At the microhabitat scale ducks likely maximize nest concealment to avoid detection by predators (Ringelman *et al.* 2018; Borgmann & Conway 2015). We found that DSR increased with a greater proportion of vegetative cover, consistent with ducks having increased survival in thicker vegetation (Ringelman *et al.* 2018). Evidence for increased survival with more graminoid cover is consistent with prairie research (Livezey 1981; Clark & Shutler 1999; Setash *et al.* 2020). Graminoid cover likely provides concealment for nesting ducks and Blue-winged Teal prefer nest-sites in graminoid cover, which composed approximately 40% of our sample size (Gloutney & Clark 1997; Baldassarre 2014; Dyson *et al.* 2019; Rohwer *et al.* 2020).

The nest concealment hypothesis is commonly proposed to explain nest-site decisions by birds (Borgmann & Conway 2015; Borgo & Conover 2015). However, other authors have noted the important tradeoff related to nest and adult survival, which is particularly relevant for ground nesting precocial birds, such as ducks (Götmark *et al.* 1995; Amat & Masero 2004). We found greater survival at nests that had increased forb cover, but detected avoidance of forb during the selection process. We suspect that hens likely tradeoff between increased cover at the nest site and their ability to detect incoming predators to avoid mortality, resulting in the need to get it 'just right'. This tradeoff process may manifest itself in lifetime fitness where hens that optimize the tradeoff (i.e., goldilocks hens) experience the greatest fitness.

4.5.3 Macrohabitat

At the macrohabitat scale we did not detect any negative effects of industrial development on nest survival of ducks similar to other recent studies (Ludlow & Davis 2018; Skaggs *et al.* 2020). Nest success increased with increasing density of pipelines (90 m), primary roads (30 m), and secondary roads (2500 m). Primary and secondary roads were also features that ducks selected (Chapter 3) suggesting that associating with roads may be adaptive. Similar results have been observed for numerous duck species across biomes (Pasitschniak-Arts *et al.* 1998; Raquel *et al.* 2015; Roy 2018; Skaggs *et al.* 2020). Collectively, these result support the hypothesis that roads may create nest predator refuges because some duck predators avoid them (Pasitschniak-Arts *et al.* 1998; Tucker *et al.* 2018), and may provide a fitness benefit for ducks. We also observed greater survival for nests with higher densities of pipelines within 90 m, which was opposite our prediction based on observed avoidance in nest site selection (Chapter 3). Here, the scale of effect was at 90 m, while for avoidance it was at 300 m, which may explain the opposite trend; however, it might also indicate a nonlinear response to pipelines. In our study area, pipelines are often wider than other anthropogenic linear features like seismic lines and might be more similar to roads due to the fact that vegetation is often maintained on these features or they are used as travel corridors for oil and gas service and monitoring, possibly providing a refugia effect.

Gravel roads represented most primary roads throughout our study area with the exception of 2 major paved highways (Alberta Highway 88 and 750). Gravel roads experienced a range of vehicle travel and maintenance based on industrial activity, which could affect how roads influence predator-prey interactions (Northrup *et al.* 2012; Lamb *et al.* 2018). For example, roads with regular traffic may provide a stronger refuge effect if it increases predator avoidance (Northrup *et al.* 2012); however these responses are likely predator species-specific if different predators vary in their response to roads. For example, wolves select roads for travel (Dickie *et al.* 2017; Newton *et al.* 2017) and wolves may reduce the prevalence of mesopredators (e.g., coyote) in association with roads (Berger *et al.* 2008). In our study area, we did not detect wolves predating duck nests but coyotes were important nest predators (Dyson *et al.* 2020). Therefore, if wolves do functionally exclude coyotes from habitat near roads, then it may create predator refugia for ducks. Bears were also a common duck nest predator in our region, and might avoid roads due to mortality risk from vehicle collisions (Lamb *et al.* 2018) or hunting access; however, other research suggests that bears may select roads for travel (Tigner *et al.* 2014; DeMars & Boutin 2018). Considering the differing effects of spatial scale on survival in association with primary and secondary roads, we interpret that duck nests close to primary roads received a direct predator refuge effect (i.e., lower probability of encounter with nest predator), while secondary roads selected at a broader spatial scale potentially acted as indicators of lower duck nest predator densities if predators are avoiding these features.

We only found a land cover effect on nest survival for fen within 90 m. However, we observed a stable negative effect of peatland land cover (fens and bogs) on nest survival across spatial scales, which suggests that peatlands are not beneficial nesting habitat for ducks. More generally, peatlands often lack open water habitats with vegetative cover for broods and may be less productive, and have less forage for incubating females or offspring relative to marsh. Peatlands might also provide more foraging opportunities for predators if movement is easier relative to marsh or if there is less visual obstruction for avian predators. However, peatlands also provide important hydrologic functions such as water retention and nutrient storage that might be more critical to maintaining suitability of nearby open water systems for ducks (Smith *et al.* 2007). Predators, such as bears, that are important nest predators in our study area (Dyson *et al.* 2020), have been found to use industrial features to access fen habitats more than expected, particularly in spring to depredate caribou neonates (DeMars & Boutin 2018). If this relationship is occurring throughout the boreal forest, then it may also increase predation risk in these habitats for ducks.

4.5.4 Nest Site Selection and Survival: Pattern from Process

Studies of nest-site selection patterns and the process of nest survival often hypothesize that nest-site selection is adaptive in the context of natural selection (Clark & Shutler 1999). Investigators have commonly failed to demonstrate this congruence between the pattern of selection and process of survival. This is not surprising if nest-site selection patterns represent long term optima (Clark & Shutler 1999), otherwise known as the adaptive peak hypothesis (Latif *et al.* 2012). Under this hypothesis, if ducks already nest in habitats that minimize predation risk, then there is not enough variation to detect relationships between nest site selection and nest success (Latif *et al.* 2012).

We found evidence of both adaptive and maladaptive nest-site selection and relationships more consistent with adaptive peaks in our study. Selection for road density appears to be adaptive from our study, because ducks selected this feature (Chapter 3) and had greater survival. Alternatively, we found hens selected nest sites with less forb cover than available (Chapter 2) but found that increased forb cover conferred a nest survival benefit. We did not observe a positive effect of overhead cover on survival, which we predicted would increase nest success given the importance of avian predators in our study area (Dyson *et al.* 2019; 2020). However, if ducks are already selecting adequate overhead cover (i.e., are at an adaptive peak), then we would not have been able to detect this relationship for survival. The relationship between selection and survival was also context dependent based on the scale of resources measured (Martin & Fahrig 2012; Moraga *et al.* 2019). The difference in scales of importance between our nest-site selection and nest survival analysis are likely driven by the different factors influencing these processes and are difficult to explain without further study. For example, scale effects are likely duck species-specific and related to predator responses in the region (Stuber & Fontaine 2019). Therefore, we predict that scales of effect should vary by duck species and spatially in relationship to the landscape context, resource availability, and predator communities.

Considering pattern and process consecutively allowed us to gain a more complete understanding of how ducks are responding to landscape change. Specifically, our first step compared nest sites to available locations (i.e., landscape context) providing inference to how ducks are using the landscape (Chapter 3). Then, comparing successful nests to unsuccessful nests allowed us to consider the consequences of those decisions. However, the latter analysis (i.e., this manuscript) was only against a subset of variability that exists on the landscape that potentially masks important relationships that a selection analysis can reveal. For example, we would have missed the avoidance of pipelines or seismic lines if we had only performed an analysis on nest survival from our data. This is particularly relevant if ducks adapt their behaviour from a perceived risk as opposed to adjusting after nest failure (Eichholz *et al.* 2012; Bleicher 2017). Therefore, we suggest that to comprehensively understand nesting ecology, researchers must evaluate nest-site selection and survival (i.e., the pattern and the process) consecutively or together as opposed to only evaluating nest survival.

If we assume that ducks can assess predation risk on the landscape prior to nesting (Eichholz *et al.* 2012), then we might interpret our evidence from nest-site selection and survival along with temporal changes in settling patterns in the region (Singer *et al.* 2020) to indicate that ducks are adapting to anthropogenic landscape change. By avoiding settling and nesting in areas with high density seismic lines and selecting areas with higher densities of roads or pipelines for nesting that may provide predator refugia, ducks may avoid potential negative effects of industrial development during the nesting period. However, the degree to which ducks can adapt without demographic implications may become constrained as development exceeds current levels, reducing options for avoidance. Many questions remain regarding the long-term health of duck populations in the boreal forest of Canada. For example, at what level might industrial development result in negative demographic consequences and how does that interact with predicted changes in duck abundance in the boreal forest under climate change scenarios (Drever *et al.* 2012)? How does forestry and natural disturbance like wildfire interact with these relationships? Are there any time-lagged responses to landscape and climate change by predators or prey that could alter these observed relationships (Ringelman *et al.* 2018)? Our results improve our understanding of boreal duck nesting ecology; however, continued research in this important breeding area is critical for developing a better understanding and managing boreal ducks.

4.5.5 Conservation and Management Implications

Decisions about how to manage the boreal forest for ducks should consider evidence from both habitat selection and survival. Many conservation programs for ducks focus on efforts to increase nest survival; however, given our relatively low predation rates from this region of the boreal forest, efforts to improve our understanding of survival during other phases of the annual cycle may prove more effective (Cowardin *et al.* 1979; Hoekman *et al.* 2002). Investigation into how ducks respond to ongoing restoration efforts of linear features (Tattersall *et al.* 2019) would also be valuable for making effective conservation decisions. Additional investigation from long term data would help to continue to evaluate the potential interactive or synergistic effects of disturbance on nesting ducks. Continuing to advance our understanding of species-specific processes and relationships across different life-history phases, including settling, nest-site selection, survival, and brood-rearing, will likely provide the greatest benefit to conservation of ducks in the boreal forest.

Chapter 5

Nest predators of ducks in the boreal forest

5.1 Overview

Nest predation is often the primary cause of nest failure for ducks throughout North America. Tremendous efforts have been made to identify the predators responsible for nest predation to benefit the conservation and management of ducks. However, we are unaware of empirical evidence that identifies the nest predators of ducks in the boreal forest, which is an important breeding area. We used camera traps on real (n = 53) and artificial nests (n = 164) from 2016 – 2018 to identify predators of boreal duck nests. We identified 8 species of duck nest predators that ate or removed eggs from nests including, American black bear (*Ursus americanus*), short-tailed or least weasel (*Mustela* spp.), Canada lynx (*Lynx canadensis*), coyote (*Canis latrans*), American marten (*Martes americana*), red squirrel (*Tamiasciurus hudsonicus*), Common Raven (*Corvus corvax*), and Red-tailed

Hawk (*Buteo jamaicensis*). Despite a long history of duck nest predator research, our study confirmed previously undocumented nest predators of ducks from the boreal forest. The suite of nest predators was different from common prairie nest predators and we did not observe common prairie nest predators at our study area. Climate change and industrial development are altering predator-prey interactions causing changes to wildlife communities in this region and our data provide an initial step in improving our understanding of boreal ducks.

5.2 Introduction

For birds, nesting is a critical life stage and success at this stage has population-level effects (Hoekman *et al.* 2002). In particular, nest failure caused by predation is a dominant factor driving population dynamics and life history evolution (Ricklefs 1969; Martin 1993). Therefore, the identification of nest predators is a fundamental step in understanding nesting ecology (Major 1991; Latif *et al.* 2012).

Identifying nest predators can be challenging, because it involves locating a nest and monitoring its fate in a manner that allows for accurate identification of the predator and minimal disturbance at the nest site (Major 1991). Artificial nests provide an alternative to locating real nests to achieve adequate sample sizes; however, the validity of inference to real nests has been cautioned by numerous studies (Major & Kendal 1996; Butler & Rotella 1998; Pärt & Wretenberg 2002; Zanette 2002). Camera systems, including continuous video recordings and still camera traps, have been used to monitor avian nest predators and are a valuable tool to identify species-specific nest predators (Pietz *et al.* 2000; King *et al.* 2001; Richardson *et al.* 2009; Ball & Bayne 2012; Ellis-Felege & Carroll 2012; Croston *et al.* 2018; Ellis *et al.* 2018). Nest cameras can accurately identify nest predators and discriminate from those species that visit pre-or-post-predation (Thompson III & Ribic 2012; Ellis-Felege & Carroll 2012; Kirol *et al.* 2018). Studies that combine the use of real and artificial nests along with camera traps can help to identify nest predators, provided researchers consider the potential differences between the two nest types when interpreting their results (Esler & Grand 1993; Ball *et al.* 2008).

Considerable effort has identified a suite of duck nest predators from the prairie and arctic biomes (Sargeant *et al.* 1993; 1998; Sovada *et al.* 2001) and the relative importance of these predators to nest success varies regionally (Pieron & Rohwer 2010). In addition, predator impacts on duck demography are consistently greater in areas where habitat loss or fragmentation alters predator abundance, community composition, or access to previously isolated areas (Greenwood *et al.* 1995; Sovada *et al.* 2001; Phillips *et al.* 2003; Pieron & Rohwer 2010). Identification of major duck nest predators has been used to guide large-scale predator management initiatives on the prairies with the overall goal of increased duck production (Clark *et al.* 1995; Garrettson & Rohwer 2001; Chodachek & Chamberlain 2006; Pieron & Rohwer 2010; Amundson *et al.* 2013). Thus, an important step is to correctly identify the regional predator community in order to inform effective management and conservation decision making.

In the boreal forest, the second most important breeding area for ducks in North America, we do not know the identity and relative importance of different avian and mammalian species to duck hen and egg predation (Slattery *et al.* 2011). Many typical predator species from the prairies either do not occur or only occur at low densities in the boreal forest, and so we cannot readily infer relationships in the boreal from prairie results. In addition, composition of boreal duck predator communities may be shifting because of rapid habitat change from oil and gas and forestry activity over the past twenty years, coupled with increasing evidence for effects of climate change, which can also influence predator-prey interactions (Dawe *et al.* 2014; Hebblewhite 2017; DeMars & Boutin 2018; Fisher & Burton 2018). Therefore, identifying current nest predators of boreal ducks will fill a critical knowledge gap for North American waterfowl conservation and management.

Our objective was to identify duck nest predators using camera traps on real and artificial nests in the boreal forest. Herein we identify duck nest predators from the western boreal forest of Alberta, Canada, which can be used as the foundation to further understand factors influencing nest survival, population dynamics, and the effect of land use change on predator-prey dynamics.

5.3 Study Area

Our study was in Canada's Boreal Plains ecozone and Alberta's boreal forest region, hereafter, the western boreal forest (WBF), north of Slave Lake, Alberta, Canada, near Utikuma Lake (Fig. 5.1; (Downing & Pettapiece 2006)). We selected study sites using a hierarchical selection criteria based on spatial layers, which considered cumulative energy development, duck density, land cover type, and excluded recently burned or logged areas (Dyson *et al.* 2019). We selected sites that represented the gradient of industrial development density on the landscape and had predicted duck pair densities greater than the median for the region (4 pairs/2.5 km^2; Ducks Unlimited Canada 2014), were accessible (i.e., within $\approx$3 km of a road or trail), and contained at least one water body (> 1 ha; Dyson *et al.* 2019).

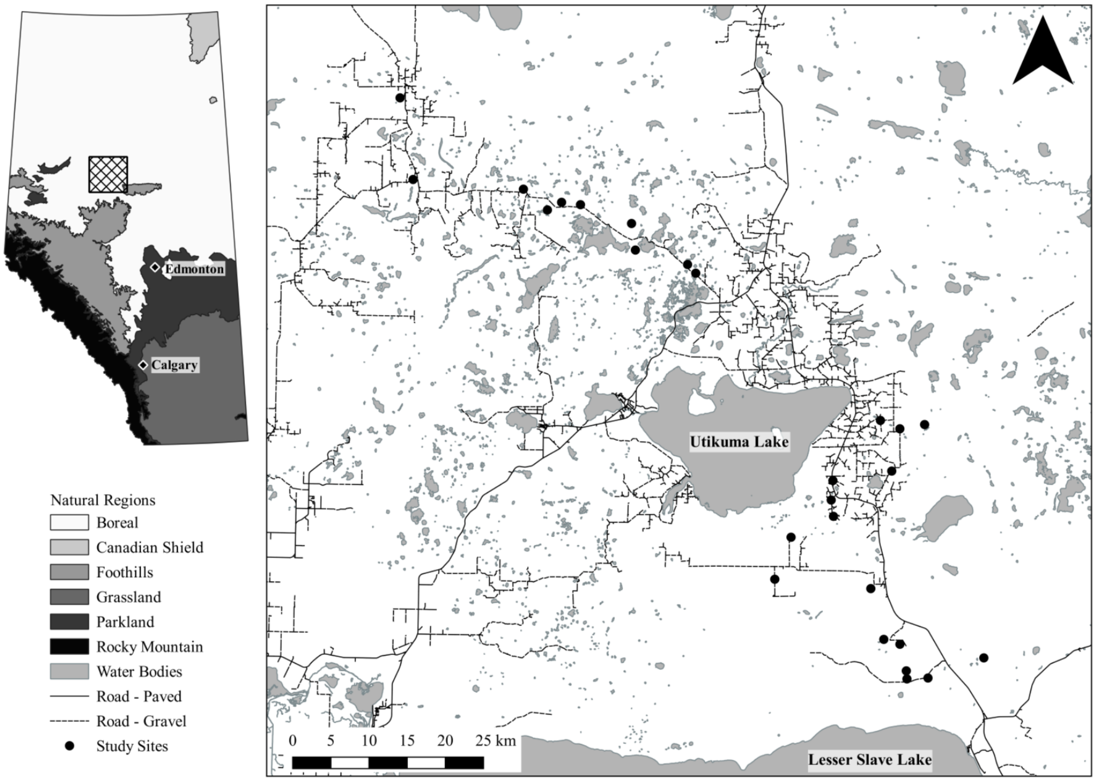

Figure 5.1: Map of the study area including locations of study sites where real and artificial nests were monitored from 2016 – 2018 in the boreal forest near Utikuma Lake, Alberta, Canada. Inlay displays the location of the study area in the boreal forest relative to the province of Alberta, Canada.

5.4 Methods

We located nests of ground nesting ducks by nest searching on foot around the shoreline of wetlands (Klett *et al.* 1986). We searched 16 sites in 2016, 24 sites in 2017, and 25 sites in 2018. We searched most sites in subsequent years, except for one site that was only searched in 2016 and one site searched in 2016 and 2018 (Fig. 5.1). When a nest was discovered, we identified the species of duck nest based on a combination of characteristics of the hen, down and breast feathers in the nest, and egg morphology. We also recorded clutch size and the age of the nest as determined by candling and floating eggs (Weller 1956; Dyson *et al.* 2019).

We installed camera traps (Moultrie 1100i, Moultrie Feeders, Birmingham, AB, USA) between 1 and 3 m from the nest bowl on natural vegetation features (e.g., trees or shrubs) that provided suitable locations for inconspicuous installation (i.e., we were able to install the camera without disturbing nesting cover). Cameras were positioned using the viewfinder option on the camera to ensure the nest bowl occurred in the field of view. Cameras were set to take a burst of 3 still images when triggered with a 5 second quiet period between triggers. We chose a short quiet period to maximize our probability of detecting a nest predation event. Day time images were captured in colour, while nighttime images were black and white and illuminated by an infrared flash.

We also placed artificial nests (n = 120 – 140 per year) at a subsample of 12 – 14 sites (10 nests/site) where we searched for real nests (Major & Kendal 1996; Bayne & Hobson 1997; Gunnarsson & Elmberg 2008; Ringelman *et al.* 2012). Artificial nests were deployed during the early (≈ 15 May initiation) and late (≈15 June initiation) nesting period (60 – 70 nests/period; 6 – 7 sites/period). Nests were placed along 2 – 300 m transects at each site perpendicular to the water's edge at 0, 50, 100, 200, and 300 m. Transects were set up at each site to maximize the distance between the two transects to achieve the greatest coverage at each respective study site. We placed nests along transects in approximate locations that closely resembled real nests nearest the transect and formed nest bowls and deposited 3 – 9 eggs/nest to mimic the appearance of real nests (Gunnarsson *et al.* 2006). We attempted to place 9 eggs in all nests in 2016 and 6 eggs in all nests in 2017 and 2018; however, logistical constraints (e.g., cracked or broken eggs) resulted in less eggs being placed in nests on some occasions.

We used large chicken eggs for artificial nests that were dyed to mimic the appearance of Mallard (*Anas platyrhynchos*) eggs with food coloring and tea (2016), tea only (2017), or willow sapling bark shavings (2018; Guyn & Clark 1997). We found that willow bark shavings provided the desired color and did not fade or wash off over time compared to the tea and food coloring. Artificial goose down was used in all nests constructed during the early period in 2016 and half of the nests in the late period to mimic the presence of duck down; however, we did not continue its use in 2017 and 2018. We were not able to procure duck down for our study (Gunnarsson & Elmberg 2008) and following the use of goose down in 2016, we decided it was not necessary to achieve the objective of identifying potential nest predators of boreal ducks. All nests were partially covered with down or vegetation before the departure of an observer.

In 2016, we distributed camera traps (n = 15) on artificial nests as follows: 2 sites received 5 traps applied to one whole transect (all 5 nests), 1 site received 3 traps applied to one transect on nests 1, 3, and 5 and one site received 2 traps on nests 2 and 4 during the early period. We repeated that strategy during the late nesting period; however, 2 additional sites received 2 cameras for a total of 19 cameras deployed during the late period. In 2017 and 2018, we installed camera traps (n = 30) on half of the artificial nests at each site (5 cameras/site), placing traps on nests 1, 3, and 5 on one transect and nests 2 and 4 on the other at each site to maximize our ability to identify species-specific predation events. We determined transect camera distribution prior to the site visit by flipping a coin.

We monitored nests every 7 – 10 days by visiting the nest site to confirm the status of the nest and count the number of eggs present. Once the fate of a nest was confirmed, we reviewed camera photos and identified nest predators for nests that were not successful. One reviewer (M. Dyson) identified all images of predators to species whenever possible; however, all weasel predation events were recorded as *Mustela* spp., because short-tailed (*M. erminea*) and least weasels (*M. nivalis*) occur in the study area and it was difficult to differentiate the species in most images. We did not identify predators for nests that were not monitored with cameras, because evidence from only nest remains can produce biased results (Sargeant *et al.* 1998; Larivière 1999). Field work practices and procedures were approved and permitted by University of Waterloo Animal Use Protocols (16-04,17-03), a Canadian Wildlife Service Scientific Research Permit (16-AB-SC004), a Canadian Wildlife Service Migratory Bird Banding Permit (0077AR), and Alberta Environment and Parks Wildlife Research and Collection permits (55236, 55237, 56909, 56910, 18-419).

5.5 Results

We found 167 duck nests, of which 147 were active when found and deployed 380 artificial nests from 2016 – 2018 (Table 5.1). We located nests of American Wigeon (*Mareca americana*), Blue-winged Teal (*Spatula discors*), Canvasback (*Aythya valisineria*), Green-winged Teal (*Anas crecca*), Lesser Scaup (*Aythya affinis*), Mallard, Northern Shoveler (*Anas clypeata*), and Ring-necked Duck (*Aytha collaris*) nests (Table 5.1). We installed camera traps on 43% of artificial nests (n = 164) and 36% of real nests (n = 53) over

3 years (Table 5.2). We detected nest predation events at 41% of nests monitored with camera traps (n = 89), with 45% (n = 24) at real nests and 40% (n = 65) at artificial nests. We did not detect any partial predation events.

Table 5.1: Summary of nest searching and monitoring efforts of real and artificial nests in the western boreal forest, Alberta, Canada, from 2016 to 2018.

Nest type[a]	# of nests			% Apparent success			% Abandoned or flooded			% Predated		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
Artificial	120	140	120	43	51	71	5	0	0	53	49	29
Early	60	70	60	12	54	58	3	0	0	85	46	42
Late	60	70	60	73	49	83	7	0	0	20	51	17
Real	57	54	56	21	35	38	16	11	18	63	54	45
AGWT	7	9	1	57	44	0	0	22	100	43	33	0
AMWI	4	3	7	25	67	29	0	0	29	75	33	43
BWTE	15	15	19	13	33	47	20	0	5	67	67	47
LESC	4	3	3	75	0	33	0	0	33	25	75	33
MALL	12	10	10	8	40	40	25	10	30	67	50	30
CANV	0	0	1	0	0	100	0	0	0	0	0	0
NSHO	1	0	1	0	0	0	0	0	0	100	0	100
RNDU	5	10	14	20	40	29	60	20	14	20	40	50
Unknown	9	4	0	0	0	0	0	25	0	100	75	0

[a] AGWT = American Green-winged Teal, AMWI = American Wigeon, BWTE = Blue-winged Teal, LESC = Lesser Scaup, MALL = Mallard, CANV = Canvasback, NSHO = Northern Shoveler, RNDU = Ring-necked Duck.

We identified 8 species of duck nest predators; 6 mammal and 2 avian species (Table 5.3). Common Raven (*Corvus corvax*; hereafter ravens) and American black bear (*Ursus americanus*; hereafter black bears) were the most frequent nest predators detected at real and artificial nests combined (Table5.3; Fig.5.2; Fig.5.3). However, short-tailed or least weasel (*Mustela* spp.) were the most common mammalian predator of real nests. Real nests were also predated by Canada lynx (*Lynx canadensis*), coyote (*Canis latrans*), and Red-tailed Hawk (*Buteo jamaicensis*) (Table 5.1; Fig.5.2). More specifically, we confirmed predation of the incubating hen at 3 of the 4 lynx events and 1 of the 3 coyote events. Additionally, we suspect that both of the Red-Tailed hawk predation events also targeted the hen (Fig. 5.2) and not the eggs, but we did not record confirmation of the hen being carried off or recover a carcass at either event. We also detected a Blue-winged Teal narrowly escaping a Red-tailed Hawk on another occasion; however, her nest was ultimately successful. Artificial nests differed from real nests in that we did not observe predation by Canada lynx or Red-tailed Hawk. Two additional species were identified predating or disturbing artificial nests; American marten (*Martes americana*) predated eggs and red squirrels (*Tamiasciurus hudsonicus*) removed or rolled eggs around the nest bowl (Table 5.3; Fig. 5.3).

Table 5.2: Summary of cameras deployed on artificial and real duck nests from 2016 to 2018 in the western boreal forest, Alberta, Canada.

	2016		2017		2018		Total	
Nest	Artificial	Real	Artificial	Real	Artificial	Real	Artificial	Real
Successful	18	8	41	4	47	7	106	19
Abandoned	0	3	0	2	0	4	0	9
Predated	16	9	29	4	13	12	58	25
Total	34	20	70	10	60	23	164	53

Table 5.3: Summary of observed western boreal forest duck nest predators at artificial and real nests as detected by cameras from 2016 to 2018 in Alberta, Canada.

	Artificial					Real				
Predator	2016	2017	2018	Total	Percent	2016	2017	2018	Total	Percent
Common Raven	6	11	8	25	38%	1	0	2	3	13%
Red-tailed Hawk	0	0	0	0	0%	1	0	1	2	8%
American black bear	7	10	2	19	29%	3	1	0	4	17%
Mustela spp.[a]	0	1	1	2	3%	1	2	3	6	25%
American marten	0	1	0	1	2%	0	0	0	0	0%
Canada lynx	0	0	0	0	0%	1	1	2	4	17%
Coyote	0	0	1	1	2%	1	0	2	3	13%
Red squirrel	1	4	1	6	9%	0	0	0	0	0%
Unknown	6	5	0	11	17%	1	0	1	2	8%
Total	20	32	13	65	100%	9	4	11	24	100%

[a] Short-tailed or least weasel.

