# Ferruginous Hawk (*Buteo regalis*) Home Range and Resource Use on Northern Grasslands in Canada

by

Jesse Laurence Watson

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Department of Biological Sciences
University of Alberta

# Abstract

Human alteration of the landscape can have implications for wildlife at the individual and population levels. The grassland ecosystem has been highly altered and is at risk of further alteration due to increasing demand for human food, pastureland, and energy development. The Ferruginous Hawk (*Buteo regalis*), a grassland obligate, has experienced declines across its range due to loss of habitat leading to its listing as a Threatened species in Canada. Understanding how breeding Ferruginous Hawks have been affected by anthropogenic change in the grassland region of southern Alberta and Saskatchewan is important to inform species recovery and management. My goal was to investigate how anthropogenic development has affected Ferruginous Hawk range use and perch choice at the level of 3$^{rd}$-order selection. I tracked 48 breeding, male Ferruginous Hawks during the 2012-2017 breeding seasons, and used high-resolution satellite telemetry to address this goal.

In Chapter 2, I measured the size of hawk core areas (50% contour; $\bar{x} = 3.54$ km$^2$ ± 8.52 SD) and home ranges (95% contour; $\bar{x} = 36.33$ km$^2$ ± 94.74 SD) ($n = 92$), the first range-size estimates for satellite-tracked Ferruginous Hawks in Canada. I used linear mixed models to test the relationship of perch density and land-cover type on range size as an indicator of range quality. I found the density of fencelines and proportion of cropland were significant influences on range quality, with higher densities of fenceline and lower proportions of cropland resulting in smaller core areas. However, at the home-range scale, there was a significant interaction between fenceline density and the proportion of cropland, with increasing densities of fenceline mediating the effect of proportion of cropland on home-range size. Additionally, increasing proportions of tame grass and tame hay resulted in smaller home ranges and thus higher range quality.

In Chapter 3, I studied 24 hawks that were monitored intensively in 2013 and 2014 with GSM transmitters, which generated a high volume of location fixes. My objective was to evaluate perch use by Ferruginous Hawks at two scales. Firstly, I estimated Resource Utilization Functions at the home-range level to compare use intensity among elevated perch types (fencelines, power distribution lines, and power transmission towers), and also among common land-cover types (native grassland, cropland, tame grass, tame hay, and idle field). Resource Utilization Functions indicated that hawks showed the highest relative use at areas near transmission towers, but they were the least abundant elevated perch types on the landscape. Hawks also showed highest use in areas near distribution lines and areas far from fencelines. Among vegetated land-cover types and relative to areas with native grassland, hawks showed highest use in areas with low levels of cropland and high levels of tame grass and tame hay. Secondly, I visited 1,436 perches of known use, distributed among 20 hawk home ranges, and measured micro-site land-cover characteristics and relative prey abundance, indexed by mammal burrow counts, within the hypothetical viewscape (i.e., 50 m) of a perched hawk. I tested the influence of these predictors on intensity of perch use, with mixed effects logistic regression. Fence posts were the most common elevated perch type, comprising 52% of all perches. Transmission towers were the most heavily-used perch type but were the least abundant perch type on the landscape, resulting in less overall use. Hawks showed higher use at perches with higher proportions of bare ground, higher burrow counts, and less cropland within 50 m. I concluded that, although prey abundance is important for Ferruginous Hawks, prey accessibility and visibility, as influenced by the juxtaposition of perch height, amount of bare ground, and relative abundance of prey are the best indicators of perch use within home ranges.

In Chapter 4, I summarize potential benefits and consequences related to human-made elevated perches on Ferruginous Hawks and recommend that future studies should investigate perch use of Ferruginous Hawks through direct observation and experimentation to determine how placement of new perches may affect breeding individuals.

## Preface

This thesis is an original work by Jesse L. Watson. The research for this thesis was conducted with the Raptor Ecology and Conservation Team (REACT), a collection of graduate students and post-doctoral fellows working to generate a comprehensive dataset of Ferruginous Hawk biology to inform conservation efforts for the species. This group is supervised by Dr. Erin Bayne at the University of Alberta and Dr. Troy Wellicome with the Canadian Wildlife Services (University of Alberta Adjunct Professor). I present all chapters in first person, as they were written by myself and edited by Dr. Bayne and Dr. Wellicome. No part of this thesis has been previously published.

This project was approved by University of Alberta Animal Care (#724) and conducted under permit AUP00000018: "Foraging and Reproduction of Wild Ferruginous Hawks" from the Research Ethics Board at the University of Alberta, the Saskatchewan Ministry of Environment (#14FW113), Alberta Environment and Sustainable Resource Development (#55483 and #55482), Alberta SARA permit #SARA-PNR-2013-0231, and the federal banding office (#10796H and #10277Z).