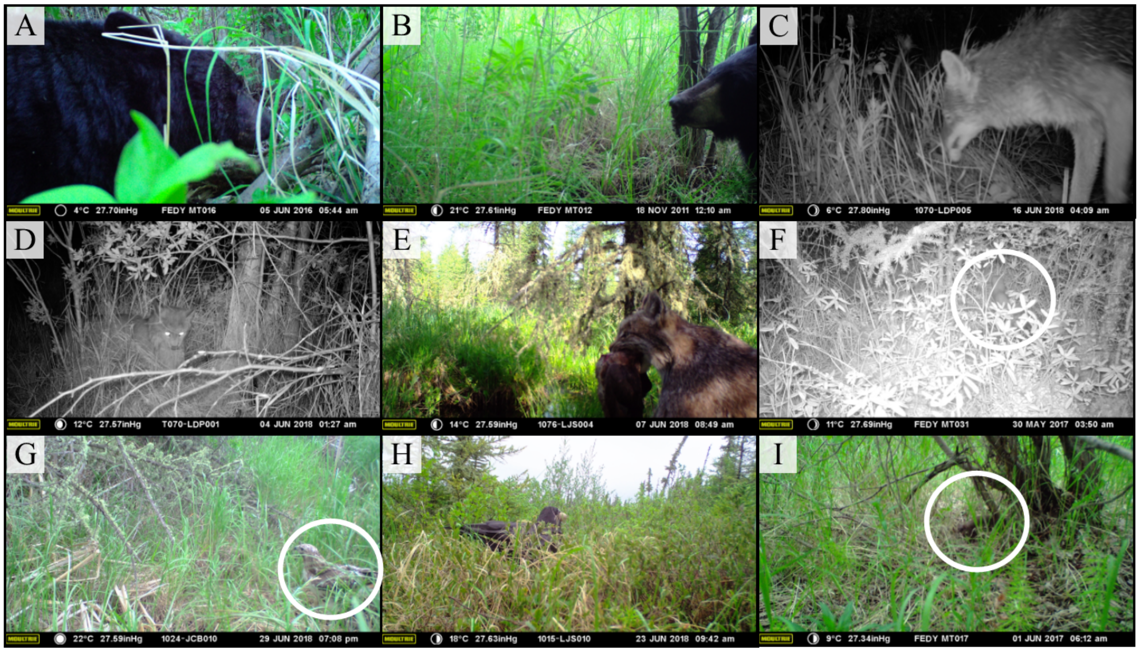

Figure 5.2: Images captured of nest predation events from real duck nests in the boreal forest of Alberta, Canada. American black bear predating an American Green-winged Teal nest (A). American black bear predating an American Wigeon nest (B). Coyote predates an egg from a Blue-winged Teal nest (C). Canada lynx encounters a Mallard nest (D). Canada lynx carries its Ring-necked Duck quarry following a predation event (E). *Mustela* spp. predating Mallard nests, with circles around the individual for aid in locating (F and I). Red-tailed Hawk lands beside a Blue-winged Teal nest during a predation event (G). Common Raven carries away a Lesser Scaup egg during a predation event (H).

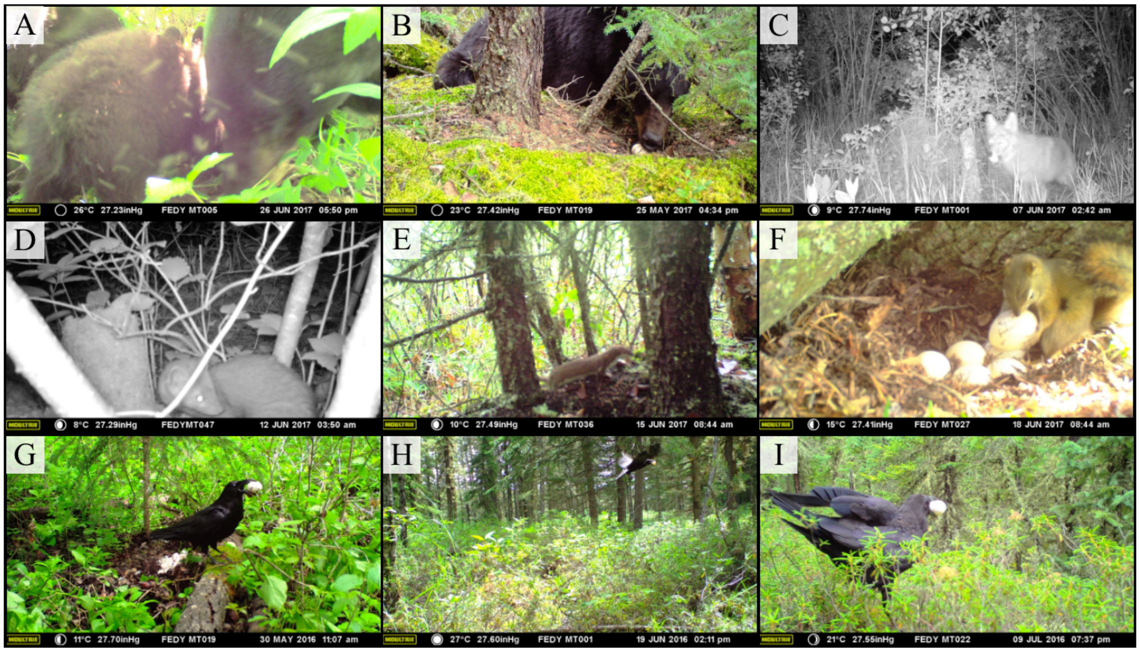

Figure 5.3: Images captured of nest predation events from artificial duck nests in the boreal forest of Alberta, Canada. American black bear sow and her cubs (A). American black bear (B). Coyote carries an egg away (C). American marten (D). *Mustela* spp. (E). Red squirrel carries an egg (F). Common Ravens (G – J).

5.6 Discussion

We identified 8 species of duck nest predators in the boreal forest using camera traps (Table 5.3; Fig. 5.2; Fig. 5.3). Our results fill a research gap by identifying important predators of duck nests in the boreal forest, a continentally significant breeding area. Notably, Common Raven were identified as a primary nest predator, which is consistent from other breeding areas and with other precocial birds (Sargeant *et al.* 1993; Dinkins *et al.* 2014). However, the primary mammalian predators were different from other regions (Sovada *et al.* 2001), suggesting that boreal ducks likely face unique predation pressures, and therefore, require different considerations for management and conservation strategies.

We observed differences in predator species richness and frequency of predation between real and artificial nests (Table 5.3), which may be related to predator foraging strategies, differences between predators of eggs vs hens, or bias associated with artificial nests (Butler & Rotella 1998; Thompson & Burhans 2004; Ball *et al.* 2008). Considering the results of real and artificial nests together suggest that black bear and Common Raven were responsible for the majority of nest predation (Table 5.3). However, considering only real nests, we did not identify an individual species responsible for the majority nest predation, while nest predation in other regions is often largely driven by one or two primary species (Sargeant *et al.* 1993; Sovada *et al.* 2001). Predators that were only detected at real nests (e.g., Canada lynx, Red-tailed Hawk) likely have a specific foraging tactic related to identifying the hen on the nest as opposed to the eggs (Table 5.3; Fig. 5.2). These predators may have used visual cues of the hen entering and exiting the nest site to locate the nest (Whelan *et al.* 1994; Clark & Wobeser 1997; Roper & Goldstein 1997; Opermanis 2004). For other species, such as red squirrels, hen presence at nests could deter predation through nest defence or nest crypsis (Montgomerie & Weatherhead 1988). We hypothesize that the lack of a dominant nest predator from real nest detections may be a result of duck nests being an opportunistic prey item, because they occur at lower nest densities in the boreal forest, which result in inefficient search efforts for many predators. Artificial nests provided us a viable technique for our study objectives; however, we concur with other authors that caution should be taken when making inference from these data as they can over or under represent predators of interest (Butler & Rotella 1998; Zanette 2002; Ball *et al.* 2008).

To our knowledge, our results provide the first confirmed observations in the literature of black bears and Canada lynx predating ducks nests. Black bears were egg predators and we did not record black bears predating hens. Other studies have suspected black bears as predators (Esler & Grand 1993; Corcoran *et al.* 2007) or observed black bears predating a Canada Goose (*Branta canadensis*) nest in the Arctic (Abraham *et al.* 1977) and grizzly (*Ursus arctos horribilis*) and polar bears (*Ursus maritimus*) have been detected eating Lesser Snow Goose (*Anser caerulescens caerulescens*) and Common Eider (*Somateria mollissima sedentaria*) nests (Johnson & Noel 2005; Gormezano *et al.* 2017). As generalist, opportunistic predators, we suspect that black bears likely randomly encounter boreal duck nests on the landscape while foraging in productive wetland riparian areas in the early spring (McDonald & Fuller 2005; Mosnier *et al.* 2008; Bastille-Rousseau *et al.* 2011; Popp *et al.* 2018). For example, black bears are calorically limited following hibernation and often forage on new shoots of graminoid species (Noyce *et al.* 1997; Bastille-Rousseau *et al.* 2011), which are often abundant along wetland edges and is important to microhabitat selection of boreal ducks (Dyson *et al.* 2019).

Canada lynx likely fill a similar niche in the boreal forest that bobcats (*Lynx rufus*) occupy elsewhere and have been reported as predators of precocial birds (e.g., sage-grouse; Lockyer *et al.* 2013; Kirol *et al.* 2018, ; bobwhites, Staller *et al.* (2005)). The predation events that we observed resulted in confirmed hen mortality and likely egg consumption on

3 of 4 occasions (Staller *et al.* 2005; Lockyer *et al.* 2013). Canada lynx are an interesting predator to consider in the boreal due to the observed cyclic population fluctuations with their primary prey (Krebs *et al.* 1995), snowshoe hares (*Lepus americanus*). Duck nests, or incubating hens, may provide an abundant alternative prey item (Mowat *et al.* 2001; Squires *et al.* 2010) for Canada lynx during spring and predation risk to hens could vary annually with hare abundance (Boutin *et al.* 1995). Lynx often engage in a sight foraging approach (Squires *et al.* 2010), which may result in lynx visually identifying nest sites of their potential prey by observing hen activity.

Corvids have been identified as important nest predators for many avian species (Andren 1992; Clark *et al.* 1995; Latif *et al.* 2012; Dinkins 2013; DeGregorio *et al.* 2016), and different corvid species exist in varying abundances across the entire breeding range of ducks. American Crow (*Corvus brachyrhynchos*) have been identified as important predators in some regions (Sargeant *et al.* 1993; Clark *et al.* 1995), but Common Raven are likely more important predators where they occur across the prairie, boreal, and into parts of the arctic biomes, because they are often behaviourally dominant and have a larger body size (Freeman & Miller 2018). Of concern, Common Raven abundance and distribution has been increasing with human development and disturbance, which could increase the risk over time for boreal nesting ducks (Angelstam 1986; Andren 1992; Bui *et al.* 2010; Dinkins *et al.* 2014). Birds of prey (i.e., raptors; Orders Accipitriformes, Strigiformes, and Facloniformes) may be under represented in our sample and pose a threat to incubating hens in the boreal forest (Table 5.3), because they are relatively abundant and they may use the hen as a visual cue for locating nests (Blohm *et al.* 1980; Opermanis *et al.* 2001; Opermanis 2004). For example, cameras may fail to detect predation events by raptors if they occur relatively quickly or outside of the cameras field of view and failed predation attempts on the hen may result in nest abandonment or predation characterization of ‘unknown’ (Opermanis *et al.* 2001).

Species of the genus *Mustela* were the most frequently detected predator of real nests (Table 5.3). We did not detect any *Mustela* spp. attempts at predating the incubating hen (Fleskes 1988). In other studies, weasels often removed or foraged on eggs over an extended time period interspersed with the return of the hen (Fleskes 1988). In our study, weasels caused abandonment following the initial encounter by removing eggs from the nest. Estimates of nest predation by weasels has not been well documented for ducks, and may have been historically underestimated, and could play a large role in nest failure for ducks (Keith 1961; Fleskes 1988). We also observed coyotes predating nests; however, we did not observe any nest predation by red foxes (*Vulpes vulpes*) or gray wolves (*Canis lupus*). Wolves are known to exclude coyotes and foxes from areas, which may help to reduce the risk of nest predation from canids (Levi *et al.* 2012); however, changes in the boreal forest may create more hospitable conditions for coyotes and could be a concern moving forward (Latham *et al.* 2013).

Climate and land use change are among the greatest threats to wildlife in the boreal forest (Slattery *et al.* 2011; Stralberg *et al.* 2015; Hebblewhite 2017). These changes have the potential to influence predator communities, altering their distribution and abundance, and therefore, have potential to influence waterfowl demographics (Fisher & Burton 2018). For example, black bear and Common Raven have increased in abundance in relation to industrial development (Andren 1992; Dinkins 2013; Tigner *et al.* 2014; DeMars & Boutin 2018). Canada lynx and coyote have been shown to be development tolerant species (Fisher & Burton 2018); however, these relationships are expected to vary regionally. For example, in response to land use change, predator management in the boreal forest has reduced wolf populations to benefit caribou (Hervieux *et al.* 2013; Serrouya *et al.* 2019), which could increase the abundance of coyotes on the landscape (Levi *et al.* 2012; Newsome & Ripple

2015). Finally, climate and land use change can result in the introduction of novel predators as ranges shift (Heim *et al.* 2017). For example, predators such as striped skunk (*Mephitis mephitis*) and norther raccoon (*Procyon lotor*) are currently rare in the boreal; however, species abundance seems to be increasing in the boreal transition zones with predicted further range expansion north (Pybus 1988; Larivière 2004; Latham 2008).

Our work provides baseline data necessary to build our understanding of ducks breeding in the boreal forest. Identifying boreal duck nest predators provides ecologists and managers with information needed to make predictions and decisions regarding the affect of land use and climate change on boreal waterfowl populations. A broader understanding is still required on how duck nest predator communities vary across space and time in the boreal forest and how rapid land use change and climate change will interact to influence predator-prey dynamics.

Chapter 6

Anthropogenic disturbance alters space use of terrestrial mammals in the western boreal forest of Alberta, Canada

6.1 Overview

Large scale anthropogenic disturbance is causing biodiversity loss and altering mammal community composition and abundance at a global scale. In Alberta's boreal forest, oil and gas exploration and extraction activities have produced a variegated landscape exposing wildlife to intensive local disturbance and broad landscape disturbance, particularly from anthropogenic linear features. Effects of disturbance on boreal woodland caribou and their predators, including wolves and black bears, have been well studied; however, the effect of

oil and gas on the broader community of boreal mammals remains less well understood. As part of a broader study to understand the effect of industrial development on the nesting ecology of ducks, we deployed 133 camera traps across 59 sites for a corrected total of 7857 trap nights from 2016 – 2018. We found predator species as a group had higher detection probabilities with greater industrial footprint, whereas prey species had lower detection probabilities. Coyotes showed both an increased detection probability and probability of use in association with industrial footprint, while bears and wolves had a higher detection probability with greater industrial footprint and Canada lynx did not appear to respond to development. For prey species, deer detection probability was lower in areas with increased industrial footprint, while snowshoe hare had an increased probability of detection, and moose appeared to show no response. In addition, we observed species specific responses to detection probability on linear features, suggesting varying behavioural responses to these industrial features. Our evidence suggests that industrial development is altering habitat use of predators and prey in the boreal forest. Together with previous identification of duck nest predators, our results highlight that industrial development increases habitat use and activity by predators in duck nesting habitat increasing predation risk. Our study provides further evidence of the far reaching effects of industrial development on boreal forest mammal communities highlighting the need for further study.

6.2 Introduction

Understanding species-habitat relationships is central to effective conservation and management. Globally, anthropogenic land use is changing species-habitat relationships leading to altered species interactions and biodiversity loss (Tscharntke *et al.* 2012). One mechanism of biodiversity loss involves alteration to predator-prey interactions, which shape ecosystem function and affect distribution and abundance of organisms (Sih *et al.* 2011). Altered competition dynamics among species can decouple coexistence mechanisms, such as spatial segregation associated with space use and resource availability, which can fundamentally change predator and prey community structure (Amarasekare 2003; Gorini *et al.* 2012). Examining the response of multiple species to anthropogenic change documents community shifts and provides insight into potential underlying mechanisms that can be used to guide management and improve our understanding of species ecology (Burgar *et al.* 2018; Farr *et al.* 2019).

Perturbations in predator-prey interactions as a result of anthropogenic disturbance have caused major ecological change globally (Venter *et al.* 2016; Burton *et al.* 2011; Packer *et al.* 2013; Lamb *et al.* 2017; Hebblewhite 2017). Agriculture and urbanization have historically been leading causes of land use change (Meyer 1992; Bayne & Hobson 1998; Rashford *et al.* 2011); however, industrial development from oil and gas exploration is a contemporary threat causing habitat loss and fragmentation across biomes (Naugle 2011; Allred *et al.* 2015; Hebblewhite 2017; Meixell & Flint 2017). Varying responses by mammals from predator and prey guilds to development create difficulty in arriving at generalizations from individual species responses, highlighting the value of simultaneous, multi-species approaches (Heim *et al.* 2019). For mammals, populations of some species may increase while others may experience declines in response to anthropogenic disturbance (Fisher & Burton 2018). For example, habitat generalist species (e.g., coyote, *Canis latrans*; white-tailed deer, *Odocoileus virginianus*) are typically predicted to increase in abundance (Latham *et al.* 2011a; 2013; Fisher *et al.* 2020), while habitat specialist species (e.g., wolverine, *Gulo gulo*; woodland caribou, *Rangifer tarandus caribou*) are predicted to decline (Sorensen *et al.* 2008; Stewart *et al.* 2016; Scrafford *et al.* 2017).

In North America, few ecosystems exist that are not experiencing wildlife community change as a result of anthropogenic disturbance (Caro *et al.* 2012). In the intermountain west, oil and gas development has altered avian and mammal communities with increased nest predation on sage grouse (*Centrocercus urophasianus*) and songbirds (Fedy *et al.* 2015; Hethcoat & Chalfoun 2015a; Kirol *et al.* 2020). In the prairies, land conversion to agriculture has resulted in mesopredator release greatly increasing predation on nesting birds, particularly ducks (Crooks & Soulé 1999; Phillips 2001; Frey & Conover 2006; Prugh *et al.* 2009). With the global demand for oil and gas resources predicted to increase, information about multiple species responses to development will improve our ability to effectively mitigate negative consequences and conserve wildlife on these working landscapes (Northrup *et al.* 2013; Tattersall *et al.* 2020).

In the boreal forest of North America, substantial growth in resource extraction industries, which include oil and gas and forestry, are causing landscape alteration as a result of industrial infrastructure and exploration activities (Pickell *et al.* 2015; Hebblewhite 2017). Current disturbance levels caused by industrial infrastructure exceed the historical range of variability caused by natural disturbance from wildfire and pests in this region raising concerns for the persistence of boreal wildlife (Pickell *et al.* 2015). Industrial linear features are the most prominent oil and gas associated infrastructure and include roads, pipelines, and seismic lines, which can be particularly influential on wildlife populations (Pickell *et al.* 2015; DeMars & Boutin 2018). The most common and widely distributed industrial linear features are seismic lines (Dabros *et al.* 2018), which are used to explore for oil and gas and can occur at high densities (Lee & Boutin 2006; Latham *et al.* 2011b; Dabros *et al.* 2018). These industrial linear features not only facilitate future development (i.e., drilling of wells, establishment of pipelines; (Johnson *et al.* 2020), but they also facilitate the movement of some wildlife (McKenzie *et al.* 2012) allowing for more efficient travel (Latham *et al.* 2011b; Dickie *et al.* 2017; Finnegan *et al.* 2018) and access for existing and novel predator species (Latham 2008; Latham *et al.* 2013; DeMars & Boutin 2018).

The wolf-caribou system has received the greatest amount of attention in the literature (Festa-Bianchet *et al.* 2011; Boutin *et al.* 2012; Serrouya *et al.* 2016; 2019; Hebblewhite 2017; Mumma *et al.* 2018; Johnson *et al.* 2019). In summary, strong evidence suggests the creation of early seral habitat from forestry cutblocks has resulted in an increase in abundance of primary prey (e.g., moose, *Alces alces*; white-tailed deer) for gray wolves (*Canis lupus*) resulting in increased wolf abundance (DeCesare *et al.* 2010; Hervieux *et al.* 2013). Subsequently, the creation of industrial linear features, namely seismic lines, facilitates wolf travel and provides access to habitat that was previously difficult to access, such as peatlands favored by caribou. This results in increased predation rates on caribou due to reduced isolation from wolves (Latham *et al.* 2011b; Muhly *et al.* 2015; Serrouya *et al.* 2016; Newton *et al.* 2017; Mumma *et al.* 2018; Pigeon *et al.* 2020). Other predators, such as black bears (*Ursus americanus*), select linear features for travel over interior forest (Tigner *et al.* 2014).

Considering a broad suite of species and impact of intervention on their interactions in management recommendations will likely produce the greatest conservation return on investment (Heim *et al.* 2019; Tattersall *et al.* 2020; Wittische *et al.* 2020). For example, wolves can play an important role in mediating mesopredator populations, such as coyote (Levi *et al.* 2012; Latham *et al.* 2013), whom are predators of small mammals and avian species (Latham *et al.* 2013; Dyson *et al.* 2020). Therefore, it is plausible that predator control efforts (Hervieux *et al.* 2014; Serrouya *et al.* 2019) could have unintended consequences on alternative prey species (e.g., small mammals or ducks) if novel predators like coyotes or other mesocarnivores (e.g., red fox, *Vulpes vulpes*; striped skunk, *Mephitis mephitis*; northern racoon, *Procyon lotor*) are able to colonize the boreal forest (Latham 2008; Latham *et al.* 2013). There is concern for the effect of predator community change on nesting birds (Mahon *et al.* 2019; Roy *et al.* 2019; Dyson *et al.* 2020) with habitat alteration and increased predation leading to biotic homogenization of avian communities (Mahon *et al.* 2016). Broader understanding of species responses to industrial footprint in the boreal forest outside of the caribou-wolf system is clearly needed to effectively conserve wildlife in this landscape.

In this study, we monitored how terrestrial mammals (hereafter mammals) responded to industrial development in central Alberta's boreal forest using camera traps. Specifically, we sought to understand if distribution and habitat use by mammalian predator and prey species differed as a response to the industrial footprint. Our efforts were part of a broader study investigating the effect of industrial development on ducks (Family Anatidae), a prey species of many terrestrial mammals in the region (Dyson *et al.* 2020). Consistent with previous research (Burgar *et al.* 2018; Fisher & Burton 2018; Tattersall *et al.* 2020), we hypothesized that the industrial footprint affected predator and prey space use. We predicted that in areas with greater industrial footprint there would be a higher probability of detecting predator species given a higher probability of use and abundance, while prey species would have a lower detection probability because of a lower probability of use and abundance due to a greater risk of predation. We also predicted that responses would vary by species within guilds having important consequences for management and conservation. Our multispecies approach provides further information about mammal responses to industrial development and advances conservation efforts for Alberta's boreal forest.

6.3 Methods

6.3.1 Study Area

Our study was located north of Slave Lake, Alberta, Canada, in the province's boreal forest natural region which is within Canada's Boreal Plains ecozone; hereafter the western boreal forest (WBF; Fig. 6.1). This region contains interspersed deciduous, mixed-wood, and coniferous forests in combination with extensive wetland complexes. Historically, natural disturbance events, such as insect outbreaks and wildfire have shaped this landscape (Downing & Pettapiece 2006; Carlson & Browne 2015). However, increasing pressure from human land use related to forestry and oil and gas development over the past few decades have created a prominent industrial footprint (Carlson & Browne 2015; Pickell *et al.* 2015).

This study was co-located with other research investigating relationships between industrial development, duck nest success, and their predators (Dyson *et al.* 2019; 2020). Therefore, our sites were selected to prioritize duck nesting areas and focused on wetlands using a hierarchical selection criteria (Dyson *et al.* 2019). We considered cumulative energy development, duck pair density, accessibility, land cover type, and forestry activities. We excluded sites that were recently logged or burned (within 20 years), because we were interested in understanding the effect of industrial development on ducks and their predators and wanted to control for potentially confounding factors (Dyson *et al.* 2019). We selected sites across the gradient of industrial development levels found in the study area that were within at least 3 km of a vehicle accessible road and contained at least 1 water body (>1 ha). A description of the study area and our process of site selection can be found in (Dyson *et al.* 2019, or Chapter 2).

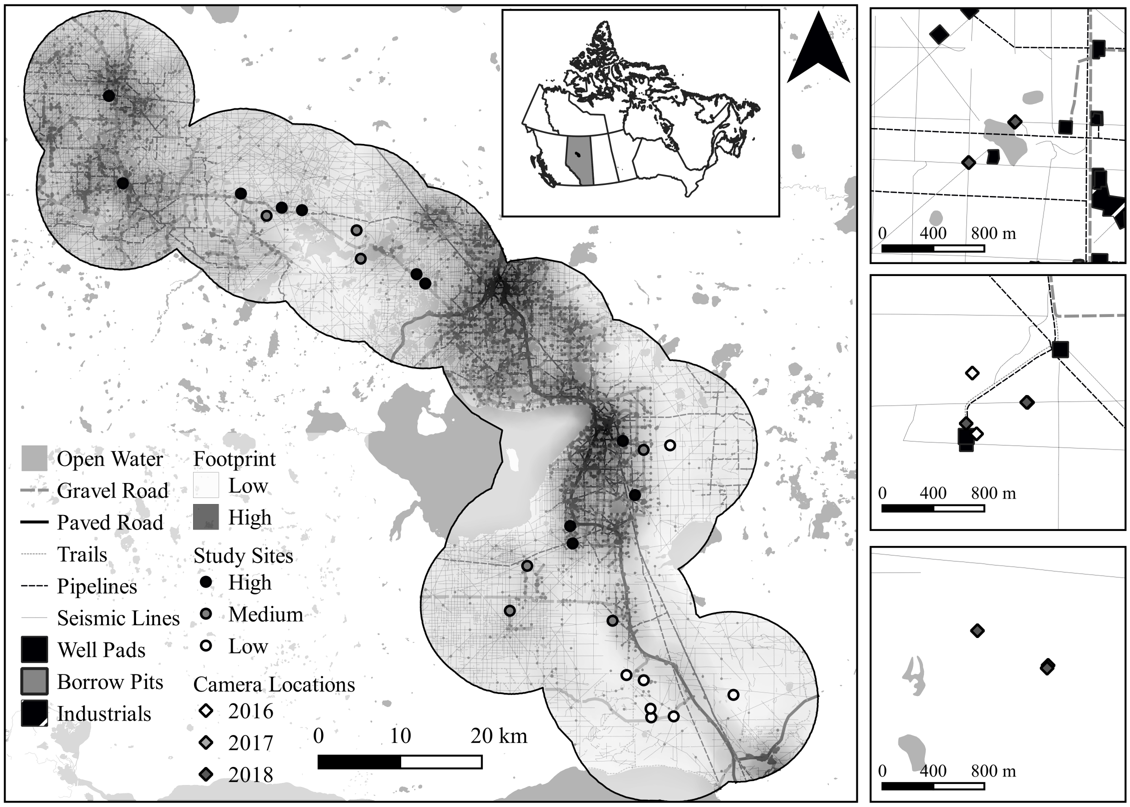

Figure 6.1: Map of the study area and study sites in the western boreal forest of Alberta, Canada from 2016 to 2018. Symbology for industrial development features is presented in the legend. Also shown is the gradient of industrial footprint summarized with a moving window at the 2500 m scale from light to dark. The right panels are examples of camera placement by year for 3 separate sites with a scale bar provided for reference. The top panel is a high development site, the middle panel is a low development site and the lower panel is a medium development site including different camera placement in 2016, 2017, and 2018.

6.3.2 Field Methods

We established 12–25 study sites per year from 2016 to 2018 and installed 2-4 cameras (Reconyx Hyperfire PC900, Reconyx Inc., Holmen, Wisconsin, USA) at each site for 20–90 days (Table 6.1, Table 6.2). In 2016, we had 20 cameras, therefore, we used shorter deployment periods (20–30 days), more cameras per site (2–4) and switched cameras to different sites half way through the season to maximize spatial coverage. We purchased an additional 20 cameras for 2017 and 16 cameras for 2018 and used 2 cameras per site that were left in place for the duration of the study period (90 days) in those years.

We installed cameras to maximize detection probability by placing them within approximately 500 m of a wetland along areas of anticipated wildlife use, which included industrial linear features at more developed sites and existent wildlife trails at sites that lacked industrial linear features (Cusack *et al.* 2015). We separated cameras by a minimum of 150 m in 2016 and at least 500 m in 2017 and 2018. We positioned cameras on trees at 50–100 cm above ground to capture medium to large-sized mammals and secured cameras to trees with python locks (Master Lock, Oak Creek, Wisconsin, USA) or steel wire. Cameras were triggered by an infrared motion sensor and we programmed cameras to high sensitivity, 5 pictures per trigger with a 3 second interval, and a 30 second quiet period. Pictures were recorded at a resolution of 1080P and each camera stored images on a 32 GB class 10 SD card (SanDisk, Milpitas, California, USA). For night time images, we used the illuminator and high quality setting. Cameras were powered by 12 AA NiMH rechargeable batteries. We monitored cameras every 7 – 21 days related to field logistics and replaced SD cards, batteries when they were below 50%.

In 2017 and 2018, cameras were paired with a scent lure (hereafter lure; O'Gorman's Long Distance Call, Broadus, Montana, USA) to maximize detection probability and a hair snag for noninvasive genetic sampling, where the scent lure and hair snag were placed within each camera's field of view 3–5 m from the camera (Fisher *et al.* 2016; Stewart *et al.* 2016). We decided to use lure after a low number of detections in 2016. In 2017, we added lure to 1 of 2 cameras per site and in 2018 we added it to all cameras. We applied scent lure using a medical tongue depressor and smeared approximately 1 tablespoon of lure on a tree directly across the camera at approximately 8 feet high. In 2017, we determined what camera received lure by flipping a coin. Lure was reapplied at each camera visit. Lure can increase the amount of time an individual spends in detection range, increasing the probability of detection, particularly for carnivores and lure does not have a negative effect on herbivores (Fisher & Burton 2012; Buyaskas *et al.* 2020; Holinda *et al.* 2020). We used lure to maximize detection probability and assumed that the zone of influence for lure was smaller in spatial scale than our site occupancy estimates (Stewart *et al.* 2019a). We were primarily interested in occupancy patterns across space and sampled the same sites annually across all years. We accounted for the variation in sampling with our modeling approaches by explicitly including a lure term for detection and a year term for occupancy.

Table 6.1: Description of study design and variables used to investigate occupancy.

Study design	
Site	Sites are independent of each other in terms of occupancy status. Each site consists of 2-4 cameras separated by a minimum of 200 m and median of 541 m.
Method	In 2016, we placed 2 – 4 cameras per site with no lure for up to 30 days at a time. In 2017 and 2018, we placed 2 cameras per site for the whole season (≈ 90 days; see Table 6.1). In 2017, we randomly selected one of two cameras at each site for lure application and in 2018 we used lure at all cameras.
Camera	One Reconyx PC900 infrared motion-triggered camera.
Parameters	
p – detection probability	The probability of detecting a species given it occupies the site and is available to be detected at a camera.
Θ – availability	The probability that at least one individual is using the area immediately surrounding the site on a given 10 day survey occasion (i.e., available for detection).
Ψ – habitat use or occupancy	The probability of habitat use at a site. The probability of an individual using the habitat surrounding a site over the course of our survey (2016 – 2018).
Variables	
Lure[a]	Whether scent lure was used at the camera.
Line[a]	Whether the camera was on an industrial linear feature (e.g., road, seismic line, pipeline).
Year[b]	Year of study (2016, 2017, 2018)
Wetland	Proportion of wetland surrounding a site centroid (for Ψ and Θ) or camera (for p).
Upland	Proportion of upland surrounding a site centroid (for Ψ and Θ) or camera (for p).
Footprint	Proportion of cumulative industrial development features (e.g., well pads, seismic lines, pipelines) surrounding a site centroid (for Ψ and Θ) or camera (for p).
Scales	
90	90 m buffer surrounding a camera used for detection models p
300	300 m buffer surrounding a camera used for detection models p
1000	1000 m buffer surrounding a camera used for detection models p
2500	2500 m buffer from the centroid of the study site used for Ψ
5000	5000 m buffer from the centroid of the study site used for Ψ

[a] Included only as covariates on detection probability

[b] Included only as a covariate on habitat use to account for the stacked design

Table 6.2: Summary of camera operation (mean and range) from 2016 – 2018 in the western boreal forest of Alberta, Canada.

Variable	2016	2017	2018
Number of sites	12	22	25
Number of nights	97.5 (72 – 124)	134.4 (78 – 158)	156.7 (112 – 176)
Active nights	97.5 (72 – 124)	131.1 (77 – 158)	152.1 (105 – 176)
Cameras/site	3.25 (2 – 4)	2 (NA)	2 (NA)
Setup dates	Jun 06 (May 15 – Jun 26)	May 19 (May 08 – Jun 19)	May 14 (May 06 – Jun 05)
Retrieval dates	Jul 07 (Jun 17 – Jul 26)	Jul 26 (Jul 25 – Jul 28)	Aug 01 (Jul 31 – Aug 02)

6.3.3 Analytical Methods

We processed camera images and identified species using Timelapse 2 software (Green *et al.* 2019). We created detection histories for mammals at each camera using camtrapR (Niedballa *et al.* 2016). We considered detection events independent when there were at least 60 minutes between detections of the same species. We defined an occasion as a 10-day period, so all images captured were collapsed into a 10-day detection history of 0 (not detected) or 1 (detected). Many cutoffs are used to define occasion lengths (Burton *et al.* 2015) and we chose 10-days to accommodate the low detection rates at our study area and to facilitate comparisons across species.

We used single-season, single-species multi-scale occupancy models (Nichols *et al.* 2008; Evans *et al.* 2019) because they allowed us to explicitly account for the hierarchical nature of our study design with regards to multiple cameras a site. We stacked years to accommodate low detection rates across sites and years (Linden & Roloff 2013; Fogg *et al.* 2014; Burnett & Roberts 2015; Ahlering & Merkord 2016; Fuller *et al.* 2016; Linden *et al.* 2017). Stacking is equivalent to estimating probability of occurrence across space and time. When stacking, occurrence and persistence are lumped into the same probability as opposed to the separate parameter estimates required when using a multi-season or dynamic occupancy model (e.g., extinction and colonization rates; MacKenzie *et al.* 2006). We treated each site-year combination as a unique site and then included year as a site covariate on occupancy.

We required a minimum of 10 sites with detections for a species to be included in our analysis (Buyaskas *et al.* 2020) to facilitate model convergence. We divided species detected into functional groups of predators and prey to investigate broader ecological patterns in addition to species-specific models to investigate species-specific patterns (Table 6.3).

Table 6.3: Summary table providing the number of detections and number of sites where detections occurred and the parameter estimates for the top models by species from 2016 - 2018 in the western boreal forest of Alberta, Canada. Species without parameter estimates were not modelled because of the low number of detections.

Species	Detections	Sites	Ψ			Θ			p		
			β	LCI	UCI	β	LCI	UCI	β	LCI	UCI
Predator			0.973	0.842	0.996	0.847	0.661	0.94	0.366	0.279	0.462
Black bear	273	54	0.954	0.612	0.992	0.818	0.55	0.943	0.303	0.206	0.415
Canada lynx	26	15	0.424	0.104	0.657	0.879	0	1	0.057	0.007	0.326
Cougar	1	1	-	-	-	-	-	-	-	-	-
Coyote	43	20	0.462	0.238	0.681	1	0	1	0.091	0.044	0.175
Fisher	9	8	-	-	-	-	-	-	-	-	-
Wolf	47	19	0.485	0.194	0.763	0.757	0.053	0.994	0.114	0.032	0.315
Marten	2	2	-	-	-	-	-	-	-	-	-
Weasel sp.	1	1	-	-	-	-	-	-	-	-	-
Prey			1	-	-	0.803	0.033	0.731	0.58	0.499	0.659
Caribou	14	6	-	-	-	-	-	-	-	-	-
Deer	672	50	0.865	0.694	0.95	0.705	0.615	0.781	0.542	0.446	0.637
Elk	3	3	-	-	-	-	-	-	-	-	-
Moose	83	35	0.74	0.528	0.878	0.822	0.055	0.997	0.13	0.058	0.269
Snowshoe hare	115	19	0.568	0.364	0.751	1	0	1	0.091	0.054	0.158

Variables

We developed a suite of biologically relevant variables to include in our multiscale occupancy models (Table 6.1). We included whether a camera was on an industrial linear feature (e.g., seismic line, pipeline) or not and the presence of lure for the detection process only and we included year for the occupancy process to account for the stacked nature of our data. Variables related to land cover and land use were considered for both detection and occupancy processes, which were represented by wetland and upland land cover derived from Ducks Unlimited Canada's Enhanced Wetland Classification layer (Ducks Unlimited Canada 2011). We also included a cumulative industrial development layer for detection and occupancy that included the aerial footprint of all industrial features occurring on the landscape, which we derived from the Alberta Biodiversity Monitoring Institute's Human Features Inventory (ABMI 2017).

We wanted to consider the scale effect for the land cover and land use variables because we predicted that spatial scale would affect species responses (Fisher *et al.* 2011; Toews *et al.* 2017; Stuber & Fontaine 2019). Therefore, we quantified these variables at multiple spatial scales using moving windows summarized across buffers (90, 300, 1000, 2500, and 5000 m). To account for the spatial relationship between parameters in our model, we only considered buffers from 90, 300, and 1000 m for detection (i.e., p) and buffers of 2500 and 5000 m for site occupancy (i.e., Ψ; Table 6.1). We expected that the probability of detection would be associated with features closer to a camera trap (within 1000 m), whereas, features associated with broader site occupancy would be affected by features at broader spatial scales consistent with our multiscale approach.

Model Development

We constructed models by first fitting the detection function (p) with unsaturated habitat use or occupancy (Ψ) and availability (Θ) parameters (i.e., intercept only). To reduce the number of candidate models to build, we tested all detection variables in a univariate framework and only carried forward variables that performed better than the intercept-only model into an additive framework and we did not consider interaction terms. We considered intercept only forms of Θ, because we assumed it was a nuisance parameter and is sufficient in this form to account for dependence in detections between the cameras at a site. Upland and wetland land cover were strongly negatively correlated across spatial scales, therefore, we did not include them in the same model for the estimation of any single parameter.

We moved the top-ranked detection model from the additive framework forward to the next step where it was held constant while we tested what spatial scale for each variable performed best to explain occupancy (Ψ) in a univariate framework. We then moved forward the top-ranked scale for each variable for occupancy into a multi-variable additive framework. In addition, we tested for a year effect on Ψ to account for the stacked nature of our data and selected the best model with AICc.

We fit multiscale occupancy models in R version 3.6.3 (R Core Team 2019) with the RPresence package version 13.5 (Nichols *et al.* 2008; Hines 2020). For all steps of the model fitting process, we excluded models that caused convergence issues (i.e, convergence warning < 3) from the final candidate set. Our models likely violate the closure assumption between sampling occasions and, therefore, we interpret our results to indicate habitat use and not occupancy (Latif *et al.* 2016).

6.4 Results

We had a total of 59 sites and 133 cameras deployed over 8044 trap nights corrected to a total of 7857 active nights to account for camera malfunction (e.g., tampering, equipment malfunction) across an annual trapping period starting mid May and ending at the end of July (Table 6.2). The most commonly detected species were deer (white-tailed and mule deer [*Odocoileus hudsonicus*]), followed by black bear, and moose (Table 6.3). Our predator multiscale occupancy models included black bear, gray wolf, coyote, and Canada lynx (*Lynx rufus*), and our prey models combined deer, moose, and snowshoe hare (*Lepus americanus*). Overall, detection probabilities were low (<20%) for most species except for deer and black bear (Table 6.3). Black bear had the greatest probability of use across the study area (Table 6.3). Here, we interpret occupancy to represent changes in habitat use (Latif *et al.* 2016) and detection to reflect the intensity of use as a function of animal abundance and selection (Steenweg *et al.* 2017).

The top-ranked predator model indicated that predators had a higher detection probability on industrial linear features, with lure, and with increasing industrial footprint within 90 m of the camera (Table 6.4, Figure 6.2). Conversely, the top-ranked prey model indicated no relationship with lure, a lower detection probability at cameras on industrial linear features and with increasing industrial footprint within 1000 m of cameras and an increased probability of detection with increasing upland land cover within 1000 m of cameras (Table 6.4, Figure 6.2).

Species-specific responses were fairly consistent within the predator group. Black bear probability of detection increased with lure and increasing industrial footprint within 90 m of the camera but decreased with greater proportion of wetland within 1000 m (Figure 6.3). Black bears were also less likely to use sites with greater wetland cover within 2500 m of a site centroid (Figure 6.3). Wolf detection probability was greater on industrial linear features and with increasing industrial footprint within 1000 m of cameras, but declined with lure. Wolf site use was greater in 2017 compared to 2016 and 2018 and increased with greater proportions of upland land cover within 2500 m of a site. Coyote detection probability increased on industrial linear features and with industrial footprint within 90 m but decreased with increasing upland within 1000 m (Figure 6.3). Coyotes were more likely to use sites with a greater proportion of industrial footprint within 2500 m of a site (Figure 6.3). Canada lynx had an increased probability of detection with lure and with wetlands within 90 m (Figure 6.3). Canada lynx habitat use decreased with greater proportions of upland within 2500m of a site and was greater in 2017 and 2018 (Figure 6.3). We were unable to quantify the effect of industrial footprint on habitat use for the lynx models due to convergence issues because of the low number of detections (Table 6.4).

For prey species, deer had a decreased probability of detection on lines, with increasing wetland land cover within 1000 m, and with increasing industrial footprint within 1000 m of cameras (Table 6.5, Figure 6.4). Deer also had greater habitat use with increasing upland land cover within 2500 m of a site (Figure 6.4). We did not include a year effect on habitat use for the deer model because they were detected at all sites in 2017, which caused convergence issues when included. Moose did not appear to be affected by any variables that we tested (Figure 6.4). Snowshoe hare had an increased probability of detection on industrial linear features, with lure, with increasing wetland land cover within 300 m and with increasing industrial footprint within 300 m (Figure 6.4). Full model selection tables for predator and prey species are presented in Appendix B

Table 6.4: Multiscale occupancy model selection results summary table showing competing models for predator species in the western boreal forest of Alberta, Canada from 2016 to 2018. Models shown are competing models (< 2 AICc) from the final stage of the model fitting procedure (Ψ). Numbers following underscores represent the top-ranked spatial scale for each covariate (e.g., Footprint_0090 is industrial footprint within 90 m). Full model candidate model sets and selection procedures (e.g., p) are available in the supplementary material for each species.

Model	K	LL	ΔAICc[a]	ωi
Predators				
Ψ() Θ() p(Lure + Footprint_0090 + Line)	6	1055.41	0	0.24
Ψ(Upland_2500) Θ() p(Lure + Footprint_0090 + Line)	7	1053.67	0.85	0.16
Ψ(Wetland_2500) Θ() p(Lure + Footprint_0090 + Line)	7	1053.73	0.9	0.15
Black bear				
Ψ(Wetland_2500) Θ() p(Lure + Footprint_0090 + Wetland_1000)	7	801.18	0	0.33
Ψ(Upland_2500) Θ() p(Lure + Footprint_0090 + Wetland_1000)	7	801.52	0.33	0.28
Wolf				
Ψ(Year) Θ() p(Footprint_1000 + Line + Lure)	8	253.14	0	0.25
Ψ(Upland_2500 + Year) Θ() p(Footprint_1000 + Line + Lure)	9	250.42	0.07	0.25
Ψ(Wetland_2500 + Year) Θ() p(Footprint_1000 + Line + Lure)	9	250.74	0.39	0.21
Ψ(Upland_2500 + Footprint_5000 + Year) Θ() p(Footprint_1000 + Line + Lure)	10	249.19	1.75	0.11
Coyote				
Ψ(Footprint_2500) Θ() p(Upland_1000 + Footprint_0090 + Line)	7	282.16	0	0.41
Canada lynx				
Ψ(Upland_2500 + Year) Θ() p(Lure + Wetland_0090)	8	185.32	0	0.34
Ψ(Upland_2500) Θ() p(Lure + Wetland_0090)	6	190.98	0.39	0.28
Ψ(Wetland_5000) Θ() p(Lure + Wetland_0090)	6	192.06	1.47	0.16
Ψ(Wetland_5000 + Year) Θ() p(Lure + Wetland_0090)	8	186.96	1.63	0.15

[a] Lowest AICc score for Predators = 1069.02, black bear = 817.38, wolf = 272.02, coyote = 298.35, Canada lynx = 204.20

Table 6.5: Multiscale occupancy model selection results summary table showing competing models for prey species in the western boreal forest of Alberta, Canada from 2016 to 2018. Models shown are competing models (< 2 AICc) from the final stage of the model fitting procedure (Ψ). Full model candidate model sets and selection procedures (e.g., p) are available in the supplementary material for each species.

Model	K	LL	ΔAICc[a]	ωi
Prey				
Ψ() Θ() p(Upland_1000 + Line + Footprint_1000)	6	1137.26	0	0.48
Deer				
Ψ(Upland_2500) Θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.14	0	0.25
Ψ(Wetland_2500) Θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.51	0.36	0.21
Ψ() () p(Line + Wetland_1000 + Footprint_1000)	6	957.46	0.73	0.18
Ψ(Footprint_5000) Θ() p(Line + Wetland_1000 + Footprint_1000)	7	955.16	1.01	0.15
Ψ(Upland_2500 + Footprint_5000) Θ() p(Line + Wetland_1000 + Footprint_1000)	8	953.21	1.75	0.11
Ψ(Wetland_2500 + Footprint_5000) Θ() p(Line + Wetland_1000 + Footprint_1000)	8	953.26	1.8	0.1
Moose				
Ψ() Θ() p()	3	475.23	0	0.32
Ψ(Upland_5000 + Footprint_5000) Θ() p()	5	471.78	1.25	0.17
Ψ(Footprint_5000) Θ() p()	4	474.75	1.82	0.13
Snowshoe hare				
Ψ() Θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	7	322.38	0	0.28
Ψ(Upland_2500) Θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.55	0.86	0.18
Ψ(Wetland_2500) Θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.84	1.15	0.16

[a] Lowest AICc score for prey = 1150.87, deer = 970.34, moose = 481.67, Snowshoe hare = 338.58

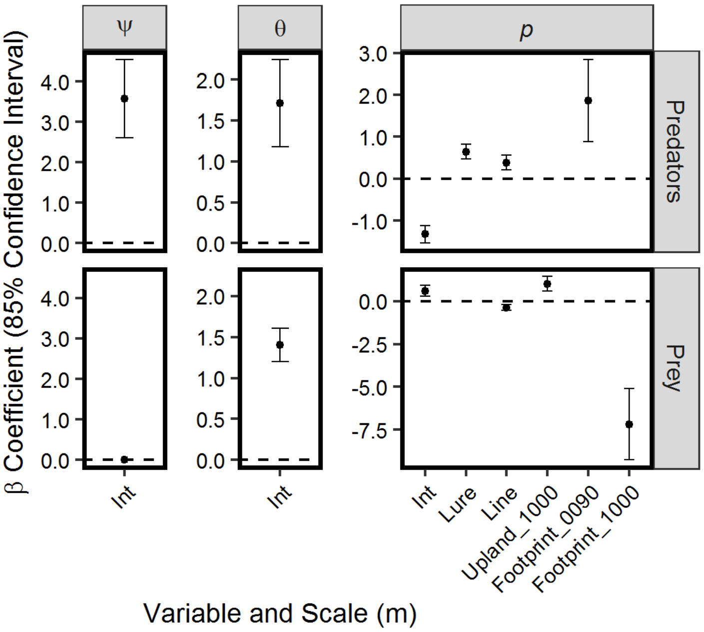

Figure 6.2: Beta coefficients and 85% confidence intervals for top models of predator and prey species use (Ψ), availability (Θ), and detection probability (p) in the western boreal forest of Alberta, Canada from 2016 to 2018. The beta coefficient for the prey model was fixed to a real parameter of 1 (i.e., 100% use) and therefore is displayed at a beta estimate of 0 with no error.

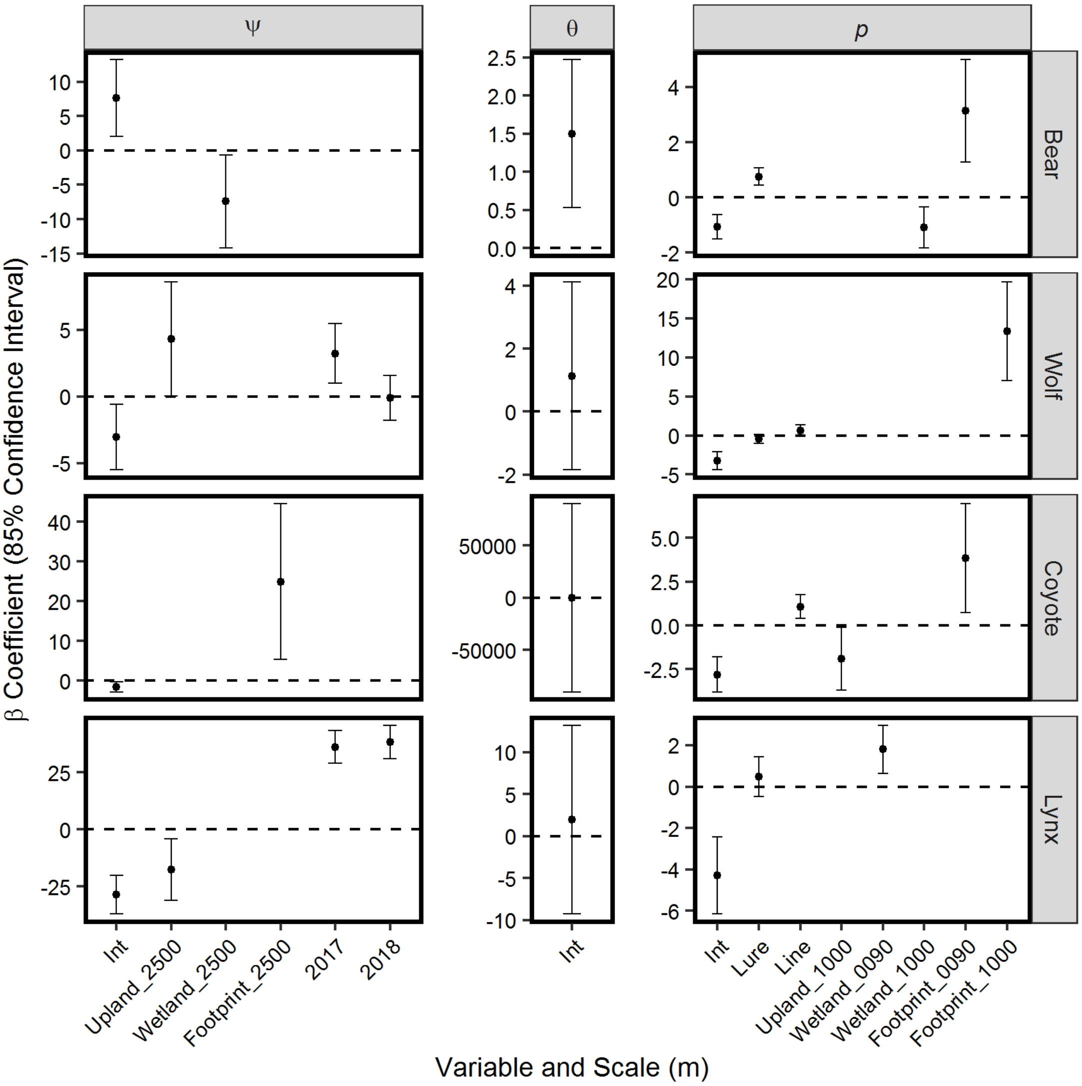

Figure 6.3: Beta coefficients and 85% confidence intervals for top models of predator species for use (Ψ), availability (Θ), and detection probability (p) in the western boreal forest of Alberta, Canada from 2016 to 2018. If a parameter estimate and error for any given parameter are not presented for a species, they were not included in the top model.

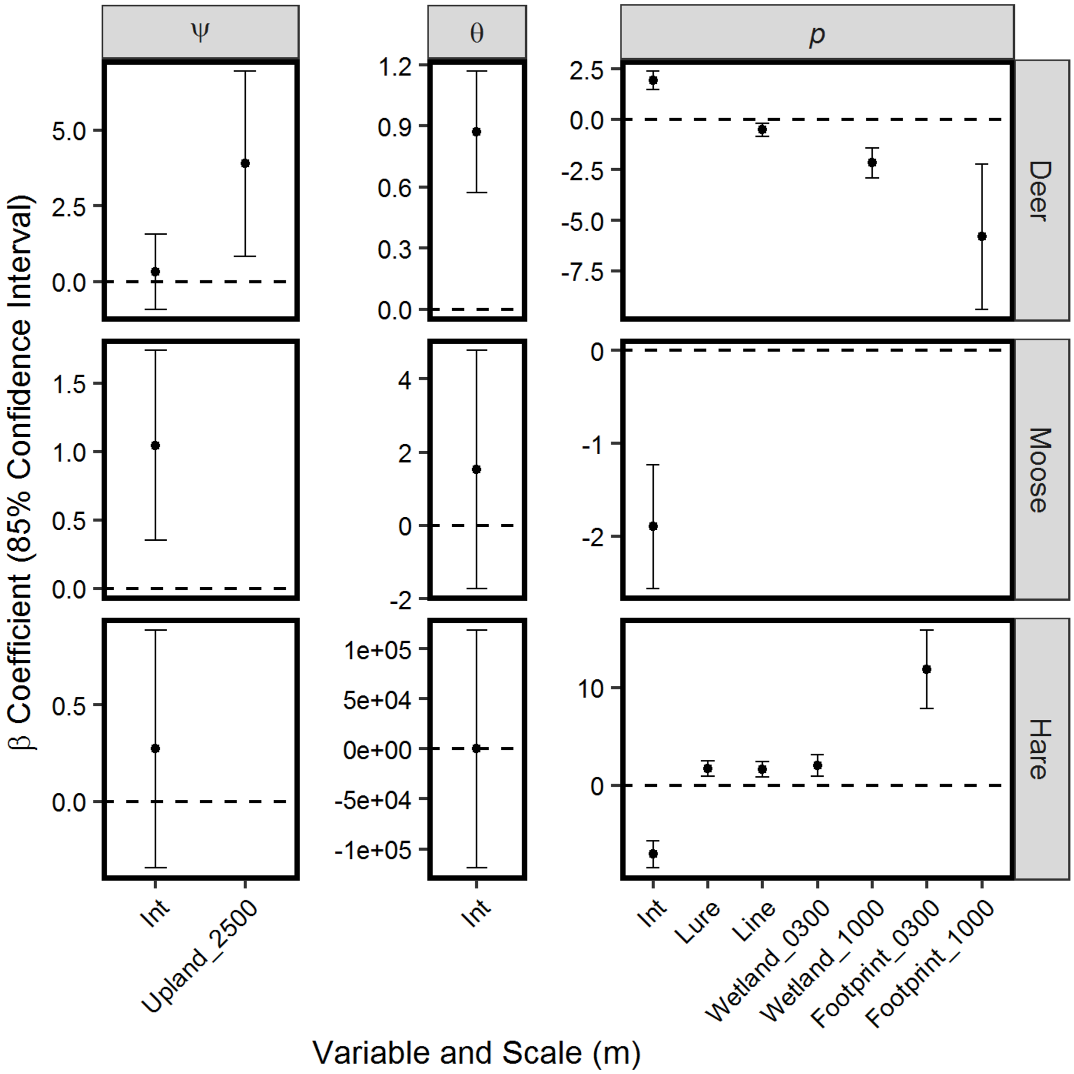

Figure 6.4: Beta coefficients and 85% confidence intervals for top models of prey species for use (Ψ), availability (Θ), and detection probability (p) in the western boreal forest of Alberta, Canada from 2016 to 2018.

6.5 Discussion

Our results indicate altered space use patterns of predators and prey caused by industrial footprint, consistent with results elsewhere in Alberta suggesting mammal communities in Alberta's boreal forest are experiencing broad scale change (Burgar *et al.* 2018; Fisher & Burton 2018; Tattersall *et al.* 2020). Increased use and detection probability for predators in areas with greater densities of industrial footprint may indicate a behavioural shift, making it more difficult for prey to avoid predation because of a more permanent predation risk (Tigner *et al.* 2014). Prey often mitigate this potential increased risk through spatial or temporal segregation from predators; however, this strategy may become more difficult over time with increasing development pressure and associated shifts in mammal community structure in the boreal forest (DeMars & Boutin 2018; Wittische *et al.* 2020).

Predators, as a guild, appeared to benefit from industrial footprint in our study because of greater use and detection probability in association with industrial features, complementary to other recent research (Wittische *et al.* 2020). Higher detection probability of coyotes, black bears, and wolves at cameras surrounded by more development may indicate greater abundance or more frequent use of these areas (Steenweg *et al.* 2018). These responses were scale dependent, where coyotes and bears showed a stronger response to development within 90 m while wolves responded at a coarser scale of 1000 m, possibly related to home range size (Fisher *et al.* 2011). Coyotes also tended to have greater use of sites with more industrial footprint, consistent with the hypothesis that industrial footprint facilitates coyote establishment in the boreal forest (Wheeldon *et al.* 2010; Latham *et al.* 2013). Meanwhile, our results suggest that wetlands are a preferred land cover type for lynx and likely provide valuable foraging habitat in the spring which overlaps with hare distribution and could facilitate opportunity to predate female ducks and their nests or other avian species (Dyson *et al.* 2020). Bears had a decreased probability of detection in wetland habitat, consistent with bear ecology, which would predict greater detection in upland habitat (Czetwertynski *et al.* 2007; Latham *et al.* 2011c; Tigner *et al.* 2014). Bears also demonstrated a positive association with industrial footprint and are known to prefer travel along seismic lines or roads which may also provide forage subsidies (Tigner *et al.* 2014; DeMars & Boutin 2018). Both canid species had increased detection on industrial linear features, which is consistent with canid movement and foraging ecology (Latham *et al.* 2013; Dickie *et al.* 2017). If industrial features facilitate incursions of predators into marginal habitat or habitat that was previously more difficult to access, such as wetlands, then predators may increase encounter rates with prey.

Prey appeared to avoid predators through decreased use or activity in areas with greater footprint or on industrial features and with greater use of upland habitat. We found deer were less likely to be detected with increasing footprint, which is consistent with other research in this region (Fisher *et al.* 2020). Although Fisher *et al.* (2020) found positive associations with block features (e.g., wells, industrials) for deer, they detected negative association with trails or unpaved roads, which we suspect might have driven our observed negative relationship. The increased use of upland land cover and lower detection probability in wetland habitat is generally consistent with deer ecology for use of preferred foraging habitat; however, their habitat preference likely varies seasonally (Latham *et al.* 2011a; Dawe *et al.* 2014; Fisher *et al.* 2020). Seismic lines may have more abundant herbaceous forage preferred by snowshoe hares promoting greater use of those features and potentially resulting in increased abundance of this important prey species on this landscape (Finnegan *et al.* 2018; MacDonald *et al.* 2020). None of the variables we examined explained variation in use or detection for moose, perhaps because of the spatial and temporal scale we measured or because moose are habitat generalists (Gillingham &

Parker 2008; Burgar *et al.* 2018).