> “That silent and timid king of hawks, the Ferruginous Rough-leg, still patrols the uninhabited sections of the state. The nest is usually situated near a colony of ground dwelling rodents, which is subject to extermination through the raids of this raptore.”
>
> \- Gerard Alan Abbott (1916)

> “The ‘*zoom*’ of a Ferruginous Roughleg as it rises vertically over my head after a half-mile stoop still sends a shiver down my spine but, whether wisely or not, I have learned to disregard it.”
>
> \- W. Ray. Salt (1939)

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# Chapter 1: Introduction

Habitat alteration by humans at the global scale has accelerated over the past century due to human influences (August et al. 2002). As human populations continue to expand, the projected rate of habitat alteration is expected to increase even faster (Laurance 2001). Human population growth and the associated land transformation translates into increased losses in biological diversity (Vitousek et al. 1997, Sanderson et al. 2002) and additionally, more land must be converted to sustain increased demands for food, fuel, and infrastructure for homes (August et al. 2002).

The world's grassland biome accounts for almost half of the earth's surface and is under increased pressure to be managed for cropland, pastureland, energy development, and recreation (Wick et al. 2016). Across North America's Great Plains, three quarters of grassland habitat has been lost to these human uses (Samson et al. 2004). By the late 1800s, immigrants from eastern Canada and Europe began plowing the land in western Canada, in hopes of becoming successful farmers. The influx of settlers resulted in 60% of the grassland region being cultivated by 1931 (Rowe and Coupland 1984). Additional changes to prairie habitat and vegetation structure were caused by livestock ranching. Additionally, exotic species such as crested wheatgrass (*Agropyron cristatum*) were planted to increase forage for livestock causing a decrease in native grass biodiversity (Atkinson 2009). By the mid-1900s, high volumes of exposed soil had blown or washed away, resulting from intensive cultivation, and overgrazing by livestock during dry conditions. Thus, chemical fertilizers and "no-till farming" were introduced to restore and maintain soil fertility (Rowe and Coupland 1984).

Since the farming boom between the 1880s-1930s, the rate of land conversion for agriculture in the Canadian grasslands has decreased significantly. However, estimates suggest that 80% of arable prairie has been lost and estimates for loss of total grassland range between 65-85% (Alberta Environmental Protection 1997, Radenbaugh and Sutter 2005). Of the remaining native grassland habitat in the three prairie provinces of Canada, most has been fragmented due to roads, railroads, and other human infrastructure (Roch and Jaeger 2014). Alberta Environmental Protection (1997) estimated the combined footprint of roads (i.e., paved, gravel, railroad, and wellsite access) at 1 km of road for every square kilometer of land in the grassland region. Road density has continued to increase, in large part because of energy development (e.g., extraction of oil and gas from shale) (Northrup and Wittemyer 2013). Alberta's grassland region alone contained nearly 75,000 oil and gas wellsites by 1997, and additional habitat loss in North America's grassland biome is imminent, as on average 50,000 new wells are developed in North America each year (International Energy Agency 2013, Allred et al. 2015).

Human alteration of grassland systems carries with it the responsibility for monitoring effects on endemic wildlife species (Samson and Knopf 1994) and developing successful strategies to mitigate impacts on populations. Our ability to maintain populations of endemic wildlife is based largely on the assumption that habitat and resource use of individual animals is non-random and driven by their requirements for survival and reproduction (Marzluff et al. 2001, Millspaugh et al. 2006, Tapia et al. 2007). Thus, understanding how land-cover alteration affects individuals and populations is key to conserving endemic wildlife. At the landscape scale, the loss or degradation of critical breeding or wintering habitat can have drastic consequences on a species distribution if individuals are unsuccessful at breeding or they relocate after habitat changes (Marquiss et al. 1985, Schmidt 2016). At the local scale, individuals that do not relocate may alter their use of land cover, which may impact regional breeding success and survival.

These effects on individual space and resource use may be subtle and are more challenging to document than direct anthropogenic impacts (e.g., mortality from powerline collisions, wind-turbine collisions, and electrocutions) (Smith and Dwyer 2016), and hence require intensive monitoring in order to be quantified. Effectiveness of monitoring can be aided considerably through marking or telemetry (Cagnacci et al. 2010).

For raptors and other predatory birds, space-use dictates the size of an individual's home range, which may in turn reflect range quality. The most important influences on home-range size include types and patch size of land cover, proximity to the nest (Keough and Conover 2012, Watson et al. 2014b, Crandall et al. 2015, Weber 2015), and resource competition with adjacent nesting pairs (Newton 1979). Prey availability (i.e., density and abundance) is vital to raptor subsistence (Baker and Brooks 1981, Smith et al. 1981, Downey et al. 2004), and is influenced by land-cover type (Moulton et al. 2006, McConnell et al. 2008, Marsh 2012), and other factors like vegetation structure (Wakeley 1978b;1979, Bechard 1982, Yosef and Grubb 1993, Chavez-Ramirez et al. 1994). Wider spacing of key resources and larger home ranges, which result in greater energy expenditure, lower nest attendance, and potentially reduced nest success (Marzluff et al. 1997a, Peery 2000, Moss et al. 2014, Michel et al. 2017) can reflect relatively poor-quality habitat. Identifying the highest quality habitats through studies of range size and space-use, combined with maintaining, and improving habitat quality, is a key objective in managing for and conserving raptor populations (Tapia et al. 2007).