Our study suggests that spatial patterns of use may be changing for mammals in response to anthropogenic disturbance. While mechanisms underlying change are unclear, interspecific interactions likely play a role in addition to land cover and land use features (Burgar *et al.* 2018; Wittische *et al.* 2020). For example, coyote and wolf detections were driven by a different suites of variables, consistent with interspecific competition causing coyotes to avoid wolves (i.e., coyotes avoided upland and wolves selected; Latham *et al.* 2013). In a separate study, coyotes selected areas away from upland boundaries and used bogs and fens more than wolves (Latham *et al.* 2013). Deer appeared to use habitat associated with development less frequently given their lower detection probability, potentially as a spatial avoidance mechanism from their primary predators, wolves and coyotes (Latham *et al.* 2011a; Dawe *et al.* 2014). Lynx and hare both had increased detection probability associated with greater amounts of wetland habitat and we would expect that lynx would have strong overlap with their most common prey species (Aubry *et al.* 2001; Krebs *et al.* 2001; Peers *et al.* 2020). Emerging analytical frameworks that allow for evaluation of coexistence and community structure and behaviour from camera trap data provide promise for future avenues of research and will improve our ability to understand the role of species interactions on distribution and abundance (Rota *et al.* 2016; Frey *et al.* 2017; Wittische *et al.* 2020). For example, while not an objective of our study, quantifying the strength of co-occurrence within species communities or temporal niche partitioning of spatially overlapping species could provide valuable additional insight into boreal mammal communities.

A primary motivation for our study was to understand how shifting predator communities might affect duck nest success (Dyson *et al.* 2019; 2020). Our results support the hypothesis that duck predators, such as bears and coyotes, may be more active in developed areas and, therefore, have a higher probability of encountering duck hens and their nests (Phillips *et al.* 2003). In addition, if coyotes are increasing their abundance and distribution in the boreal forest (Latham *et al.* 2013), and spatially separating from wolves by using wetland habitats more, then ducks may face additional predation pressure that previously did not exist in the boreal forest, if coyote predation is additive. While bears appeared to avoid wetland habitat suggesting reduced spatial overlap with ducks, we grouped fen, bog, and marsh into a large wetland category. Bears are known to avoid peatland habitat (DeMars & Boutin 2018); however, we also found similar patterns of avoidance of fen and bog habitat for ducks (Chapter 3) and marsh habitat may create areas of spatial overlap between ducks and bears. We also previously identified that weasels (short or long tailed weasels; *Mustela ermina*, *M. nivalis*) were important predators of duck nests in this region (25% of observed nests depredated; Dyson *et al.* 2020); however, we did not detect enough mustelids for this analysis (Table 6.3) to explicitly model their relationship with industrial footprint. Research from other regions in Alberta suggests that distributions of larger mustelids (e.g, American marten, *Martes americana*; fisher, *Pekani pennanti*; and wolverine, *Gulo gulo*) are also changing in response to industrial footprint and that densities are generally lower in developed areas possibly reducing predation risk for some species (Fisher *et al.* 2013; Tigner *et al.* 2015; Stewart *et al.* 2016; Scrafford *et al.* 2017). Finally, we also identified that common ravens (*Corvus corax*) were common avian nest predators (13% of observed nests depredated; Dyson *et al.* 2020); however, we were unable capture their relationship with industrial footprint with our study design and suggest that inclusion of avian predator community responses to development in the boreal forest is needed. For example, ravens have generally increased in other areas with anthropogenic development and have been expanding across western North America resulting in increased nest predation rates of other avian species (Brussee & Coates 2018; Coates *et al.* 2020).

The energy sector has invested resources into mitigating the negative effects of industrial footprint through planning and restoration efforts (Dabros *et al.* 2018; Tattersall *et al.* 2019), particular for reducing wolf-caribou interactions (Finnegan *et al.* 2018; Pigeon *et al.* 2020). These efforts could have consequences for other species and influence predator-prey interactions. For example, there is uncertainty regarding line restoration practices and natural regeneration given that wildlife trails often remain in existence following restoration and regeneration (M. Dyson personal obs., Tigner *et al.* 2014). In addition, while black bear use did decrease on regenerating lines, it was still greater than use of interior forest highlighting the potential for legacy effects of seismic lines (Tigner *et al.* 2014). Current restoration efforts do not appear to have an immediate impact on reducing wildlife use (Tattersall *et al.* 2019), therefore, prioritizing areas for protection with low or no development should be an immediate goal for protected areas. Controversial management techniques, which include wolf culling (Hervieux *et al.* 2014; Serrouya *et al.* 2019), appear to offer temporary relief to caribou in the absence of habitat regeneration and protection. However, these techniques may also result in unintended ecological consequences to other species, which might include mesopredator release (e.g. increased coyotes) resulting in increasing predation risk for other prey species in the boreal forest (e.g., ducks, hares, rodents). Furthermore, borrow pits, a common industrial feature that produce artificial ponds attractive to nesting ducks (Chapter 3), may increase attractiveness to predators to frequent borrow pits because of prey availability (Scrafford *et al.* 2020).

Considering our results in context of other research in the region (Toews *et al.* 2017; Burgar *et al.* 2018; Fisher & Burton 2018; Heim *et al.* 2019; Tattersall *et al.* 2020; Wittische *et al.* 2020), continued effort will be required to improve our understanding of the effect of industrial development on wildlife communities as well as the non mutually exclusive hypothesis of climate change driven shifts in species interactions, distribution, and abundance (Peers *et al.* 2020). Continued research is needed to investigate effects of individual features (e.g., roads, seismic lines, well pads) to improve more targeted conservation efforts, which will require broad spatial and temporal replication to appropriately address species-specific responses. Companion studies, such as telemetry studies that provide insight into behavioural modifications to space use, will also provide valuable insight into finer scale responses than camera traps can provide. We expect effective conservation and management of the boreal forest to require comprehensive approaches that integrate species specific approaches to inform community level responses.

Chapter 7

Discussion

This dissertation provides new information about the nesting ecology of boreal ducks which will be used to support conservation and management initiatives in the boreal forest under continued anthropogenic pressure. We identified nest-habitat associations for ducks at multiple orders and spatial scales and evaluated the consequences of those choices on nest success. In addition, we identified the important nest predators of ducks in the boreal forest and investigated how industrial development altered predator habitat use. Together, this work produces multiple lines of evidence to help improve our understanding of boreal duck ecology and also provides a foundation for necessary future work in this important breeding area that is expected to face continued expansion of the industrial footprint.

Our results indicate that industrial development is currently and has the potential to continue to alter the nesting ecology of boreal ducks. While we did not detect negative effects of development on nest survival, we did provide evidence of avoidance during nest-site selection for some industrial features (e.g., seismic lines, pipelines) as well as altered space use by important nest predators. Our results indicate that ducks are resilient to current levels of disturbance during nesting. It is important to note that we did not evaluate the consequences on brood survival, where negative effects could also manifest and reduce recruitment (Bloom *et al.* 2012; Gibson *et al.* 2016). Proximity to suitable brood-habitat may be just as important as nest-site selection because fitness is predicated not only on a successful nest but also on the survival of offspring to independence (Refsnider & Janzen 2010). Additionally, sub-lethal effects that could result in carry over effects (COEs) and ultimately reduced survival and fitness would not have been detected with our approach (Sedinger & Alisauskas 2014). For example, females could have reduced nesting or renesting propensity or duckling survival may be reduced if food availability is lower in areas with greater footprint (i.e., bottom up; Arnold *et al.* 2010).

Our approach was mostly limited to considering duck species by nesting guild; however, we suspect that responses to industrial development are species-specific. At the microhabitat scale, we were able to identify variation among species in nest-site selection strategies and suggest that this variation facilitates coexistence through resource partitioning (Chapter 2; Dyson *et al.* 2019). At the landscape scale, our sample did not allow us to investigate species-specific multiscale variation because there was not enough nests across a large spatial extent to detect variation between nests of different species. Therefore, we considered the nesting guild as a grouping variable (Chapter 3, Chapter 4). There is variation in population trends among boreal nesting species (Canadian Wildlife Service Waterfowl Committee 2019). Blue-winged Teal are increasing, while Mallard, American Green-winged Teal, American Wigeon, and Ring-necked Duck are in decline. Further data collection and evaluation of the mechanisms underlying these trends will prove beneficial to management and understanding expected population trajectories.

Our results are also consistent with previous research showing broad scale community change of mammal communities in the boreal forest as a result of industrial development

(Burgar *et al.* 2018; Fisher & Burton 2018; Heim *et al.* 2019; Wittische *et al.* 2020). Variation in the response among species is consistent with the identification of winners and losers on this landscape, where some species appear to benefit from development, particularly predators like bears and coyotes (Burgar *et al.* 2018; Fisher & Burton 2018; Mahon *et al.* 2019). Continued evaluation of species-specific responses to development by predators and prey will be important in association with estimates of species abundance or density, which will affect species interactions. With the predicted changes to the boreal climate, novel predators such as striped skunks (*Mephitis mephitis*) and northern racoons (*Procyon lotor*) may expand into the boreal forest (Latham 2008) and red fox (*Vulpes vulpes*) may increase in response to changes in abundance of wolves and coyotes (Newsome & Ripple 2015).

Our work provides a conceptual framework and baseline for understanding the effect of anthropogenic disturbance on nesting ecology for ducks. By investigating nest-site selection and survival as separate processes as well as identifying predators and changes in their distribution, we were able to provide stronger inference. Specifically, we demonstrate an avoidance to industrial development during nest-site selection that may reduce survival consequences at current development levels. With this evidence and our evidence demonstrating positive effects of industrial development on important nest predators, we suspect that negative demographic effects may not yet be realized or might manifest in other vital rates. To improve our understanding of boreal ducks, further data should be collected to cover the range of environmental variation expected for boreal ducks and increase sample size to allow for a more robust assessment of species-specific relationships.

7.1 Caveats and Limitations

Prior to our work, large scale on-the-ground surveys of nesting ducks had not occurred in the boreal forest. Consequently, we adapted techniques used primarily in the prairies and Arctic for nest searching (Klett *et al.* 1986; Petrula 1994). We acknowledge that our approach limited the number of locations nests could be found to our searched areas. For example, our efforts focussed on searching in proximity to wetlands and bodies of water. If predation risk is greater near wetlands, then ducks may avoid nesting in close proximity to wetlands (Greenwood *et al.* 1995). If ducks are selecting nest sites farther from water, in the upland habitats, it would increase the area required to search. While we do not have explicit evidence to determine if our sample was missing nests, we did search or explore habitat up to 300 m away from a wetland and over 3 years we located only a few nests greater than 100 m from a waterbody. In addition, wetlands are common on this landscape and therefore, we suspect that our efforts likely provided a representative sample of duck nests but acknowledge the potential for ducks to nest further from water in upland habitats and see opportunity in efforts to resolve this question.

We were primarily interested in the effect of industrial development (i.e., oil and gas) on nest success. As a result, we excluded the confounding effects of forest harvest and fire from our study design. Consequently, this limits our ability to generalize our results across the broader boreal landscape because these important drivers of landscape change are ubiquitous and likely interact with industrial development. Climate change can further exacerbate land cover and land use change in the region (Adde *et al.* 2020b), which we did not specifically study. Transferability of predictive models to novel areas have long been questioned and landscape context has been identified as a primary reason for lack of correspondence between models trained in one area and applied in another (Winiarski *et al.* 2020). To help alleviate some of these concerns, we also quantified the predictive error from our models to help provide practitioners the ability to evaluate the strength of evidence for some areas. We recommend that independent data is needed to test the predictive ability of our models applied in in novel habitats such as areas of forest harvest or wildfire.

Avian predators, particularly common ravens, were also important nest predators in our study, but our camera trap design precluded us from investigating changes in their use of habitat in association with industrial development. Formal avian point count surveys or nest counting efforts could produce more appropriate indices of abundance for avian predators such as ravens or raptor species (Bosakowski & Smith 1998; Dinkins *et al.* 2016; Brussee & Coates 2018). Our camera trap design was also not as effective for capturing small mammal species, like weasels (Genus *Mustela*). Approaches that would allow for entire community assessment are rare because of the challenge of adequately sampling for every species within a community (Ferreras *et al.* 2016; Connor *et al.* 2017). Additional cameras positioned to capture small mammals or supplementary approaches such as track plates would also improve our ability to detect small mammal species (Shonfield & Bayne 2019; Brown *et al.* 2020).

7.2 Future Work

A common theme in scientific research is that most studies generate more questions and ours is no exception. Importantly, our study occurred over a period of 3 years making it challenging to capture the range of environmental variation or time-lagged effects that might affect populations dynamics of ducks (Stephens *et al.* 2005; Ringelman *et al.* 2018). There is no substitute for the value of long term research studies to investigating complex ecological questions and the future trajectories for wildlife in the boreal forest certainly constitute a complex challenge.

The effects of forestry practices on ducks are beginning to be understood (Lemelin *et al.* 2007; McLean 2020); however, there remains much work to do. Understanding the effect of harvest block size, age, and regeneration along with cumulative effects and interactions with other disturbances are important areas of future inquiry. In addition, wildfire has played an important role in maintaining the boreal forest landscape and fire regimes are expected to change rapidly with the changing climate (Wilkinson *et al.* 2019; Wang *et al.* 2020). While there has been some research on duck responses to fire (Lewis *et al.* 2015; 2016), it is evident that more effort is needed to understand how predicted increase in fire return will affect boreal ducks.

Another important avenue for waterfowl research in the boreal forest is co-management strategies with Indigenous groups as well as the incorporation of traditional ecological knowledge in decision making (Schang *et al.* 2020; Wong *et al.* 2020). Ducks and their eggs are an important food resource in this region and understanding the effect of consumptive use during the breeding period and beyond would be valuable to our understanding of population dynamics. Furthermore, traditional ecological knowledge of important duck nesting habitat could help improve our ability to identify or confirm protected areas in accordance with our predictive models and knowledge of duck abundance (Barker *et al.* 2014; Polfus *et al.* 2014; Adde *et al.* 2020a; Singer *et al.* 2020). Continued conservation efforts in the boreal forest will be maximized through collaboration and consultation with local Indigenous peoples (Wong *et al.* 2020).

Restoration of linear features and forest recovery following development and fire is an active area of research in the boreal forest. Current efforts do not appear to be having a strong short-term effect on wildlife (Tattersall *et al.* 2019); however, long-term effects and benefits are yet to be realized. The potential for legacy effects (i.e., permanent or long-term effects) following industrial disturbance can permanently change these landscapes and should be incorporated into the planning process. For example, many researchers report the establishment of wildlife trails on linear features following recovery or restoration (Tigner *et al.* 2014, , M.Dyson pers. obs.), which could counteract the benefits of restoration and recovery efforts. Consequently, these efforts must focus on restoring landscapes to functional equivalents in addition to using other measures of success such as canopy height or stem densities (Van Rensen *et al.* 2015; Finnegan *et al.* 2018). Restoration efforts are likely to increase in this region over the coming years and active research and monitoring on effective techniques will prove valuable to sustaining wildlife populations.

Sample size is often a challenge in observational studies and we faced some limitations associated with sample size related to investigating species specific effects and industrial feature specific effects. Systematic sampling of high probability nesting areas might help alleviate some concerns associated with habitat biased nest searching efforts and increased searching effort could help locate a more suitable number of nests for detailed investigation. Alternatively, telemetry can provide unbiased estimates of nest locations; however, this approach often limits research to one species (Howerter *et al.* 2014). We attempted to use telemetry approaches to locate nest sites of Mallards as part of this work but found low nesting propensity for marked birds among other logistical challenges associated with the boreal landscape. We are working to report and publish these findings separate from this dissertation. Future consideration of telemetry approaches should consider the effects of modern transmitters (i.e., satellite or GPS Kesler *et al.* 2014; Kirol *et al.* 2020) on nesting by evaluating transmitter attachment methods (*sensu* Rotella *et al.* 1993) and their effect on movement, reproduction, survival, and behaviour.

Advances in remote sensing continue to benefit wildlife research (Matasci *et al.* 2018;

Lewis *et al.* 2018; Mahdianpari *et al.* 2020). We used a publicly available data set from the Alberta Biodiversity Monitoring Institute for land use features (ABMI 2017) paired with a proprietary land cover layer produced by Ducks Unlimited Canada (Ducks Unlimited Canada 2011). One advantage to using these available data sets is for reproducibility because other users can find and implement these layers in their own work as opposed to privately digitized layers. In addition, continued improvement in data resolution from satellites will allow for finer scale questions to be answered such as possibilities of measuring and predicting microhabitat characteristics using remotely sensed data . Unmanned aerial vehicles (UAV) could allow specific high resolution data to be collected that could help answer questions related to regeneration and restoration efforts or to understand the influence of microtopography (Gonzalez *et al.* 2016; Chen *et al.* 2017). UAVs have also proven useful for counting broods using thermal imagery and have been used for locating nests; but with limited success (Pöysä *et al.* 2018; Bushaw *et al.* 2019; Bushaw 2020). Infrared cameras may also provide an opportunity to locate and monitor nests of cavity nesters (e.g., Bufflehead, Common Goldeneye) in the boreal forest, a chronically understudied group of ducks.

Finally, our camera trap approach could be improved by employing a grid based design, sampling across the entire landscape as opposed to in association with our nest searching efforts. A grid based design is better suited for occupancy modelling approaches and would allow for investigation of abundance through the use of approaches like the Royle-Nichols extension of a single-season occupancy model or spatial mark recapture (Royle & Nichols 2003; Fuller *et al.* 2016; Dupont *et al.* 2020). Currently, advances are being made in this field to allow researchers to estimate abundance of unmarked animals, which could provide more accurate density estimates over time to help understand community responses to land cover and land use change (Burgar *et al.* 2018). Evidently, continued technological advances in field methodology and statistical approaches will improve our ability to understand these complex remote landscapes.

7.3 Final Remarks

This dissertation provides new information to scientists, managers, and practitioners that will be used for conservation planning in the region but many questions still remain. Effective conservation and management for boreal ducks is poorly understood because we are only beginning to understand the species-habitat relationships and demographic implications of industrial development. Our work provides a framework and baseline for future research to explore species-specific responses of ducks and to continue to evaluate responses over time in association with environmental variation and climate change. Continued efforts to improve our understanding of species ecology and community responses that affect the distribution and abundance of wildlife in the boreal forest are urgently needed to maintain healthy wildlife populations.

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APPENDICES

Appendix A

Plant species list for microhabitat analysis

Table A.1: List of plant species identified at nests and random locations for each duck species from 2016 - 2018 in the western boreal forest, Alberta, Canada.

			AGWT		AMWI		BWTE		CANV		LESC		MALL		NSHO		RNDU	
Species Name	Scientific Name	Guild	Nest	Rand.	Nest	Rand.	Nest	Rand.	Nest	Rand.	Nest	Rand.	Nest	Rand.	Nest	Rand.	Nest	Rand.
common yarrow	*Achillea millefolium*	Forb	.	1	1	2	4	3	.	.	.	.	.	1	.	.	.	1
carrot spp.	Apiaceae spp.	Forb	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
western columbine	*Aquilegia formosa*	Forb	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.
wild sarsaparilla	*Aralia nudicaulis*	Forb	.	.	.	2	1	.	.	.	.	.	2	4	.	.	1	1
aster spp.	*Asteracae*	Forb	2	.	1	1	3	6	.	.	.	.	1	.	.	.	.	1
water arum	*Calla palustris*	Forb	.	.	2	3	6	2	.	.	1	1	1	1	.	.	7	4
marsh marigold	*Caltha palustris*	Forb	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
fireweed	*Chamerion angustifolium*	Forb	2	1	6	5	10	10	.	.	2	1	4	1	.	.	2	3
water hemlock	*Cicuta bulbifera*	Forb	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1
canada thistle	*Cirsium arvense*	Forb	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
thistle spp.	*Cirsium* spp.	Forb	.	.	2	3	4	7	.	.	.	.	3	1	1	1	.	2
marsh cinquefoil	*Comarum palustre*	Forb	1	.	.	.	6	6	.	.	2	2	2	2	.	.	7	6
bunchberry	*Cornus canadensis*	Forb	2	.	1	2	1	3	.	.	1	1	2	6	.	.	.	1
round-leaved sundew	*Drosera rotundifolia*	Forb	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.
sundew spp.	*Drosera* spp.	Forb	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.
horsetail spp.	*Equisetum* spp.	Forb	7	7	7	7	20	18	.	1	2	1	8	7	1	1	1	3
strawberry spp.	*Fragaria* spp.	Forb	2	2	.	3	4	2	.	.	.	1	2	5	.	.	1	3
bedstraw spp.	*Galium* spp.	Forb	2	1	.	1	3	6	.	.	.	.	1	.	.	.	1	5
bicknell's geranium	*Geranium bicknellii*	Forb	2	1	2	.	5	5	.	.	1	1	1	1	.	1	.	3
cow parsnip	*Heracleum sphondylium*	Forb	.	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.
spotted touch me not	*Impatiens capensis*	Forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
creamy peavine	*Lathyrus ochroleucus*	Forb	.	.	2	.	1	.	.	.	.	.	1	.	.	.	.	.
peavine spp.	*Lathyrus* spp.	Forb	2	1	3	3	4	6	.	.	1	1	1	2	.	1	.	.
duckweed spp.	*Lemna* spp.	Forb	1	1	.	1	2	1	.	.	.	.	.	1	.	.	9	5
twinflower	*Linnaea borealis*	Forb	2	.	1	.	.	3	.	.	.	.	.	2	.	.	.	.
yellow loosestrife	*Lysimachia punctata*	Forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
tufted loosestrife	*Lysimachia thyrsiflora*	Forb	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	1
canada mayflower	*Maianthemum canadense*	Forb	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
maianthemum spp.	*Maianthemum spp.*	Forb	.	.	.	1	4	3	.	.	1	.	1	1	.	.	1	1
Three leaved solomon	*Maianthemum trifolium*	Forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
yellow sweet clover	*Melilotus officinalis*	Forb	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
sweet clover	*Melilotus spp.*	Forb	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
wild mint	*Mentha arvensis*	Forb	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	2
bluebells spp.	*Mertensia spp.*	Forb	.	.	1	.	2	1	.	.	.	.	.	.	.	.	.	.
bishop's cap	*Mitella nuda*	Forb	.	.	.	1	.	.	.	.	.	1	1	1	.	.	.	.
water cress	*Nasturtium officinale*	Forb	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
coltsfoot spp.	*Petasites spp.*	Forb	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
plantain spp.	*Plantago spp.*	Forb	.	.	.	1	2	.	.	.	.	.	.	.	.	.	.	.

smartweed spp.	*Polygonum spp.*	Forb	.	.	.	.	.	.	.	.	.	.	1	1	.	.	1	.
cinquefoil spp.	*Potentilla spp.*	Forb	.	.	.	1	1	1	.	.	1	.	.	1	1	.	3	1
wintergreen spp.	*Pyrola spp.*	Forb	.	.	2	.	.	1	.	.	.	.	.	1	.	.	.	2
cloudberry	*Rubus chamaemorus*	Forb	.	.	.	.	.	.	.	.	2	4	4	2	.	.	.	2
dewberry	*Rubus pubescens*	Forb	1	.	2	4	4	4	.	.	1	.	3	.	.	1	1	2
curled dock	*Rumex crispus*	Forb	.	.	1	1	.	.	.	.	.	.	.	.	.	.	1	1
dock spp.	*Rumex spp.*	Forb	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.
marsh skullcap	*Scutellaria galericulata*	Forb	1	.	.	1	1	2	.	.	.	1	.	1	.	.	4	4
solidago spp.	*Solidago spp.*	Forb	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
chickweed spp.	*Stellaria spp.*	Forb	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
dandelion spp.	*Taraxacum* spp.	Forb	1	3	.	3	3	4	.	.	.	.	.	.	1	1	.	.
marsh ragwort	*Tephroseris palustris*	Forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.
tall meadow rue	*Thalictrum dasycarpum*	Forb	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
alsike clover	*Trifolium hybridum*	Forb	.	1	.	.	.	1	.	.	.	.	.	.	1	.	.	.
clover spp.	*Trifolium* sp.	Forb	.	1	.	1	2	1	.	.	.	.	.	.	.	.	.	.
cattail spp.	*Typha* spp.	Forb	1	2	.	1	3	2	.	.	.	.	.	2	.	.	14	6
Unidentified forb	Unidentified forb	Forb	1	.	.	.	.	3	.	.	.	1	.	.	.	.	3	1
stinging nettle	*Urtica dioica*	Forb	.	1	3	4	3	3	.	.	.	.	.	1	.	.	1	4
bladderwort	*Utricularia* sp.	Forb	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.
purple vetch	*Vicia americana*	Forb	.	1	.	.	1	.	.	.	.	.	1	1	.	.	.	.
vetch spp.	*Vicia* spp.	Forb	2	1	2	1	3	3	.	.	.	.	3	.	.	.	.	.
violet spp.	*Viola* spp.	Forb	2	.	.	.	.	1	.	.	.	.	.	1	.	.	.	1
bluejoint	*Calamagrostis canadensis*	Gram.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
sedge spp.	*Carex* spp.	Gram.	2	2	2	2	20	17	1	.	3	4	7	7	1	.	26	18
cotton grass	*Eriophorum* spp.	Gram.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
Graminoid spp.	Graminoid spp.	Gram.	11	10	10	11	36	29	1	.	5	5	15	16	1	1	16	14
alder spp.	*Alnus* spp.	Shrub	2	1	1	2	3	4	.	.	.	.	2	6	.	.	1	1
saskatoon	*Amelanchier alnifolia*	Shrub	.	.	.	.	1	2	.	.	.	.	.	1	.	.	1	1
bog rosemary	*Andromeda polifolia*	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
bog birch	*Betula nana*	Shrub	.	.	.	1	3	5	.	.	3	2	1	2	.	.	2	6
paper birch	*Betula papyrifera*	Shrub	2	2	4	2	9	6	.	.	.	.	3	2	.	.	3	2
leather leaf	*Chamaedaphne calyculata*	Shrub	.	.	.	.	2	1	.	.	3	1	.	.	.	.	.	.
red-osier dogwood	*Cornus sericea*	Shrub	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.
woodland strawberry	*Fragaria vesca*	Forb	4	1	1	2	1	1	.	.	.	.	.	.	.	.	.	.
tamarack	*Larix laricina*	Shrub	1	.	.	.	.	.	.	.	1	.	3	.	.	.	1	3
twining honeysuckle	*Lonicera dioica*	Shrub	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
bracted honeysuckle	*Lonicera involucrata*	Shrub	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.
honeysuckle spp.	*Lonicera* spp.	Shrub	1	.	.	1	2	5	.	.	.	1	2	1	.	.	.	.
sweet gale	*Myrica gale*	Shrub	.	.	.	.	.	.	.	.	1	1	.	.	.	.	1	.
white spruce	*Picea glauca*	Shrub	1	.	1	.	1	1	.	1	1	1	.	1	.	.	.	1
black spruce	*Picea mariana*	Shrub	1	.	.	.	4	4	.	.	3	4	9	6	.	.	.	6
balsam poplar	*Populus balsimifera*	Shrub	2	1	1	.	2	3	.	.	.	.	.	2	1	1	.	.
trembling aspen	*Populus tremuloides*	Shrub	2	.	2	3	6	3	.	1	.	.	4	2	.	1	2	1

black cottonwood	*Populus trichocarpa*	Shrub	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
labrador tea	*Rhododendron groenlandicum*	Shrub	2	.	.	.	6	5	.	.	4	4	7	5	.	.	4	9
northern gooseberry	*Ribes oxyacanthoides*	Shrub	1	1	1	1	.	.	.	.	.	.	1	.	.	.	.	.
currant sp.	*Ribes* spp.	Shrub	2	.	.	.	2	3	.	.	.	.	.	2	.	.	.	.
wild red currant	*Ribes triste*	Shrub	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
prickly rose	*Rosa acicularis*	Shrub	2	1	4	7	9	5	.	1	1	1	4	7	.	1	.	2
rose sp.	*Rosa* spp.	Shrub	1	1	2	.	1	2	.	.	.	.	2	3	.	.	.	1
dwarf raspberry	*Rubus pubescens*	Shrub	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
raspberry spp.	*Rubus* spp.	Shrub	3	.	2	4	11	9	.	.	.	.	2	2	.	1	.	3
rubus spp.	*Rubus* spp.	Shrub	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
willow spp.	*Salix* spp.	Shrub	9	9	9	6	26	21	1	1	5	4	15	9	.	1	11	11
soapberry	*Shepherdia canadensis*	Shrub	1	.	.	.	1	.	.	.	1	1	2	2	.	.	.	.
small bog cranberry	*Vaccinium oxycoccos*	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
blueberry spp.	*Vaccinium* spp.	Shrub	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1
bog cranberry	*Vaccinium vitis-idaea*	Shrub	1	.	.	.	3	3	.	.	3	4	6	6	.	.	.	8
low bush cranberry	*Viburnum edule*	Shrub	.	.	2	4	.	2	.	.	1	1	3	3	.	.	1	1
water	NA	NA	2	2	1	1	9	5	.	.	3	1	2	5	.	.	17	9

Appendix B

Full model selection tables from occupancy modelling of terrestrial mammals

Supplementary Material 1. Predator Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Lure)	4	1065.687	0.0000	0.97
Ψ() θ() p(Line)	4	1074.009	8.3226	0.02
Ψ() θ() p(Footprint_0090)	4	1074.317	8.6308	0.01
Ψ() θ() p()	3	1081.807	13.8160	0.00
Ψ() θ() p(Wetland_0090)	4	1081.118	15.4316	0.00
Ψ() θ() p(Wetland_0300)	4	1081.141	15.4544	0.00
Ψ() θ() p(Upland_1000)	4	1081.324	15.6374	0.00
Ψ() θ() p(Footprint_0300)	4	1081.415	15.7281	0.00
Ψ() θ() p(Upland_0090)	4	1081.520	15.8329	0.00
Ψ() θ() p(Wetland_1000)	4	1081.529	15.8427	0.00
Ψ() θ() p(Upland_0300)	4	1081.553	15.8664	0.00
Ψ() θ() p(Footprint_1000)	4	1081.737	16.0501	0.00
Additive Detection Models				
Ψ() θ() p(Lure + Footprint_0090 + Line)	6	1055.408	0.0000	0.56
Ψ() θ() p(Lure + Line)	5	1059.915	2.0239	0.20
Ψ() θ() p(Lure + Footprint_0090)	5	1060.057	2.1654	0.19
Ψ() θ() p(Lure)	4	1065.687	5.4041	0.04
Ψ() θ() p(Footprint_0090 + Line)	5	1068.052	10.1612	0.00
Ψ() θ() p(Line)	4	1074.009	13.7267	0.00
Ψ() θ() p(Footprint_0090)	4	1074.317	14.0349	0.00
Ψ() θ() p()	3	1081.807	19.2201	0.00
Ψ Scale Models				
Ψ() θ() p(Lure + Footprint_0090 + Line)	6	1055.408	0.0000	0.26
Ψ(Upland_2500) θ() p(Lure + Footprint_0090 + Line)	7	1053.674	0.8466	0.17
Ψ(Wetland_2500) θ() p(Lure + Footprint_0090 + Line)	7	1053.727	0.8994	0.17
Ψ(Wetland_5000) θ() p(Lure + Footprint_0090 + Line)	7	1054.391	1.5638	0.12
Ψ(Upland_5000) θ() p(Lure + Footprint_0090 + Line)	7	1054.518	1.6912	0.11
Ψ(Footprint_2500) θ() p(Lure + Footprint_0090 + Line)	7	1054.898	2.0712	0.09
Ψ(Footprint_5000) θ() p(Lure + Footprint_0090 + Line)	7	1055.139	2.3114	0.08
Ψ Occupancy Models				
Ψ() θ() p(Lure + Footprint_0090 + Line)	6	1055.408	0.0000	0.24
Ψ(Upland_2500) θ() p(Lure + Footprint_0090 + Line)	7	1053.674	0.8466	0.16
Ψ(Wetland_2500) θ() p(Lure + Footprint_0090 + Line)	7	1053.727	0.8994	0.15
Ψ(Footprint_2500) θ() p(Lure + Footprint_0090 + Line)	7	1054.898	2.0712	0.08
Ψ(Upland_2500 + Year) θ() p(Lure + Footprint_0090 + Line)	9	1049.494	2.1439	0.08
Ψ(Year) θ() p(Lure + Footprint_0090 + Line)	8	1052.778	2.6347	0.06
Ψ(Wetland_2500 + Year) θ() p(Lure + Footprint_0090 + Line)	9	1050.142	2.7919	0.06
Ψ(Wetland_2500 + Footprint_2500) θ() p(Lure + Footprint_0090 + Line)	8	1053.368	3.2245	0.05
Ψ(Upland_2500 + Footprint_2500) θ() p(Lure + Footprint_0090 + Line)	8	1053.479	3.3362	0.04
Ψ(Footprint_2500 + Year) θ() p(Lure + Footprint_0090 + Line)	9	1051.404	4.0542	0.03
Ψ(Upland_2500 + Footprint_2500 + Year) θ() p(Lure + Footprint_0090 + Line)	10	1049.097	4.6570	0.02
Ψ(Wetland_2500 + Footprint_2500 + Year) θ() p(Lure + Footprint_0090 + Line)	10	1049.509	5.0689	0.02

[a] Lowest AICc score for Univariate = 1074.427; Additive =1069.023; Scale = 1069.023; Occupancy = 1069.023

Supplementary Material 2. Bear Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Lure)	4	815.3709	0.0000	0.94
Ψ() θ() p(Footprint_0090)	4	823.0502	7.6793	0.02
Ψ() θ() p(Line)	4	825.1480	9.7771	0.01
Ψ() θ() p(Wetland_1000)	4	825.7271	10.3562	0.01
Ψ() θ() p()	3	828.2733	10.5980	0.00
Ψ() θ() p(Upland_1000)	4	826.1631	10.7922	0.00
Ψ() θ() p(Footprint_1000)	4	826.4753	11.1044	0.00
Ψ() θ() p(Upland_0300)	4	826.6226	11.2517	0.00
Ψ() θ() p(Footprint_0300)	4	827.1181	11.7472	0.00
Ψ() θ() p(Wetland_0300)	4	827.6224	12.2515	0.00
Ψ() θ() p(Upland_0090)	4	827.7661	12.3952	0.00
Ψ() θ() p(Wetland_0090)	4	828.1545	12.7836	0.00
Additive Detection Models				
Ψ() θ() p(Lure + Footprint_0090 + Wetland_1000)	6	806.1521	0.0000	0.38
Ψ() θ() p(Lure + Footprint_0090 + Line + Wetland_1000)	7	804.6922	1.1200	0.22
Ψ() θ() p(Lure + Footprint_0090)	5	810.8774	2.2400	0.12
Ψ() θ() p(Lure + Footprint_0090 + Line)	6	809.3251	3.1700	0.08
Ψ() θ() p(Lure + Wetland_1000)	5	812.0324	3.4000	0.07
Ψ() θ() p(Lure + Wetland_1000 + Line)	6	810.4253	4.2700	0.05
Ψ() θ() p(Lure)	4	815.3709	4.3400	0.04
Ψ() θ() p(Lure + Line)	5	813.5099	4.8700	0.03
Ψ() θ() p(Footprint_0090 + Wetland_1000 + Line)	6	816.1616	10.0100	0.00
Ψ() θ() p(Footprint_0090 + Line)	5	820.1445	11.5100	0.00
Ψ() θ() p(Footprint_0090)	4	823.0502	12.0200	0.00
Ψ() θ() p(Line)	4	825.1480	14.1200	0.00
Ψ() θ() p(Wetland_1000 + Line)	5	822.8614	14.2300	0.00
Ψ() θ() p(Wetland_1000)	4	825.7271	14.7000	0.00
Ψ() θ() p()	3	828.2733	14.9400	0.00
Ψ Scale Models				
Ψ(Wetland_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	801.1839	0.0000	0.28
Ψ(Upland_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	801.5156	0.3300	0.23
Ψ(Upland_5000) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	802.0176	0.8300	0.18
Ψ(Wetland_5000) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	802.1166	0.9300	0.17
Ψ() θ() p(Lure + Footprint_0090 + Wetland_1000)	6	806.1521	2.3900	0.08
Ψ(Footprint_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	806.0673	4.8800	0.02
Ψ(Footprint_5000) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	806.1021	4.9200	0.02
Ψ Occupancy Models				
Ψ(Wetland_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	801.1839	0.0000	0.33
Ψ(Upland_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	801.5156	0.3300	0.28
Ψ() θ() p(Lure + Footprint_0090 + Wetland_1000)	6	806.1521	2.3900	0.10
Ψ(Wetland_2500 + Footprint_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	8	800.9840	2.4800	0.10
Ψ(Upland_2500 + Footprint_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	8	801.0390	2.5400	0.09
Ψ(Footprint_2500) θ() p(Lure + Footprint_0090 + Wetland_1000)	7	806.0673	4.8800	0.03
Ψ(Wetland_2500 + Year) θ() p(Lure + Footprint_0090 + Wetland_1000)	9	800.7645	5.0600	0.03
Ψ(Upland_2500 + Year) θ() p(Lure + Footprint_0090 + Wetland_1000)	9	801.0817	5.3800	0.02
Ψ(Year) θ() p(Lure + Footprint_0090 + Wetland_1000)	8	805.5284	7.0300	0.01
Ψ(Wetland_2500 + Footprint_2500 + Year) θ() p(Lure + Footprint_0090 + Wetland_1000)	10	800.4600	7.6600	0.01
Ψ(Upland_2500 + Footprint_2500 + Year) θ() p(Lure + Footprint_0090 + Wetland_1000)	10	800.5093	7.7100	0.01
Ψ(Footprint_2500 + Year) θ() p(Lure + Footprint_0090 + Wetland_1000)	9	805.2396	9.5300	0.00

[a] Lowest AICc score for Univariate = 824.1116; Additive = 819.7675; Scale = 817.3800; Occupancy = 817.3800

Supplementary Material 3. Lynx Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Wetland_0090)	4	202.8085	0.0000	0.33
Ψ() θ() p(Wetland_1000)	4	204.1244	1.3159	0.17
Ψ() θ() p(Upland_0090)	4	204.3863	1.5778	0.15
Ψ() θ() p(Upland_1000)	4	204.7304	1.9219	0.13
Ψ() θ() p(Wetland_0300)	4	205.7571	2.9486	0.07
Ψ() θ() p(Lure)	4	206.5438	3.7353	0.05
Ψ() θ() p(Upland_0300)	4	207.0709	4.2624	0.04
Ψ() θ() p(Footprint_0090)	4	207.9143	5.1058	0.03
Ψ() θ() p(Line)	4	208.6623	5.8538	0.02
Ψ() θ() p()	3	211.5394	6.4265	0.01
Ψ() θ() p(Footprint_0300)	4	211.2272	8.4187	0.00
Ψ() θ() p(Footprint_1000)	4	211.5003	8.6918	0.00
Additive Detection Models				
Ψ() θ() p(Wetland_0090 + Lure)	5	197.8560	0.0000	0.29
Ψ() θ() p(Wetland_0090 + Footprint_0090 + Lure)	6	196.1980	0.8253	0.19
Ψ() θ() p(Wetland_0090 + Line + Lure)	6	196.9017	1.5290	0.13
Ψ() θ() p(Wetland_0090 + Footprint_0090)	5	200.1311	2.2751	0.09
Ψ() θ() p(Wetland_0090)	4	202.8085	2.5612	0.08
Ψ() θ() p(Wetland_0090 + Footprint_0090 + Line + Lure)	7	195.7955	3.0035	0.06
Ψ() θ() p(Wetland_0090 + Line)	5	201.5742	3.7182	0.04
Ψ() θ() p(Wetland_0090 + Footprint_0090 + Line)	6	199.5692	4.1965	0.04
Ψ() θ() p(Footprint_0090 + Lure)	5	203.5178	5.6618	0.02
Ψ() θ() p(Lure)	4	206.5438	6.2965	0.01
Ψ() θ() p(Line + Lure)	5	204.1680	6.3120	0.01
Ψ() θ() p(Footprint_0090 + Line + Lure)	6	202.1487	6.7760	0.01
Ψ() θ() p(Footprint_0090)	4	207.9143	7.6670	0.01
Ψ() θ() p(Footprint_0090 + Line)	5	205.8732	8.0172	0.01
Ψ() θ() p(Line)	4	208.6623	8.4150	0.00
Ψ() θ() p()	3	211.5394	8.9877	0.00
Ψ Scale Models				
Ψ(Upland_2500) θ() p(Lure + Wetland_0090)	6	190.9785	0.0000	0.33
Ψ(Upland_5000) θ() p(Lure + Wetland_0090)	6	191.2410	0.2625	0.29
Ψ(Wetland_5000) θ() p(Lure + Wetland_0090)	6	192.0628	1.0843	0.19
Ψ(Wetland_2500) θ() p(Lure + Wetland_0090)	6	193.2184	2.2399	0.11
Ψ() θ() p(Lure + Wetland_0090)	5	197.8560	4.3942	0.04
Ψ(Footprint_5000) θ() p(Lure + Wetland_0090)	6	195.9697	4.9912	0.03
Ψ(Footprint_2500) θ() p(Lure + Wetland_0090)	6	197.0705	6.0920	0.02
Ψ Occupancy Models				
Ψ(Upland_2500 + fYear) θ() p(Lure + Wetland_0090)	8	185.3247	0.0000	0.34
Ψ(Upland_2500) θ() p(Lure + Wetland_0090)	6	190.9785	0.3892	0.28
Ψ(Wetland_5000) θ() p(Lure + Wetland_0090)	6	192.0628	1.4735	0.16
Ψ(Wetland_5000 + fYear) θ() p(Lure + Wetland_0090)	8	186.9568	1.6321	0.15
Ψ() θ() p(Lure + Wetland_0090)	5	197.8560	4.7834	0.03
Ψ(fYear) θ() p(Lure + Wetland_0090)	7	193.1750	5.1664	0.03

[a] Lowest AICc score for Univariate = 211.5492; Additive = 208.9881; Scale = 204.5939; Occupancy = 204.2047

Supplementary Material 4.Coyote Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Upland_1000)	4	296.3111	0.0000	0.2000
Ψ() θ() p(Wetland_0300)	4	296.6579	0.3468	0.1700
Ψ() θ() p(Footprint_0090)	4	297.0124	0.7013	0.1400
Ψ() θ() p(Wetland_1000)	4	297.3082	0.9971	0.1200
Ψ() θ() p(Upland_0300)	4	297.5367	1.2256	0.1100
Ψ() θ() p(Line)	4	297.9728	1.6617	0.0900
Ψ() θ() p(Upland_0090)	4	299.3204	3.0093	0.0500
Ψ() θ() p()	3	301.9253	3.3098	0.0400
Ψ() θ() p(Wetland_0090)	4	300.2218	3.9107	0.0300
Ψ() θ() p(Footprint_1000)	4	301.1522	4.8411	0.0200
Ψ() θ() p(Lure)	4	301.5265	5.2154	0.0200
Ψ() θ() p(Footprint_0300)	4	301.9245	5.6134	0.0100
Additive Detection Models				
Ψ() θ() p(Upland_1000 + Footprint_0090 + Line)	6	287.1758	0.0000	0.4212
Ψ() θ() p(Upland_1000 + Line)	5	290.5439	0.8848	0.2706
Ψ() θ() p(Footprint_0090 + Line)	5	292.3522	2.6931	0.1096
Ψ() θ() p(Upland_1000 + Footprint_0090)	5	292.9325	3.2734	0.0820
Ψ() θ() p(Upland_1000)	4	296.3111	4.2607	0.0500
Ψ() θ() p(Footprint_0090)	4	297.0124	4.9620	0.0352
Ψ() θ() p(Line)	4	297.9728	5.9224	0.0218
Ψ() θ() p()	3	301.9253	7.5705	0.0096
Ψ Scale Models				
Ψ(Footprint_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	7	282.1581	0.0000	0.4100
Ψ(Footprint_5000) θ() p(Upland_1000 + Footprint_0090 + Line)	7	282.5837	0.4256	0.3300
Ψ() θ() p(Upland_1000 + Footprint_0090 + Line)	6	287.1758	2.4370	0.1200
Ψ(Wetland_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	7	287.0996	4.9415	0.0300
Ψ(Upland_5000) θ() p(Upland_1000 + Footprint_0090 + Line)	7	287.1638	5.0057	0.0300
Ψ(Wetland_5000) θ() p(Upland_1000 + Footprint_0090 + Line)	7	287.1725	5.0144	0.0300
Ψ(Upland_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	7	287.1727	5.0146	0.0300
Ψ Occupancy Models				
Ψ(Footprint_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	7	282.1581	0.0000	0.4100
Ψ() θ() p(Upland_1000 + Footprint_0090 + Line)	6	287.1758	2.4370	0.1200
Ψ(Upland_5000 + Footprint_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	8	282.0606	2.5864	0.1100
Ψ(Wetland_2500 + Footprint_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	8	282.1565	2.6823	0.1100
Ψ(Footprint_2500 + fYear) θ() p(Upland_1000 + Footprint_0090 + Line)	9	279.7659	3.0852	0.0900
Ψ(fYear) θ() p(Upland_1000 + Footprint_0090 + Line)	8	284.3166	4.8424	0.0400
Ψ(Wetland_2500) θ() p(Upland_1000 + Footprint_0090 + Line)	7	287.0996	4.9415	0.0300
Ψ(Upland_5000) θ() p(Upland_1000 + Footprint_0090 + Line)	7	287.1638	5.0057	0.0300
Ψ(Wetland_2500 + Footprint_2500 + fYear) θ() p(Upland_1000 + Footprint_0090 + Line)	10	279.7268	5.9560	0.0200
Ψ(Upland_5000 + Footprint_2500 + fYear) θ() p(Upland_1000 + Footprint_0090 + Line)	10	279.7439	5.9731	0.0200
Ψ(Wetland_2500 + fYear) θ() p(Upland_1000 + Footprint_0090 + Line)	9	284.1503	7.4696	0.0100
Ψ(Upland_5000 + fYear) θ() p(Upland_1000 + Footprint_0090 + Line)	9	284.3140	7.6333	0.0100

[a] Lowest AICc score for Univariate = 305.0518; Additive = 300.7912; Scale = 298.3542; Occupancy = 298.3542

Supplementary Material 5. Wolf Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Footprint_1000)	4	269.3389	0.0000	0.64
Ψ() θ() p(Line)	4	272.8172	3.4783	0.11
Ψ() θ() p(Footprint_0300)	4	273.2838	3.9449	0.09
Ψ() θ() p(Lure)	4	274.3958	5.0569	0.05
Ψ() θ() p()	3	277.6146	5.9713	0.03
Ψ() θ() p(Upland_0090)	4	277.0059	7.6670	0.01
Ψ() θ() p(Footprint_0090)	4	277.0075	7.6686	0.01
Ψ() θ() p(Upland_0300)	4	277.2696	7.9307	0.01
Ψ() θ() p(Wetland_1000)	4	277.5198	8.1809	0.01
Ψ() θ() p(Wetland_0090)	4	277.5452	8.2063	0.01
Ψ() θ() p(Wetland_0300)	4	277.5516	8.2127	0.01
Ψ() θ() p(Upland_1000)	4	277.6057	8.2668	0.01
Additive Detection Models				
Ψ() θ() p(Footprint_1000 + Line)	5	266.7990	0.0000	0.24
Ψ() θ() p(Footprint_1000 + Lure)	5	266.9401	0.1411	0.23
Ψ() θ() p(Footprint_1000)	4	269.3389	0.1486	0.23
Ψ() θ() p(Footprint_1000 + Line + Lure)	6	264.7921	0.4764	0.19
Ψ() θ() p(Line)	4	272.8172	3.6269	0.04
Ψ() θ() p(Line + Lure)	5	270.5294	3.7304	0.04
Ψ() θ() p(Lure)	4	274.3958	5.2055	0.02
Ψ() θ() p()	3	277.6146	6.1199	0.01
Ψ Scale Models				
Ψ() θ() p(Footprint_1000 + Line + Lure)	6	264.7921	0.0000	0.22
Ψ(Upland_2500) θ() p(Footprint_1000 + Line + Lure)	7	262.5210	0.3096	0.19
Ψ(Wetland_2500) θ() p(Footprint_1000 + Line + Lure)	7	262.6641	0.4527	0.17
Ψ(Upland_5000) θ() p(Footprint_1000 + Line + Lure)	7	262.9995	0.7881	0.15
Ψ(Wetland_5000) θ() p(Footprint_1000 + Line + Lure)	7	263.1430	0.9316	0.14
Ψ(Footprint_5000) θ() p(Footprint_1000 + Line + Lure)	7	264.4364	2.2250	0.07
Ψ(Footprint_2500) θ() p(Footprint_1000 + Line + Lure)	7	264.7406	2.5292	0.06
Ψ Occupancy Models				
Ψ(Year) θ() p(Footprint_1000 + Line + Lure)	8	253.1384	0.0000	0.25
Ψ(Upland_2500 + Year) θ() p(Footprint_1000 + Line + Lure)	9	250.4176	0.0727	0.25
Ψ(Wetland_2500 + Year) θ() p(Footprint_1000 + Line + Lure)	9	250.7379	0.3930	0.21
Ψ(Upland_2500 + Footprint_5000 + Year) θ() p(Footprint_1000 + Line + Lure)	10	249.1851	1.7500	0.11
Ψ(Wetland_2500 + Footprint_5000 + Year) θ() p(Footprint_1000 + Line + Lure)	10	249.8764	2.4413	0.08
Ψ(Footprint_5000 + Year) θ() p(Footprint_1000 + Line + Lure)	9	253.0853	2.7404	0.06
Ψ() θ() p(Footprint_1000 + Line + Lure)	6	264.7921	6.3891	0.01
Ψ(Upland_2500) θ() p(Footprint_1000 + Line + Lure)	7	262.5210	6.6987	0.01
Ψ(Wetland_2500) θ() p(Footprint_1000 + Line + Lure)	7	262.6641	6.8418	0.01
Ψ(Upland_2500 + Footprint_5000) θ() p(Footprint_1000 + Line + Lure)	8	260.1579	7.0195	0.01
Ψ(Wetland_2500 + Footprint_5000) θ() p(Footprint_1000 + Line + Lure)	8	260.8557	7.7173	0.01
Ψ(Footprint_5000) θ() p(Footprint_1000 + Line + Lure)	7	264.4364	8.6141	0.00

[a] Lowest AICc score for Univariate = 278.0796; Additive = 277.9311; Scale = 278.4075; Occupancy = 272.0184

Supplementary Material 6. Prey Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Footprint_1000)	4	1146.331	0.0000	0.99
Ψ() θ() p(Upland_1000)	4	1155.486	9.1551	0.01
Ψ() θ() p(Wetland_1000)	4	1159.808	13.4770	0.00
Ψ() θ() p(Wetland_0090)	4	1161.047	14.7164	0.00
Ψ() θ() p(Upland_0300)	4	1162.649	16.3184	0.00
Ψ() θ() p(Upland_0090)	4	1162.936	16.6047	0.00
Ψ() θ() p(Line)	4	1163.490	17.1586	0.00
Ψ() θ() p(Wetland_0300)	4	1164.417	18.0859	0.00
Ψ() θ() p()	3	1170.754	22.1184	0.00
Ψ() θ() p(Footprint_0300)	4	1169.968	23.6372	0.00
Ψ() θ() p(Lure)	4	1170.411	24.0802	0.00
Ψ() θ() p(Footprint_0090)	4	1170.655	24.3240	0.00
Additive Detection Models				
Ψ() θ() p(Upland_1000 + Line + Footprint_1000)	6	1137.259	0.0000	0.36
Ψ() θ() p(Wetland_1000 + Line + Footprint_1000)	6	1137.712	0.4530	0.29
Ψ() θ() p(Upland_1000 + Footprint_1000)	5	1141.371	1.6287	0.16
Ψ() θ() p(Wetland_1000 + Footprint_1000)	5	1141.692	1.9499	0.14
Ψ() θ() p(Footprint_1000)	4	1146.331	4.1975	0.04
Ψ() θ() p(Upland_1000 + Line)	5	1149.255	9.5128	0.00
Ψ() θ() p(Upland_1000)	4	1155.486	13.3526	0.00
Ψ() θ() p(Wetland_1000 + Line)	5	1153.422	13.6795	0.00
Ψ() θ() p(Wetland_1000)	4	1159.808	17.6745	0.00
Ψ() θ() p(Line)	4	1163.490	21.3561	0.00
Ψ() θ() p()	3	1170.754	26.3159	0.00
Ψ Scale Models				
Ψ() θ() p(Upland_1000 + Line + Footprint_1000)	6	1137.259	0.0000	0.38
Ψ(Upland_2500) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.10
Ψ(Wetland_2500) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.10
Ψ(Footprint_2500) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.10
Ψ(Upland_5000) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.10
Ψ(Wetland_5000) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.10
Ψ(Footprint_5000) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.10
Ψ Occupancy Models				
Ψ() θ() p(Upland_1000 + Line + Footprint_1000)	6	1137.259	0.0000	0.48
Ψ(Wetland_2500) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.13
Ψ(Footprint_2500) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.13
Ψ(Upland_2500) θ() p(Upland_1000 + Line + Footprint_1000)	7	1137.259	2.5807	0.13
Ψ(fYear) θ() p(Upland_1000 + Line + Footprint_1000)	8	1137.259	5.2646	0.03
Ψ(Upland_2500 + Footprint_2500) θ() p(Upland_1000 + Line + Footprint_1000)	8	1137.259	5.2646	0.03
Ψ(Wetland_2500 + Footprint_2500) θ() p(Upland_1000 + Line + Footprint_1000)	8	1137.259	5.2646	0.03
Ψ(Upland_2500 + fYear) θ() p(Upland_1000 + Line + Footprint_1000)	9	1137.259	8.0581	0.01
Ψ(Footprint_2500 + fYear) θ() p(Upland_1000 + Line + Footprint_1000)	9	1137.259	8.0581	0.01
Ψ(Wetland_2500 + fYear) θ() p(Upland_1000 + Line + Footprint_1000)	9	1137.259	8.0581	0.01
Ψ(Upland_2500 + Footprint_2500 + fYear) θ() p(Upland_1000 + Line + Footprint_1000)	10	1137.259	10.9679	0.00
Ψ(Wetland_2500 + Footprint_2500 + fYear) θ() p(Upland_1000 + Line + Footprint_1000)	10	1137.259	10.9679	0.00

[a] Lowest AICc score for Univariate = 1155.072; Additive = 1150.874; Scale = 1150.874; Occupancy = 1150.874

Supplementary Material 7. Deer Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Upland_1000)	4	968.7533	0.0000	0.59
Ψ() θ() p(Wetland_1000)	4	970.7720	2.0187	0.22
Ψ() θ() p(Wetland_0300)	4	971.7694	3.0161	0.13
Ψ() θ() p(Wetland_0090)	4	974.9768	6.2235	0.03
Ψ() θ() p(Upland_0300)	4	975.3437	6.5904	0.02
Ψ() θ() p(Upland_0090)	4	977.4044	8.6511	0.01
Ψ() θ() p(Footprint_1000)	4	977.5321	8.7788	0.01
Ψ() θ() p(Line)	4	983.6837	14.9304	0.00
Ψ() θ() p(Footprint_0090)	4	985.8073	17.0540	0.00
Ψ() θ() p()	3	990.9391	19.8814	0.00
Ψ() θ() p(Footprint_0300)	4	989.4854	20.7321	0.00
Ψ() θ() p(Lure)	4	990.6972	21.9439	0.00
Additive Detection Models				
Ψ() θ() p(Line + Wetland_1000 + Footprint_1000)	6	957.4564	0.0000	0.32
Ψ() θ() p(Line + Upland_1000 + Footprint_1000)	6	957.6465	0.1901	0.29
Ψ() θ() p(Upland_1000 + Line)	5	960.7695	0.8298	0.21
Ψ() θ() p(Wetland_1000 + Line)	5	963.1899	3.2502	0.06
Ψ() θ() p(Wetland_1000 + Footprint_1000)	5	963.2259	3.2862	0.06
Ψ() θ() p(Upland_1000 + Footprint_1000)	5	963.9841	4.0444	0.04
Ψ() θ() p(Upland_1000)	4	968.7533	6.4223	0.01
Ψ() θ() p(Wetland_1000)	4	970.7720	8.4410	0.00
Ψ() θ() p(Footprint_1000)	4	977.5321	15.2011	0.00
Ψ() θ() p(Line)	4	983.6837	21.3527	0.00
Ψ() θ() p()	3	990.9391	26.3037	0.00
Ψ Scale Models				
Ψ(Upland_2500) θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.1432	0.0000	0.21
Ψ(Wetland_2500) θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.5054	0.3622	0.17
Ψ(Upland_5000) θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.8733	0.7301	0.15
Ψ() θ() p(Line + Wetland_1000 + Footprint_1000)	6	957.4564	0.7325	0.14
Ψ(Footprint_5000) θ() p(Line + Wetland_1000 + Footprint_1000)	7	955.1565	1.0133	0.13
Ψ(Wetland_5000) θ() p(Line + Wetland_1000 + Footprint_1000)	7	955.2997	1.1565	0.12
Ψ(Footprint_2500) θ() p(Line + Wetland_1000 + Footprint_1000)	7	955.9900	1.8468	0.08
Ψ Occupancy Models				
Ψ(Upland_2500) θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.1432	0.0000	0.25
Ψ(Wetland_2500) θ() p(Line + Wetland_1000 + Footprint_1000)	7	954.5054	0.3622	0.21
Ψ() θ() p(Line + Wetland_1000 + Footprint_1000)	6	957.4564	0.7325	0.18
Ψ(Footprint_5000) θ() p(Line + Wetland_1000 + Footprint_1000)	7	955.1565	1.0133	0.15
Ψ(Upland_2500 + Footprint_5000) θ() p(Line + Wetland_1000 + Footprint_1000)	8	953.2089	1.7496	0.11
Ψ(Wetland_2500 + Footprint_5000) θ() p(Line + Wetland_1000 + Footprint_1000)	8	953.2553	1.7960	0.10

[a] Lowest AICc score for Univariate = 977.4940; Additive = 971.0718; Scale = 970.3393; Occupancy = 970.3393

Supplementary Material 8. Moose Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p()	3	475.2305	0.0000	0.1931
Ψ() θ() p(Wetland_0090)	4	474.3592	1.4331	0.0943
Ψ() θ() p(Lure)	4	474.3895	1.4634	0.0929
Ψ() θ() p(Upland_0090)	4	474.4531	1.5270	0.0900
Ψ() θ() p(Footprint_1000)	4	474.7380	1.8119	0.0780
Ψ() θ() p(Wetland_1000)	4	475.0599	2.1338	0.0664
Ψ() θ() p(Upland_0300)	4	475.0828	2.1567	0.0657
Ψ() θ() p(Footprint_0300)	4	475.0859	2.1598	0.0656
Ψ() θ() p(Footprint_0090)	4	475.1100	2.1839	0.0648
Ψ() θ() p(Upland_1000)	4	475.1229	2.1968	0.0644
Ψ() θ() p(Line)	4	475.1510	2.2249	0.0635
Ψ() θ() p(Wetland_0300)	4	475.2238	2.2977	0.0612
Additive Detection Models				
Ψ() θ() p()	3	475.2305	0.0000	0.2500
Ψ() θ() p(Wetland_0090)	4	474.3592	1.4331	0.1200
Ψ() θ() p(Lure)	4	474.3895	1.4634	0.1200
Ψ() θ() p(Upland_0090)	4	474.4531	1.5270	0.1200
Ψ() θ() p(Footprint_1000)	4	474.7380	1.8119	0.1000
Ψ() θ() p(Wetland_0090 + Footprint_1000)	5	473.2771	2.7423	0.0600
Ψ() θ() p(Upland_0090 + Footprint_1000)	5	473.2899	2.7551	0.0600
Ψ() θ() p(Wetland_0090 + Lure)	5	473.5694	3.0346	0.0500
Ψ() θ() p(Upland_0090 + Lure)	5	473.6200	3.0852	0.0500
Ψ() θ() p(Lure + Upland_0090 + Footprint_1000)	6	472.3650	4.3135	0.0300
Ψ() θ() p(Lure + Wetland_0090 + Footprint_1000)	6	472.4253	4.3738	0.0300
Ψ Scale Models				
Ψ() θ() p()	3	475.2305	0.0000	0.3200
Ψ(Footprint_5000) θ() p()	4	474.7510	1.8249	0.1300
Ψ(Footprint_2500) θ() p()	4	474.7681	1.8420	0.1300
Ψ(Upland_5000) θ() p()	4	474.9645	2.0384	0.1200
Ψ(Upland_2500) θ() p()	4	475.1022	2.1761	0.1100
Ψ(Wetland_5000) θ() p()	4	475.2224	2.2963	0.1000
Ψ(Wetland_2500) θ() p()	4	475.2268	2.3007	0.1000
Ψ Occupancy Models				
Ψ() θ() p()	3	475.2305	0.0000	0.3200
Ψ(Upland_5000 + Footprint_5000) θ() p()	5	471.7799	1.2451	0.1700
Ψ(Footprint_5000) θ() p()	4	474.7510	1.8249	0.1300
Ψ(Upland_5000) θ() p()	4	474.9645	2.0384	0.1200
Ψ(Wetland_5000) θ() p()	4	475.2224	2.2963	0.1000
Ψ(Wetland_5000 + Footprint_5000) θ() p()	5	473.9400	3.4052	0.0600
Ψ(fYear) θ() p()	5	474.6061	4.0713	0.0400
Ψ(Upland_5000 + Footprint_5000 + fYear) θ() p()	7	471.2065	5.7357	0.0200
Ψ(Footprint_5000 + fYear) θ() p()	6	474.2830	6.2315	0.0100
Ψ(Upland_5000 + fYear) θ() p()	6	474.3026	6.2511	0.0100
Ψ(Wetland_5000 + fYear) θ() p()	6	474.5887	6.5372	0.0100
Ψ(Wetland_5000 + Footprint_5000 + fYear) θ() p()	7	473.3243	7.8535	0.0100

[a] Lowest AICc score for Univariate = 481.6669; Additive = 481.6669; Scale = 481.6669; Occupancy = 481.6669

Supplementary Material 9. Snowshoe Hare Models

Model	K	LL	ΔAICc[a]	ω_i
Univariate Detection Models				
Ψ() θ() p(Footprint_0300)	4	356.0041	0.0000	0.30
Ψ() θ() p(Wetland_0300)	4	356.8629	0.8588	0.19
Ψ() θ() p(Lure)	4	357.1065	1.1024	0.17
Ψ() θ() p(Upland_0300)	4	357.3947	1.3906	0.15
Ψ() θ() p(Line)	4	358.1350	2.1309	0.10
Ψ() θ() p(Wetland_1000)	4	360.9644	4.9603	0.02
Ψ() θ() p(Upland_1000)	4	361.6004	5.5963	0.02
Ψ() θ() p(Footprint_0090)	4	362.1865	6.1824	0.01
Ψ() θ() p(Upland_0090)	4	362.5163	6.5122	0.01
Ψ() θ() p()	3	366.0158	7.7073	0.01
Ψ() θ() p(Wetland_0090)	4	364.0582	8.0541	0.01
Ψ() θ() p(Footprint_1000)	4	365.9691	9.9650	0.00
Additive Detection Models				
Ψ() θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	7	322.3803	0.0000	0.67
Ψ() θ() p(Line + Upland_0300 + Footprint_0300 + Lure)	7	323.8199	1.4396	0.32
Ψ() θ() p(Wetland_0300 + Line + Footprint_0300)	6	334.3774	9.4164	0.01
Ψ() θ() p(Upland_0300 + Line + Footprint_0300)	6	336.0305	11.0695	0.00
Ψ() θ() p(Wetland_0300 + Footprint_0300)	5	345.9344	18.4901	0.00
Ψ() θ() p(Upland_0300 + Lure)	5	347.1908	19.7465	0.00
Ψ() θ() p(Wetland_0300 + Lure)	5	347.2817	19.8374	0.00
Ψ() θ() p(Upland_0300 + Line)	5	348.4502	21.0059	0.00
Ψ() θ() p(Upland_0300 + Footprint_0300)	5	348.4715	21.0272	0.00
Ψ() θ() p(Wetland_0300 + Line)	5	349.0186	21.5743	0.00
Ψ() θ() p(Lure + Line)	5	349.8387	22.3944	0.00
Ψ() θ() p(Footprint_0300)	4	356.0041	26.1685	0.00
Ψ() θ() p(Wetland_0300)	4	356.8629	27.0273	0.00
Ψ() θ() p(Lure)	4	357.1065	27.2709	0.00
Ψ() θ() p(Upland_0300)	4	357.3947	27.5591	0.00
Ψ() θ() p(Line)	4	358.1350	28.2994	0.00
Ψ() θ() p()	3	366.0158	33.8758	0.00
Ψ Scale Models				
Ψ() θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	7	322.3803	0.0000	0.27
Ψ(Upland_2500) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.5525	0.8561	0.17
Ψ(Wetland_2500) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.8439	1.1475	0.15
Ψ(Upland_5000) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.9980	1.3016	0.14
Ψ(Wetland_5000) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	321.0937	1.3973	0.13
Ψ(Footprint_5000) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	322.2971	2.6007	0.07
Ψ(Footprint_2500) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	322.3431	2.6467	0.07
Ψ Occupancy Models				
Ψ() θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	7	322.3803	0.0000	0.28
Ψ(Upland_2500) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.5525	0.8561	0.18
Ψ(Wetland_2500) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	320.8439	1.1475	0.16
Ψ(Footprint_5000) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	8	322.2971	2.6007	0.08
Ψ(fYear) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	9	319.5267	2.6238	0.08
Ψ(Upland_2500 + Footprint_5000) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	9	319.9795	3.0766	0.06
Ψ(Wetland_2500 + Footprint_5000) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	9	320.5078	3.6049	0.05
Ψ(Upland_2500 + fYear) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	10	317.7486	3.7556	0.04
Ψ(Wetland_2500 + fYear) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	10	318.1713	4.1783	0.03
Ψ(Footprint_5000 + fYear) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	10	319.5062	5.5132	0.02
Ψ(Upland_2500 + Footprint_5000 + fYear) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	11	317.5195	6.5601	0.01
Ψ(Wetland_2500 + Footprint_5000 + fYear) θ() p(Line + Wetland_0300 + Footprint_0300 + Lure)	11	318.0646	7.1052	0.01

[a] Lowest AICc score for Univariate = 364.7448; Additive = 338.5764; Scale = 338.5764; Occupancy = 338.5764

Appendix C

Permits

ACC Cat.4

UNIVERSITY OF WATERLOO
OFFICE OF RESEARCH ETHICS

ANIMAL CARE COMMITTEE
CERTIFICATE OF FULL ETHICS APPROVAL: NEW ANIMAL UTILIZATION PROJECT PROPOSAL (PROVISIONAL CONDITIONS SATISFIED)

All research and teaching activities at the University of Waterloo which use live, non-human vertebrate animals must be conducted in compliance with the Animals for Research Act of Ontario (Revised Statutes of Ontario), the Guide to the Care and Use of Experimental Animals from the Canadian Council on Animal Care and the University of Waterloo's Guidelines for the Care and Use of Animals in Research and Teaching.

Principal Investigator(s):	Brad Fedy;		
Department or School:	Environment & Resource Studies;		
Co-Investigator(s):	Stuart Slattery;		
Student Investigator(s):	Matt Dyson;		
Project Title :	Waterfowl nest success in the western boreal forest (Pilot Study).		
AUPP # :	16-04	**Approval Date:**	March 29, 2016
Number of Animals Approved:	100 Birds	**Invasiveness Category:**	C

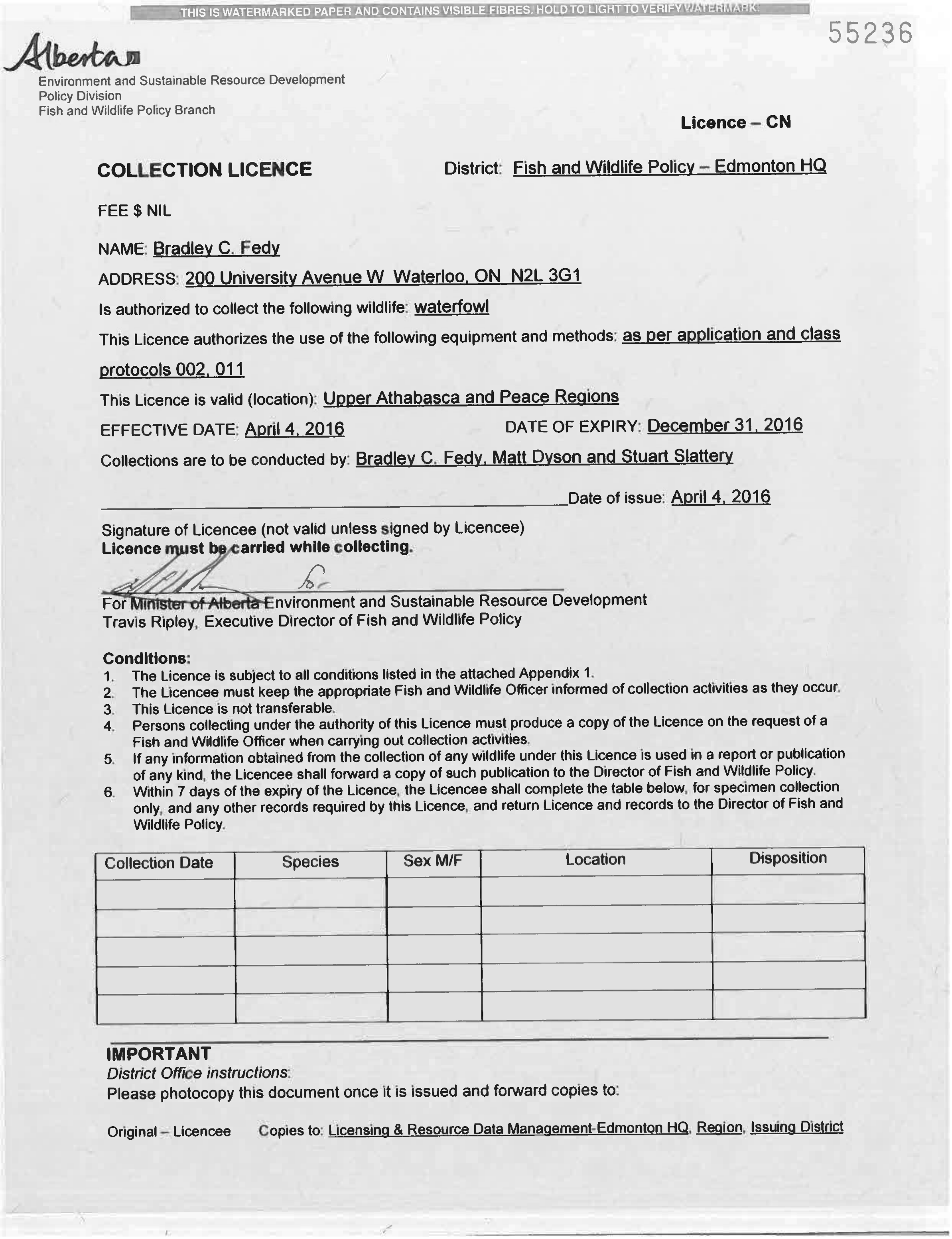
The above Animal Utilization Project Proposal (AUPP) has been reviewed by members of the Animal Care Committee at the University of Waterloo and has been found to comply with the requirements of the *Animals for Research Act*, the Canadian Council on Animal Care's *Guide to the Care and Use of Experimental Animals,* and the University's *Guidelines for the Care and Use of Animals in Research and Teaching.*

The information provided in response to the special conditions outlined on the Provisional Ethics Approval Certificate was considered acceptable, and as a result, this application now has full ethics approval for a twelve month period from the date shown.

An AUPP representing continuing research must be renewed annually and can be renewed three times using the Renewal Form. A Renewal Form must be submitted for ethics review well in advance of the expiration date to prevent any break in ethics approval coverage.

Note: the project covered by this AUPP must be conducted according to the procedures described in the application. Requests for subsequent modifications to approved AUPPs must be communicated in writing to the Chief Ethics Officer, Office of Research Ethics, using the Modification Form.

Maureen Nummelin, PhD.,
Chief Ethics Officer
Office of Research Ethics



55236

Alberta
Environment and Sustainable Resource Development
Policy Division
Fish and Wildlife Policy Branch

Licence – CN

COLLECTION LICENCE

District: Fish and Wildlife Policy – Edmonton HQ

FEE $ NIL

NAME: Bradley C. Fedy

ADDRESS: 200 University Avenue W Waterloo, ON N2L 3G1

Is authorized to collect the following wildlife: waterfowl

This Licence authorizes the use of the following equipment and methods: as per application and class protocols 002, 011

This Licence is valid (location): Upper Athabasca and Peace Regions

EFFECTIVE DATE: April 4, 2016 DATE OF EXPIRY: December 31, 2016

Collections are to be conducted by: Bradley C. Fedy, Matt Dyson and Stuart Slattery

______________________________ Date of issue: April 4, 2016

Signature of Licencee (not valid unless signed by Licencee)
Licence must be carried while collecting.

For ~~Minister of Alberta~~ Environment and Sustainable Resource Development
Travis Ripley, Executive Director of Fish and Wildlife Policy

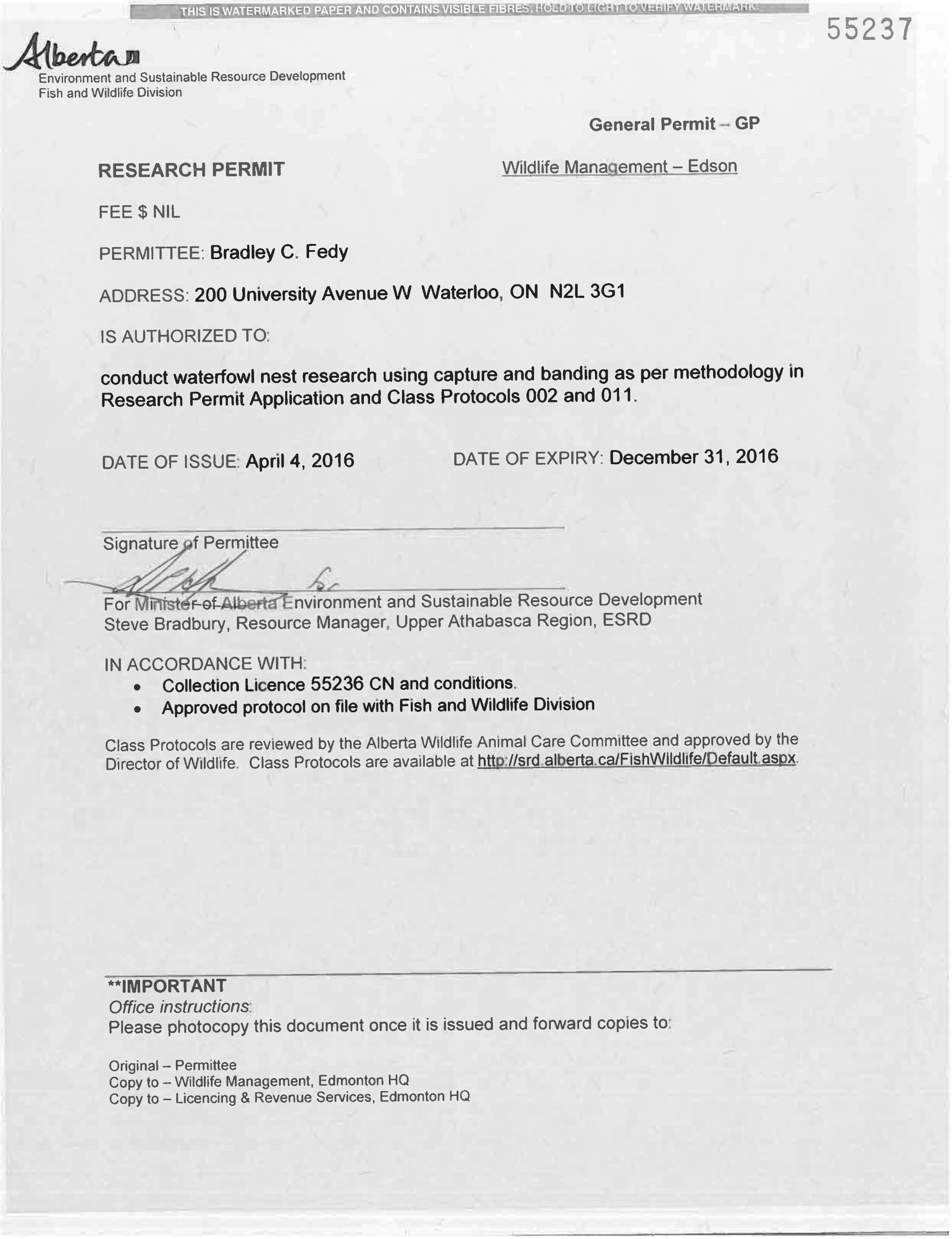
Conditions:

1. The Licence is subject to all conditions listed in the attached Appendix 1.
2. The Licencee must keep the appropriate Fish and Wildlife Officer informed of collection activities as they occur.
3. This Licence is not transferable.
4. Persons collecting under the authority of this Licence must produce a copy of the Licence on the request of a Fish and Wildlife Officer when carrying out collection activities.
5. If any information obtained from the collection of any wildlife under this Licence is used in a report or publication of any kind, the Licencee shall forward a copy of such publication to the Director of Fish and Wildlife Policy.
6. Within 7 days of the expiry of the Licence, the Licencee shall complete the table below, for specimen collection only, and any other records required by this Licence, and return Licence and records to the Director of Fish and Wildlife Policy.

Collection Date	Species	Sex M/F	Location	Disposition

IMPORTANT
District Office instructions:
Please photocopy this document once it is issued and forward copies to:

Original – Licencee Copies to: Licensing & Resource Data Management-Edmonton HQ, Region, Issuing District



55237

Alberta
Environment and Sustainable Resource Development
Fish and Wildlife Division

General Permit – GP

RESEARCH PERMIT

Wildlife Management – Edson

FEE $ NIL

PERMITTEE: **Bradley C. Fedy**

ADDRESS: **200 University Avenue W Waterloo, ON N2L 3G1**

IS AUTHORIZED TO:

conduct waterfowl nest research using capture and banding as per methodology in Research Permit Application and Class Protocols 002 and 011.

DATE OF ISSUE: **April 4, 2016**

DATE OF EXPIRY: **December 31, 2016**

Signature of Permittee

For Minister of Alberta Environment and Sustainable Resource Development
Steve Bradbury, Resource Manager, Upper Athabasca Region, ESRD

IN ACCORDANCE WITH:

- **Collection Licence 55236 CN and conditions.**
- **Approved protocol on file with Fish and Wildlife Division**

Class Protocols are reviewed by the Alberta Wildlife Animal Care Committee and approved by the Director of Wildlife. Class Protocols are available at http://srd.alberta.ca/FishWildlife/Default.aspx.

****IMPORTANT**
Office instructions:
Please photocopy this document once it is issued and forward copies to:

Original – Permittee
Copy to – Wildlife Management, Edmonton HQ
Copy to – Licencing & Revenue Services, Edmonton HQ

Environment Canada Environnement Canada

Environment Canada

Environnement Canada

Canadian Wildlife Service - PERMIT

PERMIS - Service Canadien de la Faune

SCIENTIFIC PERMIT - TAKE
permit to / for *permis de / pour*

Alberta
in the province(s) *dans la/les province(s)*

16-AB-SC004
permit no. *no. de permis*

Bradley Fedy
University of Waterloo
School of Environment, Resources, and Sustainability
200 University Ave. W
Waterloo, ON
N2L 3G1

name and address *nom et addresse*

4.(1)
issued under section *délivré en vertu de l'article*

Migratory Birds Regulations
of *de*

01-May-2016 amended:
date of issue *date d'émission*

01-May-2016
date of expiry *date d'expiration*

Annual report due by

for the minister *pour le ministre*

Special Conditions

1. The permit holder is authorized to conduct nest searches for the following species to a maximum of 100 nests combined: Mallard; Blue-Winged Teal; Green-winged Teal; American Wigeon; Lesser Scaup; and Greater Scaup. It is recognized that nest of other upland nesting waterfowl may be encountered and these must be reported in accordance with Condition #3 below. The following restrictions and/or allowances apply to all nest searching efforts: searches will be conducted at approximately 3 week intervals from the middle of May to the end of July; searching between 0800 and 1700 hrs only with no searching to occur during inclement weather; searches to be performed by teams of 4 individuals using a combination of rope-drags and use of willow switches and, if required, utilizing trained dogs. Insertion of iButton temperature probes (maximum 30) in real nests is authorized . The use of artificial nests is also authorized and both real (found) and artificial nests may be revisited at 7-10 day intervals to determine nest fate. The use of trail cameras is authorized on a maximum of 20 natural nests and 20 artifical nests. All efforts will be made to ensure that cameras are not placed in a manner that could increase nest predation.

The study will take place within an approximate 200 km radius of Red Earth Creek, Alberta.

All activities will take place in accordance with approved animal care protocol 16-04 as authorized by the University of Waterloo.

2. Matthew Dyson, Matthew Turnbull, Alex Meeker, Chris Kahlmeier, Stuart Slattery, Jim Devries, Howie Singer, Moriah Tanguay and Jared Knockaert are nominees under this permit and are authorized to act on behalf of the permit holder.

All individuals conducting work under this permit must have a signed copy of this permit on their person while working in the field and/or lab. Any changes to nominees during the duration of the permit must be reported to this office immediately by written communication in order for them to be authorized to assist with the work.

Canada

3. **The permit holder must provide Environment Canada with a detailed written report of all activities on or before the annual report date indicated above. In order to extend the permit for another year without reapplication, a request to do so must be submitted with the aforementioned report.**

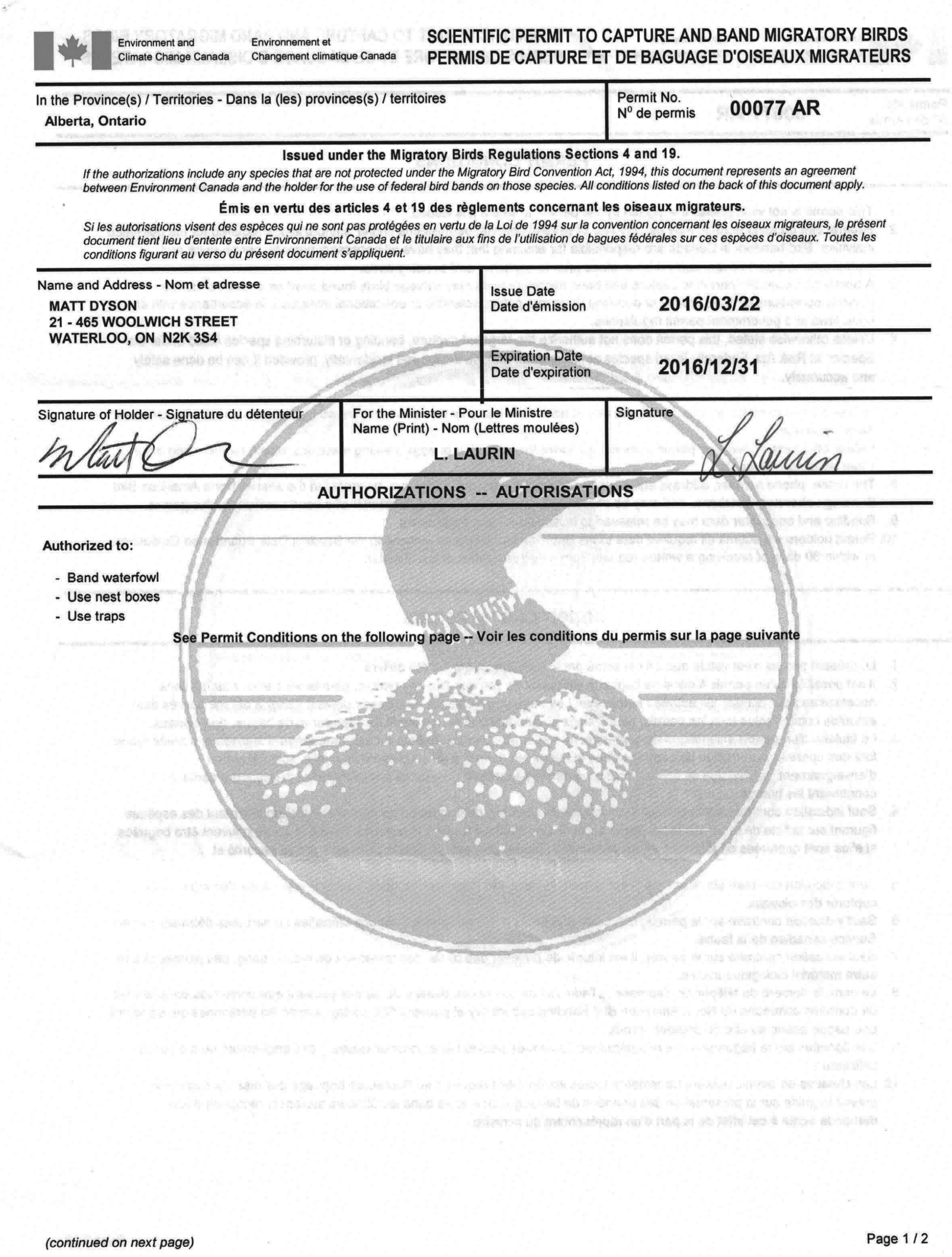
   Any changes to the nominee list along with up-to-date animal care submission and approval documents (where applicable) should be submitted at the same time if feasible or, at the latest, by one month prior to proceeding with permitted activities.

General Conditions

1. By signing this document you bind yourself to respect all terms and conditions of this permit.
2. Anyone carrying out work under the authority of this permit must have a signed copy of this permit while working in the field and/or lab and it shall be shown on request by a Game Officer or RCMP Officer.
3. This permit is NOT VALID in any Federal or Provincial Game Preserve or Bird Sanctuary or National or Provincial Park, National Wildlife Area, Wildlife Management Unit or other protected areas without authorization.
4. The issuance of this permit does not exempt the permit holder from compliance with all relevant Canadian, Provincial and Territorial Laws, and Regulations otherwise applicable nor does it exempt the permit holder from complying with applicable jurisdictional bylaws.
5. Animal care approval (where applicable) must be kept up-to-date in order for this permit to remain valid.
6. No Migratory Birds, eggs or parts thereof taken under the authority of this permit shall be killed for consumption, sold, traded or bartered except as provided by the terms of this permit.
7. It is recommended that the permit holder advise local RCMP and Conservation Officers of his/her field activities.
8. Unless otherwise stated, this permit does not authorize the possession, killing, taking, capturing and banding, or disturbing of species listed on Schedule 1 of the Species at Risk Act as threatened, endangered or extirpated.

I declare that I have read and understand this Permit, including all the conditions attached.

Signature of permit holder



Environment and Climate Change Canada | Environnement et Changement climatique Canada

SCIENTIFIC PERMIT TO CAPTURE AND BAND MIGRATORY BIRDS
PERMIS DE CAPTURE ET DE BAGUAGE D'OISEAUX MIGRATEURS

In the Province(s) / Territories - Dans la (les) provinces(s) / territoires

Alberta, Ontario

Permit No.
N° de permis **00077 AR**

Issued under the Migratory Birds Regulations Sections 4 and 19.

If the authorizations include any species that are not protected under the Migratory Bird Convention Act, 1994, this document represents an agreement between Environment Canada and the holder for the use of federal bird bands on those species. All conditions listed on the back of this document apply.

Émis en vertu des articles 4 et 19 des règlements concernant les oiseaux migrateurs.

Si les autorisations visent des espèces qui ne sont pas protégées en vertu de la Loi de 1994 sur la convention concernant les oiseaux migrateurs, le présent document tient lieu d'entente entre Environnement Canada et le titulaire aux fins de l'utilisation de bagues fédérales sur ces espèces d'oiseaux. Toutes les conditions figurant au verso du présent document s'appliquent.

Name and Address - Nom et adresse

MATT DYSON
21 - 465 WOOLWICH STREET
WATERLOO, ON N2K 3S4

Issue Date
Date d'émission **2016/03/22**

Expiration Date
Date d'expiration **2016/12/31**

Signature of Holder - Signature du détenteur

For the Minister - Pour le Ministre
Name (Print) - Nom (Lettres moulées)
L. LAURIN

Signature L. Laurin

AUTHORIZATIONS -- AUTORISATIONS

Authorized to:

- Band waterfowl
- Use nest boxes
- Use traps

See Permit Conditions on the following page -- Voir les conditions du permis sur la page suivante

(continued on next page)

Page 1 / 2

UNIVERSITY OF WATERLOO
OFFICE OF RESEARCH ETHICS

ANIMAL CARE COMMITTEE
CERTIFICATE OF FULL ETHICS APPROVAL:

AMENDMENT/MODIFICATION TO A PREVIOUSLY APPROVED ANIMAL UTILIZATION PROJECT PROPOSAL

All research and teaching activities at the University of Waterloo which use live, non-human vertebrate animals must be conducted in compliance with the Animals for Research Act of Ontario (Revised Statutes of Ontario) of the Ontario Ministry of Agriculture, Food and Rural Affairs, the Guidelines from the Canadian Council on Animal Care and the University of Waterloo's Guidelines for the Care and Use of Animals in Research and Teaching. All amendments/modifications to previously approved research and teaching AUPPs must receive ethics approval through the Animal Care Committee before the changes can be incorporated into the protocol.

Principal Investigator: B. Fedy

Department or School: Environment and Resource Studies

Co Investigator: M. Dyson

Project Title: Waterfowl nest success in the western boreal forest: Does industrial development alter predation?

AUPP #: 17-03 **Approval Date: March 28, 2017**

Number of Animals Approved: 753 (New #)

The above amendment/modification to a previously approved Animal Utilization Project Proposal (AUPP) has been reviewed by a sub-committee of the Animal Care Committee. Based on this review, this amendment/modification request has been found to comply with the requirements of the *Animals for Research Act, the Guidelines from Canadian Council on Animal Care and the University's Guidelines for the Care and Use of Animals in Research and Teaching.*

The project covered by this AUPP must be conducted according to procedures described in the original application and all subsequent amendments/modifications.

Cindy Futher

Cindy Futher
Research Ethics Advisor
Office of Research Ethics

Environment Canada Environnement Canada

Environment Canada ***Environnement Canada***

Canadian Wildlife Service - PERMIT
PERMIS - Service Canadien de la Faune

SCIENTIFIC PERMIT - TAKE
permit to / for *permis de / pour*

Alberta
in the province(s) *dans la/les province(s)*

16-AB-SC004
permit no. *no. de permis*

4.(1)
issued under section *délivré en vertu de l'article*

Migratory Birds Regulations
of *de*

01-May-2016 amended: 25-APR-2017
date of issue *date d'émission*

01-May-2018
date of expiry *date d'expiration*

Bradley Fedy
University of Waterloo
School of Environment, Resources, and Sustainability
200 University Ave. W
Waterloo, ON
N2L 3G1

name and address *nom et addresse*

31-Jan-2018
Annual report due by

for the minister *pour le ministre*

Special Conditions

1. The permit holder is authorized to conduct nest searches for the following species to a maximum of 100 nests combined: Mallard; Blue-Winged Teal; Green-winged Teal; Northern Shoveler; American Wigeon; Ring-necked Duck; Lesser Scaup; and Greater Scaup. It is recognized that nest of other ground nesting waterfowl may be encountered and these must be reported in accordance with Condition #3 below. The following restrictions and/or allowances apply to all nest searching efforts: searches will be conducted at approximately 3 week intervals from the middle of May to the end of July; searching between 0800 and 1700 hrs. only with no searching to occur during inclement weather; searches to be performed by teams of up to 8 individuals using a combination of rope-drags and use of willow switches and, if required, utilizing trained dogs. Insertion of iButton temperature probes (maximum 30) in real nests is authorized. The use of artificial nests is also authorized and both real (found) and artificial nests may be revisited at 7-10 day intervals to determine nest fate. The use of trail cameras is authorized on a maximum of 40 natural nests and 60 artificial nests. All efforts will be made to ensure that cameras are not placed in a manner that could increase nest predation.

The study will take place within an approximate 200 km radius of Red Earth Creek, Alberta.

All activities will take place in accordance with approved animal care protocol 17-03 as authorized by the University of Waterloo.

2. Matt Dyson, Matt Garrick, Moriah Tanguay, Mya VanWoudenberg, Lee Scholl, Jim Devries, Howie Singer, and Jared Knockaert are nominees under this permit and are authorized to act on behalf of the permit holder.

All individuals conducting work under this permit must have a signed copy of this permit on their person while working in the field and/or lab. Any changes to nominees during the duration of the permit must be reported to this office immediately by written communication in order for them to be authorized to assist with the work.

Canada

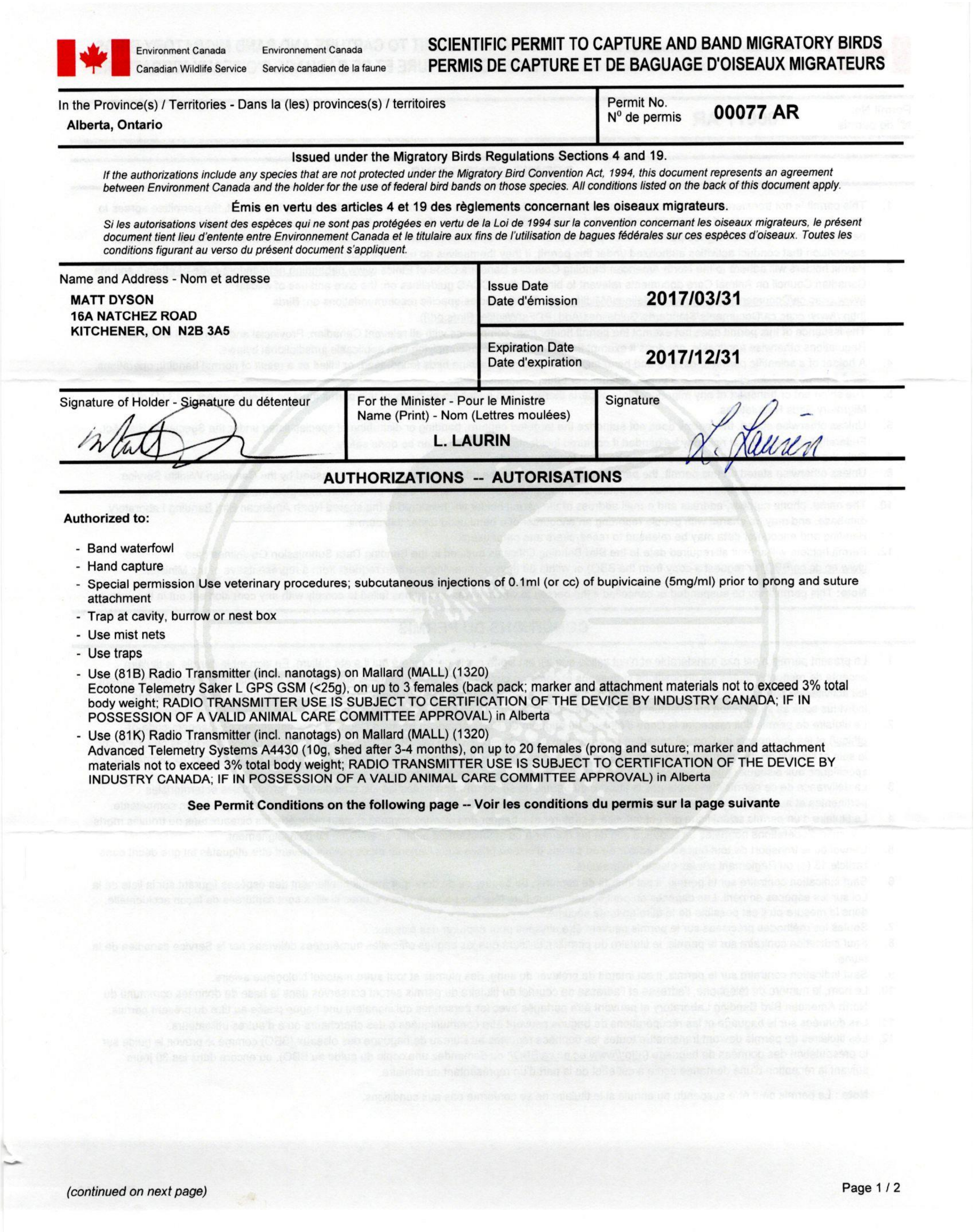
3. **The permit holder must provide Environment Canada with a detailed written report of all activities on or before the annual report date indicated above. In order to extend the permit for another year without reapplication, a request to do so must be submitted with the aforementioned report.**
   Any changes to the nominee list along with up-to-date animal care submission and approval documents (where applicable) should be submitted at the same time if feasible or, at the latest, by one month prior to proceeding with permitted activities.

General Conditions

1. By signing this document you bind yourself to respect all terms and conditions of this permit.
2. Anyone carrying out work under the authority of this permit must have a signed copy of this permit while working in the field and/or lab and it shall be shown on request by a Game Officer or RCMP Officer.
3. This permit is NOT VALID in any Federal or Provincial Game Preserve or Bird Sanctuary or National or Provincial Park, National Wildlife Area, Wildlife Management Unit or other protected areas without authorization.
4. The issuance of this permit does not exempt the permit holder from compliance with all relevant Canadian, Provincial and Territorial Laws, and Regulations otherwise applicable nor does it exempt the permit holder from complying with applicable jurisdictional bylaws.
5. Animal care approval (where applicable) must be kept up-to-date in order for this permit to remain valid.
6. No Migratory Birds, eggs or parts thereof taken under the authority of this permit shall be killed for consumption, sold, traded or bartered except as provided by the terms of this permit.
7. It is recommended that the permit holder advise local RCMP and Conservation Officers of his/her field activities.
8. Unless otherwise stated, this permit does not authorize the possession, killing, taking, capturing and banding, or disturbing of species listed on Schedule 1 of the Species at Risk Act as threatened, endangered or extirpated.

I declare that I have read and understand this Permit, including all the conditions attached.

Signature of permit holder



Environment Canada Environnement Canada
Canadian Wildlife Service Service canadien de la faune

SCIENTIFIC PERMIT TO CAPTURE AND BAND MIGRATORY BIRDS
PERMIS DE CAPTURE ET DE BAGUAGE D'OISEAUX MIGRATEURS

In the Province(s) / Territories - Dans la (les) provinces(s) / territoires
Alberta, Ontario

Permit No.
N^o de permis **00077 AR**

Issued under the Migratory Birds Regulations Sections 4 and 19.

If the authorizations include any species that are not protected under the Migratory Bird Convention Act, 1994, this document represents an agreement between Environment Canada and the holder for the use of federal bird bands on those species. All conditions listed on the back of this document apply.

Émis en vertu des articles 4 et 19 des règlements concernant les oiseaux migrateurs.

Si les autorisations visent des espèces qui ne sont pas protégées en vertu de la Loi de 1994 sur la convention concernant les oiseaux migrateurs, le présent document tient lieu d'entente entre Environnement Canada et le titulaire aux fins de l'utilisation de bagues fédérales sur ces espèces d'oiseaux. Toutes les conditions figurant au verso du présent document s'appliquent.

Name and Address - Nom et adresse

MATT DYSON
16A NATCHEZ ROAD
KITCHENER, ON N2B 3A5

Issue Date
Date d'émission **2017/03/31**

Expiration Date
Date d'expiration **2017/12/31**

Signature of Holder - Signature du détenteur

For the Minister - Pour le Ministre
Name (Print) - Nom (Lettres moulées)
L. LAURIN

Signature

AUTHORIZATIONS -- AUTORISATIONS

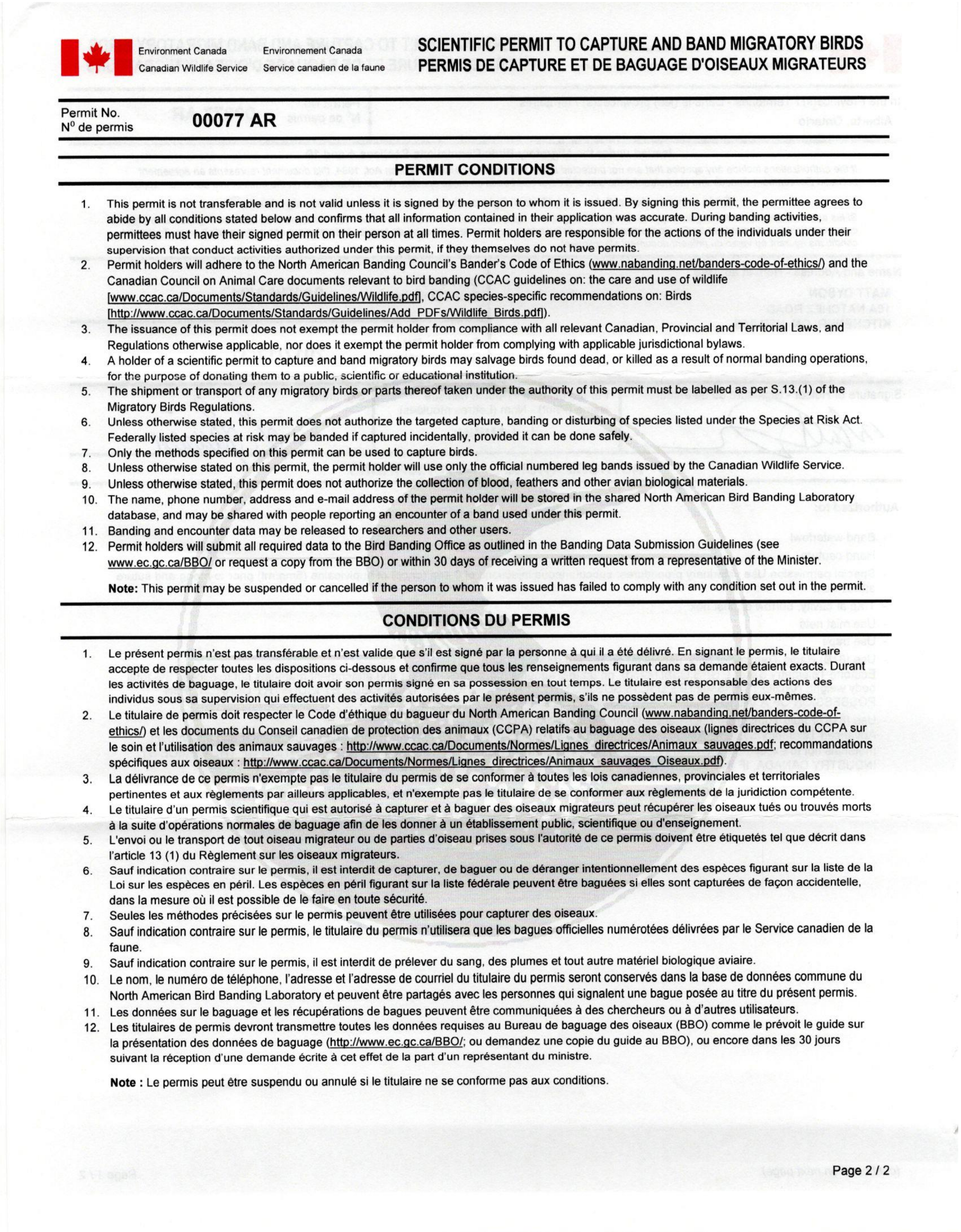
Authorized to:

- Band waterfowl
- Hand capture
- Special permission Use veterinary procedures; subcutaneous injections of 0.1ml (or cc) of bupivicaine (5mg/ml) prior to prong and suture attachment
- Trap at cavity, burrow or nest box
- Use mist nets
- Use traps
- Use (81B) Radio Transmitter (incl. nanotags) on Mallard (MALL) (1320)
  Ecotone Telemetry Saker L GPS GSM (<25g), on up to 3 females (back pack; marker and attachment materials not to exceed 3% total body weight; RADIO TRANSMITTER USE IS SUBJECT TO CERTIFICATION OF THE DEVICE BY INDUSTRY CANADA; IF IN POSSESSION OF A VALID ANIMAL CARE COMMITTEE APPROVAL) in Alberta
- Use (81K) Radio Transmitter (incl. nanotags) on Mallard (MALL) (1320)
  Advanced Telemetry Systems A4430 (10g, shed after 3-4 months), on up to 20 females (prong and suture; marker and attachment materials not to exceed 3% total body weight; RADIO TRANSMITTER USE IS SUBJECT TO CERTIFICATION OF THE DEVICE BY INDUSTRY CANADA; IF IN POSSESSION OF A VALID ANIMAL CARE COMMITTEE APPROVAL) in Alberta

See Permit Conditions on the following page -- Voir les conditions du permis sur la page suivante

(continued on next page)

Page 1 / 2



Environment Canada Environnement Canada
Canadian Wildlife Service Service canadien de la faune

SCIENTIFIC PERMIT TO CAPTURE AND BAND MIGRATORY BIRDS
PERMIS DE CAPTURE ET DE BAGUAGE D'OISEAUX MIGRATEURS

Permit No. / N⁰ de permis **00077 AR**

PERMIT CONDITIONS

1. This permit is not transferable and is not valid unless it is signed by the person to whom it is issued. By signing this permit, the permittee agrees to abide by all conditions stated below and confirms that all information contained in their application was accurate. During banding activities, permittees must have their signed permit on their person at all times. Permit holders are responsible for the actions of the individuals under their supervision that conduct activities authorized under this permit, if they themselves do not have permits.
2. Permit holders will adhere to the North American Banding Council's Bander's Code of Ethics (www.nabanding.net/banders-code-of-ethics/) and the Canadian Council on Animal Care documents relevant to bird banding (CCAC guidelines on: the care and use of wildlife [www.ccac.ca/Documents/Standards/Guidelines/Wildlife.pdf], CCAC species-specific recommendations on: Birds [http://www.ccac.ca/Documents/Standards/Guidelines/Add_PDFs/Wildlife_Birds.pdf]).
3. The issuance of this permit does not exempt the permit holder from compliance with all relevant Canadian, Provincial and Territorial Laws, and Regulations otherwise applicable, nor does it exempt the permit holder from complying with applicable jurisdictional bylaws.
4. A holder of a scientific permit to capture and band migratory birds may salvage birds found dead, or killed as a result of normal banding operations, for the purpose of donating them to a public, scientific or educational institution.
5. The shipment or transport of any migratory birds or parts thereof taken under the authority of this permit must be labelled as per S.13.(1) of the Migratory Birds Regulations.
6. Unless otherwise stated, this permit does not authorize the targeted capture, banding or disturbing of species listed under the Species at Risk Act. Federally listed species at risk may be banded if captured incidentally, provided it can be done safely.
7. Only the methods specified on this permit can be used to capture birds.
8. Unless otherwise stated on this permit, the permit holder will use only the official numbered leg bands issued by the Canadian Wildlife Service.
9. Unless otherwise stated, this permit does not authorize the collection of blood, feathers and other avian biological materials.
10. The name, phone number, address and e-mail address of the permit holder will be stored in the shared North American Bird Banding Laboratory database, and may be shared with people reporting an encounter of a band used under this permit.
11. Banding and encounter data may be released to researchers and other users.
12. Permit holders will submit all required data to the Bird Banding Office as outlined in the Banding Data Submission Guidelines (see www.ec.gc.ca/BBO/ or request a copy from the BBO) or within 30 days of receiving a written request from a representative of the Minister.

Note: This permit may be suspended or cancelled if the person to whom it was issued has failed to comply with any condition set out in the permit.

CONDITIONS DU PERMIS

1. Le présent permis n'est pas transférable et n'est valide que s'il est signé par la personne à qui il a été délivré. En signant le permis, le titulaire accepte de respecter toutes les dispositions ci-dessous et confirme que tous les renseignements figurant dans sa demande étaient exacts. Durant les activités de baguage, le titulaire doit avoir son permis signé en sa possession en tout temps. Le titulaire est responsable des actions des individus sous sa supervision qui effectuent des activités autorisées par le présent permis, s'ils ne possèdent pas de permis eux-mêmes.
2. Le titulaire de permis doit respecter le Code d'éthique du bagueur du North American Banding Council (www.nabanding.net/banders-code-of-ethics/) et les documents du Conseil canadien de protection des animaux (CCPA) relatifs au baguage des oiseaux (lignes directrices du CCPA sur le soin et l'utilisation des animaux sauvages : http://www.ccac.ca/Documents/Normes/Lignes_directrices/Animaux_sauvages.pdf; recommandations spécifiques aux oiseaux : http://www.ccac.ca/Documents/Normes/Lignes_directrices/Animaux_sauvages_Oiseaux.pdf).
3. La délivrance de ce permis n'exempte pas le titulaire du permis de se conformer à toutes les lois canadiennes, provinciales et territoriales pertinentes et aux règlements par ailleurs applicables, et n'exempte pas le titulaire de se conformer aux règlements de la juridiction compétente.
4. Le titulaire d'un permis scientifique qui est autorisé à capturer et à baguer des oiseaux migrateurs peut récupérer les oiseaux tués ou trouvés morts à la suite d'opérations normales de baguage afin de les donner à un établissement public, scientifique ou d'enseignement.
5. L'envoi ou le transport de tout oiseau migrateur ou de parties d'oiseau prises sous l'autorité de ce permis doivent être étiquetés tel que décrit dans l'article 13 (1) du Règlement sur les oiseaux migrateurs.
6. Sauf indication contraire sur le permis, il est interdit de capturer, de baguer ou de déranger intentionnellement des espèces figurant sur la liste de la Loi sur les espèces en péril. Les espèces en péril figurant sur la liste fédérale peuvent être baguées si elles sont capturées de façon accidentelle, dans la mesure où il est possible de le faire en toute sécurité.
7. Seules les méthodes précisées sur le permis peuvent être utilisées pour capturer des oiseaux.
8. Sauf indication contraire sur le permis, le titulaire du permis n'utilisera que les bagues officielles numérotées délivrées par le Service canadien de la faune.
9. Sauf indication contraire sur le permis, il est interdit de prélever du sang, des plumes et tout autre matériel biologique aviaire.
10. Le nom, le numéro de téléphone, l'adresse et l'adresse de courriel du titulaire du permis seront conservés dans la base de données commune du North American Bird Banding Laboratory et peuvent être partagés avec les personnes qui signalent une bague posée au titre du présent permis.
11. Les données sur le baguage et les récupérations de bagues peuvent être communiquées à des chercheurs ou à d'autres utilisateurs.
12. Les titulaires de permis devront transmettre toutes les données requises au Bureau de baguage des oiseaux (BBO) comme le prévoit le guide sur la présentation des données de baguage (http://www.ec.gc.ca/BBO/; ou demandez une copie du guide au BBO), ou encore dans les 30 jours suivant la réception d'une demande écrite à cet effet de la part d'un représentant du ministre.

Note : Le permis peut être suspendu ou annulé si le titulaire ne se conforme pas aux conditions.

ACC Cat.5

UNIVERSITY OF WATERLOO
OFFICE OF RESEARCH ETHICS

ANIMAL CARE COMMITTEE
CERTIFICATE OF FULL ETHICS APPROVAL:
RENEWAL OF ANIMAL UTILIZATION PROJECT PROPOSAL

All research and teaching activities at the University of Waterloo which use live, non-human vertebrate animals must be conducted in compliance with the Animals for Research Act of Ontario (Revised Statutes of Ontario), the Guide to the Care and Use of Experimental Animals from the Canadian Council on Animal Care and the University of Waterloo's Guidelines for the Care and Use of Animals in Research and Teaching.

Principal Investigator(s):	Bradley Fedy; Matt Dyson		
Department or School:	Environment & Resource Studies		
Co-Investigator(s):	Stuart Slattery		
Student Investigator(s):			
Project Title :	Waterfowl nest success in the western boreal forest: Does industrial development alter predation?		
AUPP # :	17-03	**Approval Date:**	February 27, 2018
Number of Animals Approved:	952 Waterflow	**Invasiveness Category:**	C

The above Animal Utilization Project Proposal (AUPP) Renewal Form has been reviewed by members of the Animal Care Committee at the University of Waterloo in compliance with the requirements of the *Animals for Research Act*, the Canadian Council on Animal Care's *Guide to the Care and Use of Experimental Animals,* and the University's *Guidelines for the Care and Use of Animals in Research and Teaching.*

Approval of the original AUPP is extended for an additional twelve month period from the date shown.

An AUPP representing continuing research must be renewed annually and can be renewed three times after original ethics approval. A Renewal Form must be submitted for ethics review well in advance of the expiration date to prevent any break in ethics approval coverage.

Note: the project covered by the original AUPP and the corresponding Renewal Form must be conducted according to the procedures described in the application. Requests for subsequent modifications to approved AUPPs must be communicated in writing to the Research Ethics Advisor, Office of Research Ethics, using the modification form.

Cindy Futher - Mar 7/18.

Cindy Futher
Research Ethics Advisor
Office of Research Ethics

Alberta Environment and Parks
Policy and Planning Division
Fish and Wildlife Policy Branch

#18-419

General Permit - GP

Region: Lower Peace

RESEARCH PERMIT
FEE $ NIL

PERMITTEE: Brad Fedy, University of Waterloo

ADDRESS: 200 University Ave. W, Waterloo, MB N2L3G1

IS AUTHORIZED TO: Trap and Band waterfowl within research area, attach radio transmitters and track waterfowl, Nest search and monitor nests with nest camera traps, place and monitor Predator camera traps, lure and hair snag sites.

DATE OF ISSUE: April 06, 2018

DATE OF EXPIRY: December 31, 2018

Signature of Permittee

Natalka Melnycky

IN ACCORDANCE WITH: The approved research plan (application # 12864207) and Class Protocol(s) #002, #011

Class Protocols are reviewed by the Alberta Wildlife Animal Care Committee and approved by the Director of Fish and Wildlife Policy.Class Protocols are available at http://aep.alberta.ca/fish-wildlife/wildlife-research-collection/default.aspx.

Conditions:

1. The Permit is subject to all conditions listed in the attached Appendix 1.
2. Individuals banding waterfowl must have current federal banding permit.
3. Signs must be placed at nearest access point, indicating the presence of a hair-snag site with lure at all hair-snag sites.
4. Field staff must follow bear smart principles when working in proximity of hair-snag sites, including carrying bear-spray and being trained in how to use it.

Alberta Environment and Parks
Policy and Planning Division
Fish and Wildlife Policy Branch

#18-419

Licence - CN

Region: Lower Peace

COLLECTION LICENCE
FEE $ NIL

NAME: Brad Fedy, University of Waterloo

ADDRESS: 200 University Ave. W, Waterloo, MB N2L3G1

Is authorized, subject to the conditions of this licence, and in accordance with the approved research plan # 12864207, to hunt* or collect, the following wildlife species: Waterfowl unintentionally killed during waterfowl research.

This Licence authorizes the use of the following equipment and methods: Radio transmitter attachment will use standard surgical instruments and supplies as outlined in our Animal Care Protocol. See abbreviated list below. Decoy traps, Camera traps, Wire, Lure, Surgical Instruments: Needle Driver (5 Olsen-Hegar) Adson forceps with Debaky toothing 12.5cm #3 Scalpel handle #11 Scalpel blades Blunt forceps 14cm Surgery Supplies: Gauze sponges 1ml syringes with single use needles Replacement injection needles single use Transmitter Telemetry Receiver to test transmitters PDS II Sutures 3-0 Taper (RB-1) 3-0 Prolene (2-metric) blue monofilament Peel-off cucumber facial mask Surgical Solutions etc: Betadine solution in flip top bottle Isopropyl alcohol in flip top bottle Endure Sterile water for injection Rubbermaid containers (size 4-cup) for holding instruments in glutaraldehyde solution Sterile water for rinsing

This Licence is valid (location): Lower Peace, Upper Athabasca

EFFECTIVE DATE: April 01, 2018

DATE OF EXPIRY: December 31, 2018

Hunting and/or collection is to be conducted by: Brad Fedy, Matt Dyson, PhD Candidate, University of Waterloo Dr. Stuart Slattery, Ducks Unlimited Canada Dr. Jim Devries, Ducks Unlimited Canada Howie Singer, Ducks Unlimited Canada Jared Knockaert, Ducks Unlimited Canada Research Technician 1 (RT1) RT2 RT3 RT4 RT5

Date of issue: April 06, 2018
Signature of Licencee (not valid until signed by the Licencee)
Licence must be carried while hunting or collecting.

Natalka Melnycky

**The meaning of the word "hunt" is inclusive of activities within the definition of "hunt" in the Wildlife Act except that the activity authorized by this licence is limited to what is expressly stated in it and, to be lawful, that activity must occur in accordance with the approved research plan and licence conditions.*

Conditions:

1. Any mortalities associated with the research must be reported to AEP wildlife staff during field operations.
2. Prior to any capture work being done, AEP wildlife biologists should be contacted and kept informed.

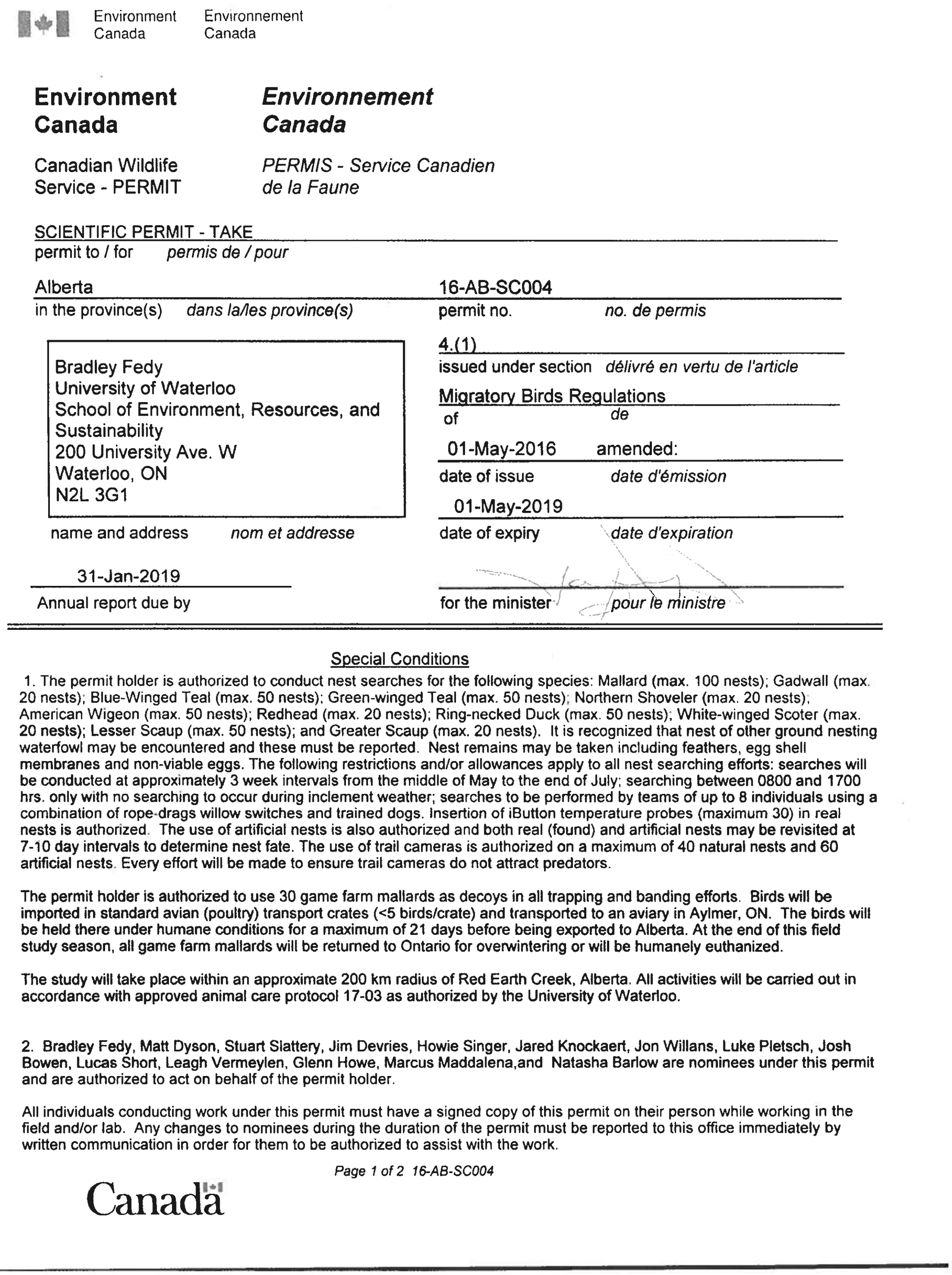
Appendix 1: Research Permit General Permit Conditions
Addendum to Research Permit #18-419

1. All research must be conducted according to the approved Research Plan (the approved application).
2. It is the responsibility of the Permittee to contact the appropriate Regional Wildlife Biologist and District Fish and Wildlife Officer and the appropriate landowner prior to the commencement of any permitted activities. Contact information for Wildlife Management staff is available at: http://aep.alberta.ca/about-us/contact-us/fisheries-wildlife-management-area-contacts.aspx or by calling 310-0000 and asking for the appropriate Wildlife Management office.
3. The permit is valid only for research and collection activities in the specific area and for the dates identified on the permit.
4. For activities in any Provincial Park, Ecological Reserve, Wildland Provincial Park, Natural Area, or Wilderness Area, additional approvals for access may be required. Please contact your local Alberta Environment and Parks, Parks Division authority.
5. The Permittee is responsible for ensuring that public safety is not endangered by activities associated with the project.
6. The Permittee shall be held accountable for damages to resources or property arising directly or indirectly from the project.
7. The issuance of this Permit does not exempt the holder from any other Canadian Laws that might otherwise apply.
8. All captured animals must be handled in a humane manner and according to the approved Research Plan (the approved application) as well as any additional approvals or instructions provided by the Wildlife Animal Care Committee.
9. Animals captured using immobilization drugs must follow the Chemical Immobilization of Wildlife: Drug Volume Calculation Tables: http://aep.alberta.ca/fish-wildlife/wildlife-research-collection/documents/WR-ChemicalImmobilizationWildlife-DrugVolumeCalculation-2016.pdf
10. If radio telemetry is a component of the research, the Permittee is responsible for providing up-to-date information on frequency deployment including date, general location, species, transmitter type, manufacturer, and expected transmitter life.
11. A report of the past year's activities (which can be part of the renewal application), including any issues such as accidental mortality/oversampling exceeding 10%, is required before permits will be renewed or new permits will be issued. If the project has finished and the permit will not be renewed, the report is due within 30 days of the expiry of the permit.
12. All observations made during your project are to be provided within either:
    a) A FWMIS Load Form, or
    b) Where USFWS bands are used in the project, a "Band Manager" or "BANDIT" digital export. Note: Banding data locations are to be provided as Latitude/Longitude in Degrees-Minutes-Seconds.

    FWMIS.xls digital files can be accessed at the following web site:
    http://aep.alberta.ca/fish-wildlife/fwmis/wildlife-load-forms.aspx

    Instructions for submitting banding data are available at:
    http://aep.alberta.ca/fish-wildlife/wildlife-research-collection/default.aspx

    This completed data file, including the permit number, is to be attached to your annual or final progress report, upon completion of the project (no later than December 1st annually).



Environment Canada Environnement Canada

Environment Canada ***Environnement Canada***

Canadian Wildlife Service - PERMIT *PERMIS - Service Canadien de la Faune*

SCIENTIFIC PERMIT - TAKE
permit to / for *permis de / pour*

Alberta
in the province(s) *dans la/les province(s)*

16-AB-SC004
permit no. *no. de permis*

4.(1)
issued under section *délivré en vertu de l'article*

Migratory Birds Regulations
of *de*

01-May-2016 amended:
date of issue *date d'émission*

01-May-2019
date of expiry *date d'expiration*

Bradley Fedy
University of Waterloo
School of Environment, Resources, and Sustainability
200 University Ave. W
Waterloo, ON
N2L 3G1

name and address *nom et addresse*

31-Jan-2019
Annual report due by

for the minister *pour le ministre*

Special Conditions

1. The permit holder is authorized to conduct nest searches for the following species: Mallard (max. 100 nests); Gadwall (max. 20 nests); Blue-Winged Teal (max. 50 nests); Green-winged Teal (max. 50 nests); Northern Shoveler (max. 20 nests); American Wigeon (max. 50 nests); Redhead (max. 20 nests); Ring-necked Duck (max. 50 nests); White-winged Scoter (max. 20 nests); Lesser Scaup (max. 50 nests); and Greater Scaup (max. 20 nests). It is recognized that nest of other ground nesting waterfowl may be encountered and these must be reported. Nest remains may be taken including feathers, egg shell membranes and non-viable eggs. The following restrictions and/or allowances apply to all nest searching efforts: searches will be conducted at approximately 3 week intervals from the middle of May to the end of July; searching between 0800 and 1700 hrs. only with no searching to occur during inclement weather; searches to be performed by teams of up to 8 individuals using a combination of rope-drags willow switches and trained dogs. Insertion of iButton temperature probes (maximum 30) in real nests is authorized. The use of artificial nests is also authorized and both real (found) and artificial nests may be revisited at 7-10 day intervals to determine nest fate. The use of trail cameras is authorized on a maximum of 40 natural nests and 60 artificial nests. Every effort will be made to ensure trail cameras do not attract predators.

The permit holder is authorized to use 30 game farm mallards as decoys in all trapping and banding efforts. Birds will be imported in standard avian (poultry) transport crates (<5 birds/crate) and transported to an aviary in Aylmer, ON. The birds will be held there under humane conditions for a maximum of 21 days before being exported to Alberta. At the end of this field study season, all game farm mallards will be returned to Ontario for overwintering or will be humanely euthanized.

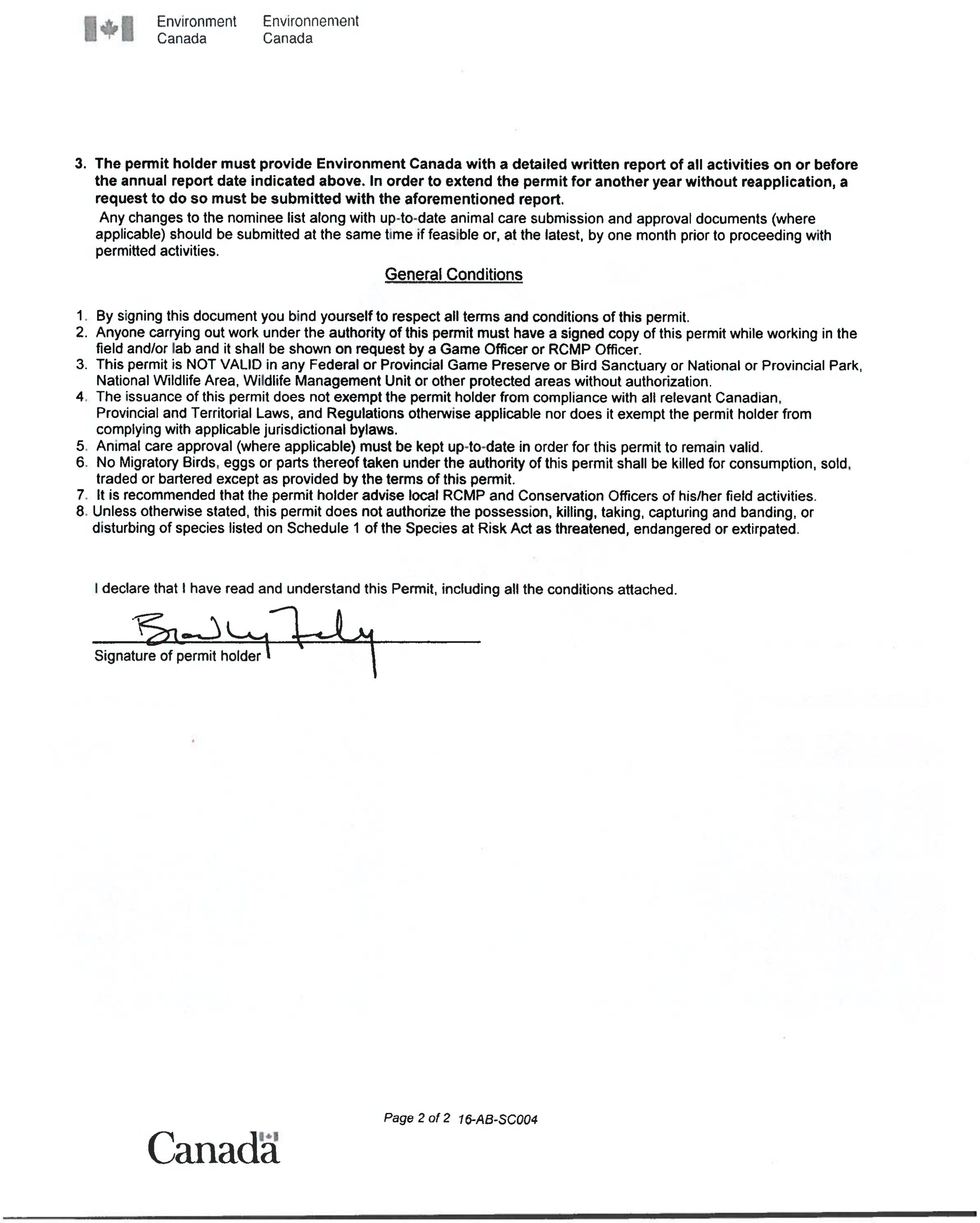
The study will take place within an approximate 200 km radius of Red Earth Creek, Alberta. All activities will be carried out in accordance with approved animal care protocol 17-03 as authorized by the University of Waterloo.

2. Bradley Fedy, Matt Dyson, Stuart Slattery, Jim Devries, Howie Singer, Jared Knockaert, Jon Willans, Luke Pletsch, Josh Bowen, Lucas Short, Leagh Vermeylen, Glenn Howe, Marcus Maddalena,and Natasha Barlow are nominees under this permit and are authorized to act on behalf of the permit holder.

All individuals conducting work under this permit must have a signed copy of this permit on their person while working in the field and/or lab. Any changes to nominees during the duration of the permit must be reported to this office immediately by written communication in order for them to be authorized to assist with the work.

Page 1 of 2 16-AB-SC004

Canada



Environment Canada Environnement Canada

3. **The permit holder must provide Environment Canada with a detailed written report of all activities on or before the annual report date indicated above. In order to extend the permit for another year without reapplication, a request to do so must be submitted with the aforementioned report.**
   Any changes to the nominee list along with up-to-date animal care submission and approval documents (where applicable) should be submitted at the same time if feasible or, at the latest, by one month prior to proceeding with permitted activities.

<u>General Conditions</u>

1. By signing this document you bind yourself to respect all terms and conditions of this permit.
2. Anyone carrying out work under the authority of this permit must have a signed copy of this permit while working in the field and/or lab and it shall be shown on request by a Game Officer or RCMP Officer.
3. This permit is NOT VALID in any Federal or Provincial Game Preserve or Bird Sanctuary or National or Provincial Park, National Wildlife Area, Wildlife Management Unit or other protected areas without authorization.
4. The issuance of this permit does not exempt the permit holder from compliance with all relevant Canadian, Provincial and Territorial Laws, and Regulations otherwise applicable nor does it exempt the permit holder from complying with applicable jurisdictional bylaws.
5. Animal care approval (where applicable) must be kept up-to-date in order for this permit to remain valid.
6. No Migratory Birds, eggs or parts thereof taken under the authority of this permit shall be killed for consumption, sold, traded or bartered except as provided by the terms of this permit.
7. It is recommended that the permit holder advise local RCMP and Conservation Officers of his/her field activities.
8. Unless otherwise stated, this permit does not authorize the possession, killing, taking, capturing and banding, or disturbing of species listed on Schedule 1 of the Species at Risk Act as threatened, endangered or extirpated.

I declare that I have read and understand this Permit, including all the conditions attached.

Bradley Fedy
Signature of permit holder

Page 2 of 2 16-AB-SC004

Canada

Environment Canada Environnement Canada
Canadian Wildlife Service Service canadien de la faune

SCIENTIFIC PERMIT TO CAPTURE AND BAND MIGRATORY BIRDS
PERMIS DE CAPTURE ET DE BAGUAGE D'OISEAUX MIGRATEURS

In the Province(s) / Territories - Dans la (les) provinces(s) / territoires
Alberta, Ontario

Permit No.
N⁰ de permis **00077 AR**

Issued under the Migratory Birds Regulations Sections 4 and 19.

If the authorizations include any species that are not protected under the Migratory Bird Convention Act, 1994, this document represents an agreement between Environment Canada and the holder for the use of federal bird bands on those species. All conditions listed on the back of this document apply.

Émis en vertu des articles 4 et 19 des règlements concernant les oiseaux migrateurs.

Si les autorisations visent des espèces qui ne sont pas protégées en vertu de la Loi de 1994 sur la convention concernant les oiseaux migrateurs, le présent document tient lieu d'entente entre Environnement Canada et le titulaire aux fins de l'utilisation de bagues fédérales sur ces espèces d'oiseaux. Toutes les conditions figurant au verso du présent document s'appliquent.

Name and Address - Nom et adresse
MATT DYSON
16A NATCHEZ ROAD
KITCHENER, ON N2B 3A5

Issue Date
Date d'émission **2018/04/04**

Expiration Date
Date d'expiration **2018/12/31**

Signature of Holder - Signature du détenteur

For the Minister - Pour le Ministre
Name (Print) - Nom (Lettres moulées)
L. LAURIN

Signature
C. Marie for L. Laurin

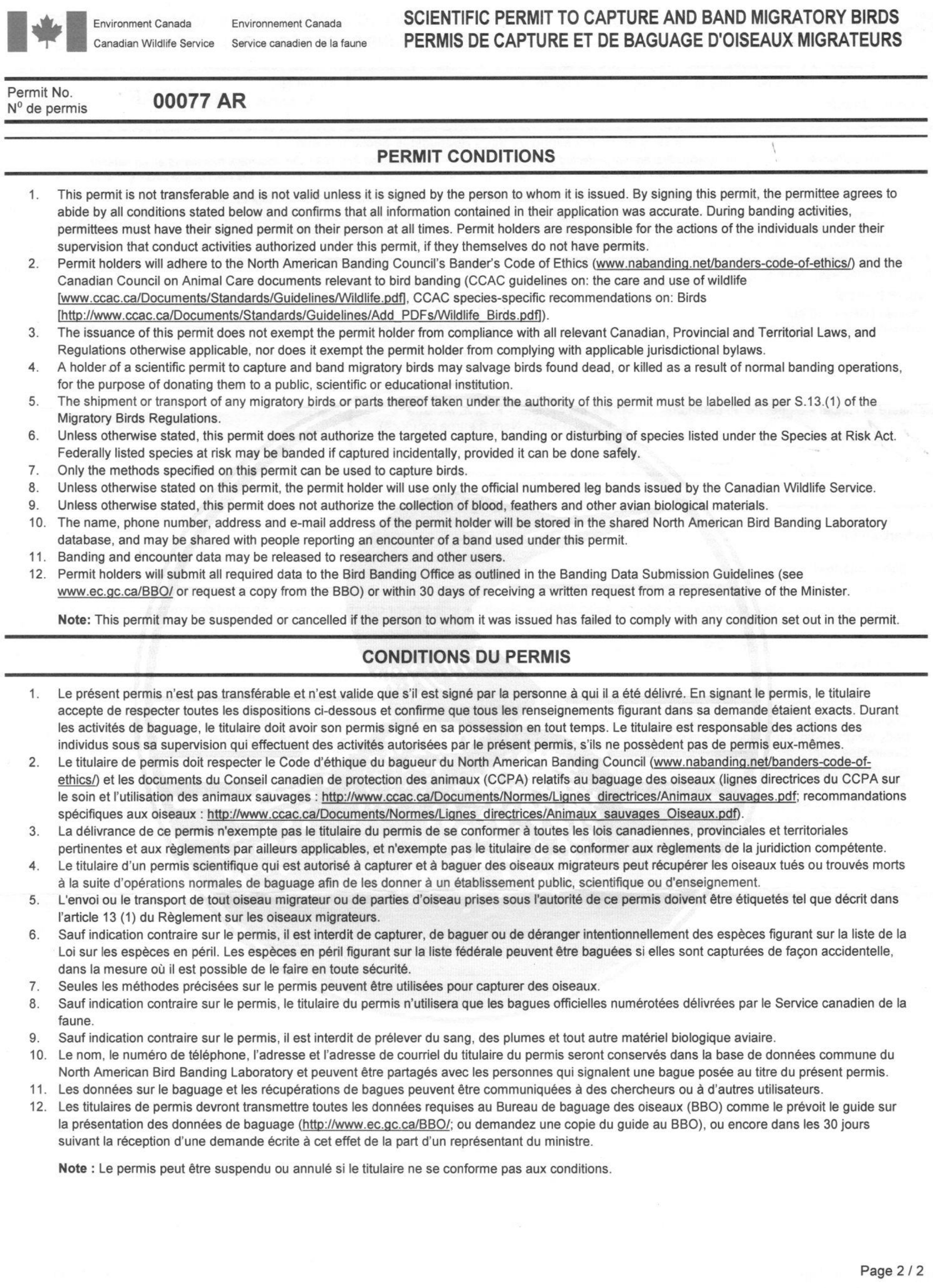
AUTHORIZATIONS -- AUTORISATIONS

Authorized to:

- Band waterfowl
- Hand capture
- Special permission: Use veterinary procedures; subcutaneous injections of 0.1ml (or cc) of bupivicaine (5mg/ml) prior to prong and suture attachment
- Trap at cavity, burrow or nest box
- Use mist nets
- Use traps
- Use (81B) radio transmitter (incl. nanotags) on Mallard (MALL) (1320)
  Ecotone Telemetry Saker L GPS GSM (<25g), on up to 3 females (back pack; marker and attachment materials not to exceed 3% total body weight;radio transmitter use is subject to certification of the device by Industry Canada; if in possession of a valid Animal Care Committee Approval) in Alberta
- Use (81K) radio transmitter (incl. nanotags) on Mallard (MALL) (1320)
  Advanced Telemetry Systems A4430 (10g, shed after 3-4 months), on up to 20 females (prong and suture; marker and attachment materials not to exceed 3% total body weight; radio transmitter use is subject to certification of the device by Industry Canada; if in possession of a valid Animal Care Committee Approval) in Alberta

See Permit Conditions on the following page -- Voir les conditions du permis sur la page suivante

(continued on next page)



Environment Canada Environnement Canada
Canadian Wildlife Service Service canadien de la faune

SCIENTIFIC PERMIT TO CAPTURE AND BAND MIGRATORY BIRDS
PERMIS DE CAPTURE ET DE BAGUAGE D'OISEAUX MIGRATEURS

Permit No.
N⁰ de permis **00077 AR**

PERMIT CONDITIONS

1. This permit is not transferable and is not valid unless it is signed by the person to whom it is issued. By signing this permit, the permittee agrees to abide by all conditions stated below and confirms that all information contained in their application was accurate. During banding activities, permittees must have their signed permit on their person at all times. Permit holders are responsible for the actions of the individuals under their supervision that conduct activities authorized under this permit, if they themselves do not have permits.
2. Permit holders will adhere to the North American Banding Council's Bander's Code of Ethics (www.nabanding.net/banders-code-of-ethics/) and the Canadian Council on Animal Care documents relevant to bird banding (CCAC guidelines on: the care and use of wildlife [www.ccac.ca/Documents/Standards/Guidelines/Wildlife.pdf], CCAC species-specific recommendations on: Birds [http://www.ccac.ca/Documents/Standards/Guidelines/Add_PDFs/Wildlife_Birds.pdf]).
3. The issuance of this permit does not exempt the permit holder from compliance with all relevant Canadian, Provincial and Territorial Laws, and Regulations otherwise applicable, nor does it exempt the permit holder from complying with applicable jurisdictional bylaws.
4. A holder of a scientific permit to capture and band migratory birds may salvage birds found dead, or killed as a result of normal banding operations, for the purpose of donating them to a public, scientific or educational institution.
5. The shipment or transport of any migratory birds or parts thereof taken under the authority of this permit must be labelled as per S.13.(1) of the Migratory Birds Regulations.
6. Unless otherwise stated, this permit does not authorize the targeted capture, banding or disturbing of species listed under the Species at Risk Act. Federally listed species at risk may be banded if captured incidentally, provided it can be done safely.
7. Only the methods specified on this permit can be used to capture birds.
8. Unless otherwise stated on this permit, the permit holder will use only the official numbered leg bands issued by the Canadian Wildlife Service.
9. Unless otherwise stated, this permit does not authorize the collection of blood, feathers and other avian biological materials.
10. The name, phone number, address and e-mail address of the permit holder will be stored in the shared North American Bird Banding Laboratory database, and may be shared with people reporting an encounter of a band used under this permit.
11. Banding and encounter data may be released to researchers and other users.
12. Permit holders will submit all required data to the Bird Banding Office as outlined in the Banding Data Submission Guidelines (see www.ec.gc.ca/BBO/ or request a copy from the BBO) or within 30 days of receiving a written request from a representative of the Minister.

Note: This permit may be suspended or cancelled if the person to whom it was issued has failed to comply with any condition set out in the permit.

CONDITIONS DU PERMIS

1. Le présent permis n'est pas transférable et n'est valide que s'il est signé par la personne à qui il a été délivré. En signant le permis, le titulaire accepte de respecter toutes les dispositions ci-dessous et confirme que tous les renseignements figurant dans sa demande étaient exacts. Durant les activités de baguage, le titulaire doit avoir son permis signé en sa possession en tout temps. Le titulaire est responsable des actions des individus sous sa supervision qui effectuent des activités autorisées par le présent permis, s'ils ne possèdent pas de permis eux-mêmes.
2. Le titulaire de permis doit respecter le Code d'éthique du bagueur du North American Banding Council (www.nabanding.net/banders-code-of-ethics/) et les documents du Conseil canadien de protection des animaux (CCPA) relatifs au baguage des oiseaux (lignes directrices du CCPA sur le soin et l'utilisation des animaux sauvages : http://www.ccac.ca/Documents/Normes/Lignes_directrices/Animaux_sauvages.pdf; recommandations spécifiques aux oiseaux : http://www.ccac.ca/Documents/Normes/Lignes_directrices/Animaux_sauvages_Oiseaux.pdf).
3. La délivrance de ce permis n'exempte pas le titulaire du permis de se conformer à toutes les lois canadiennes, provinciales et territoriales pertinentes et aux règlements par ailleurs applicables, et n'exempte pas le titulaire de se conformer aux règlements de la juridiction compétente.
4. Le titulaire d'un permis scientifique qui est autorisé à capturer et à baguer des oiseaux migrateurs peut récupérer les oiseaux tués ou trouvés morts à la suite d'opérations normales de baguage afin de les donner à un établissement public, scientifique ou d'enseignement.
5. L'envoi ou le transport de tout oiseau migrateur ou de parties d'oiseau prises sous l'autorité de ce permis doivent être étiquetés tel que décrit dans l'article 13 (1) du Règlement sur les oiseaux migrateurs.
6. Sauf indication contraire sur le permis, il est interdit de capturer, de baguer ou de déranger intentionnellement des espèces figurant sur la liste de la Loi sur les espèces en péril. Les espèces en péril figurant sur la liste fédérale peuvent être baguées si elles sont capturées de façon accidentelle, dans la mesure où il est possible de le faire en toute sécurité.
7. Seules les méthodes précisées sur le permis peuvent être utilisées pour capturer des oiseaux.
8. Sauf indication contraire sur le permis, le titulaire du permis n'utilisera que les bagues officielles numérotées délivrées par le Service canadien de la faune.
9. Sauf indication contraire sur le permis, il est interdit de prélever du sang, des plumes et tout autre matériel biologique aviaire.
10. Le nom, le numéro de téléphone, l'adresse et l'adresse de courriel du titulaire du permis seront conservés dans la base de données commune du North American Bird Banding Laboratory et peuvent être partagés avec les personnes qui signalent une bague posée au titre du présent permis.
11. Les données sur le baguage et les récupérations de bagues peuvent être communiquées à des chercheurs ou à d'autres utilisateurs.
12. Les titulaires de permis devront transmettre toutes les données requises au Bureau de baguage des oiseaux (BBO) comme le prévoit le guide sur la présentation des données de baguage (http://www.ec.gc.ca/BBO/; ou demandez une copie du guide au BBO), ou encore dans les 30 jours suivant la réception d'une demande écrite à cet effet de la part d'un représentant du ministre.

Note : Le permis peut être suspendu ou annulé si le titulaire ne se conforme pas aux conditions.