The distribution of hunting structures, particularly elevated perches, and their relationship to prey distribution may be a particularly important influence on raptor space use (Widén 1994, Lynn et al. 2006, Howe et al. 2014). Numerous studies have demonstrated that the presence of artificial perches may alter territory size and/or shape or cause shifts in breeding areas (Hall et al.

1981, Yosef 1993, Kay et al. 1994, Widén 1994, Lynn et al. 2006, Coates et al. 2014, Smith and Dwyer 2016). However, the presence of artificial perches does not always result in their use by birds (Bohall and Collopy 1984). Research by Leyhe and Ritchison (2004) and Andersson et al. (2009) suggests that perch height, as well as vegetation height, affect a predator's perch choice because they alter prey vulnerability and capture success by predators. Furthermore, the addition of artificial perches can reduce the suitability of habitat for prey species because of their perceived risk of predation (Andersson 1980, Wallander et al. 2006). As man-made structures continue to be constructed, more onus must be put on understanding how they affect raptor perching, hunting behaviour, and associated home-range size and shape.

### *1.1.1 Study Species*

The Ferruginous Hawk (*Buteo regalis*) is a prairie-dwelling raptor that breeds throughout grasslands of North America. Within Canada, Ferruginous Hawks breed between March and August throughout the mixed and moist grassland ecoregions, in southern Alberta, Saskatchewan, and Manitoba. Ferruginous Hawks are stenophagous and in Canada, primarily consume Richardson's ground squirrels (*Urocitellus richardsonii*). Richardson's ground squirrels are a highly abundant rodent species that are active above ground during the day between late February and October, coinciding with the Ferruginous Hawk breeding season (Downey 2003). The widespread abundance of this prey and its ability to proliferate in areas of low vegetation, make them an ideal food item for Ferruginous Hawks. Habitat adjacent to roads where the soil has been disturbed, and moisture is concentrated by ditches, often supports ground squirrels, and hence many Ferruginous Hawks can be found perching on distribution poles and fence posts along roadsides. In addition to ground squirrels, Ferruginous Hawks eat small microtine species (mice and voles), lagomorphs, birds, reptiles, and amphibians (Ng et al. 2017). Male hawks provide most of the food for the nesting female and nestlings (Ng et al. 2017). Much of the male's time is spent perching throughout the pair's home range while hunting, resting, and guarding the territory. In contrast, adult females are much more nest-centric during the nesting season, and depending on the stage of the breeding cycle, can be found incubating, brooding, or spending time on the nest near their nestlings (J. L. Watson pers. obs.). As the season progresses, females often supplement the male's hunting efforts by bringing additional food to the nest (Wakeley 1978a).

Breeding Ferruginous Hawks nesting in undeveloped areas can be found in flat, arid areas within shrub-steppe or grassland habitat. Typical terrain is low-elevation and sparsely populated with trees. Historically, breeding individuals nested on and hunted exclusively from natural substrates including large rocks/pillars, the ground, and trees (Cameron 1914, Decker and Bowles 1926, Ng et al. 2017). More recent anthropogenic changes in the landscapes have provided a variety of artificial structures for nesting and perching, including transmission towers, distribution poles, windmills, oil/gas shacks, bales, and fence posts (Wakeley 1979, Olendorff 1993, Bayne et al. 2014).

Efforts by Schmutz et al. (1984) to erect platforms in suitable habitat on the Canadian prairies where natural nest structures were lacking has helped maintain territory occupancy. Tree-rows from historical farmsteads often support Ferruginous Hawk nests, and elevated artificial structures such as gas-shacks also provide suitable nesting substrate (Neal 2011, Ng et al. 2017). Past research indicates that petroleum development on a landscape scale can have positive, neutral, or negative effects on Ferruginous Hawk breeding success (Van Horn 1993, Zelenak and Rotella 1997, Smith et al. 2010, Keough et al. 2015). Thus, cumulative effects of cultivation and petroleum development are of concern if they relate to Ferruginous Hawk declines. To date, no research has investigated how anthropogenic development affects Ferruginous Hawk 3rd-order resource selection as it particularly relates to changing perch structure, vegetation, and prey. There is a strong need to fill this gap in our knowledge because Ferruginous Hawk populations are facing similar threats throughout their breeding range. A better understanding of how this species copes with extensive habitat alteration will allow for improved management where additional development is expected.

### *1.1.2 Study Area*

I conducted this study during the summers of 2012-2017. The study area was located in the southern grasslands of Alberta and Saskatchewan, predominatly within the mixed grassland ecoregion. The western boundary was located near Pincher Creek, Alberta (49.29° N, 113.56° W) within the fescue grassland ecoregion and the western edge of the moist mixed grassland ecoregion. The eastern boundary was near Weyburn, Saskatchewan (49.39° N, 103.51° W) within the eastern boundary of the moist mixed grassland region. The northern extent of the study area was near Kindersley, Saskatchewan (51.28° N, 109.09° W), and the southern boundary was along the 49th parellel, which forms the Canadian/U.S.A. border. In total, the study area covered > 200,000 $km^2$ (Figure 1.1).

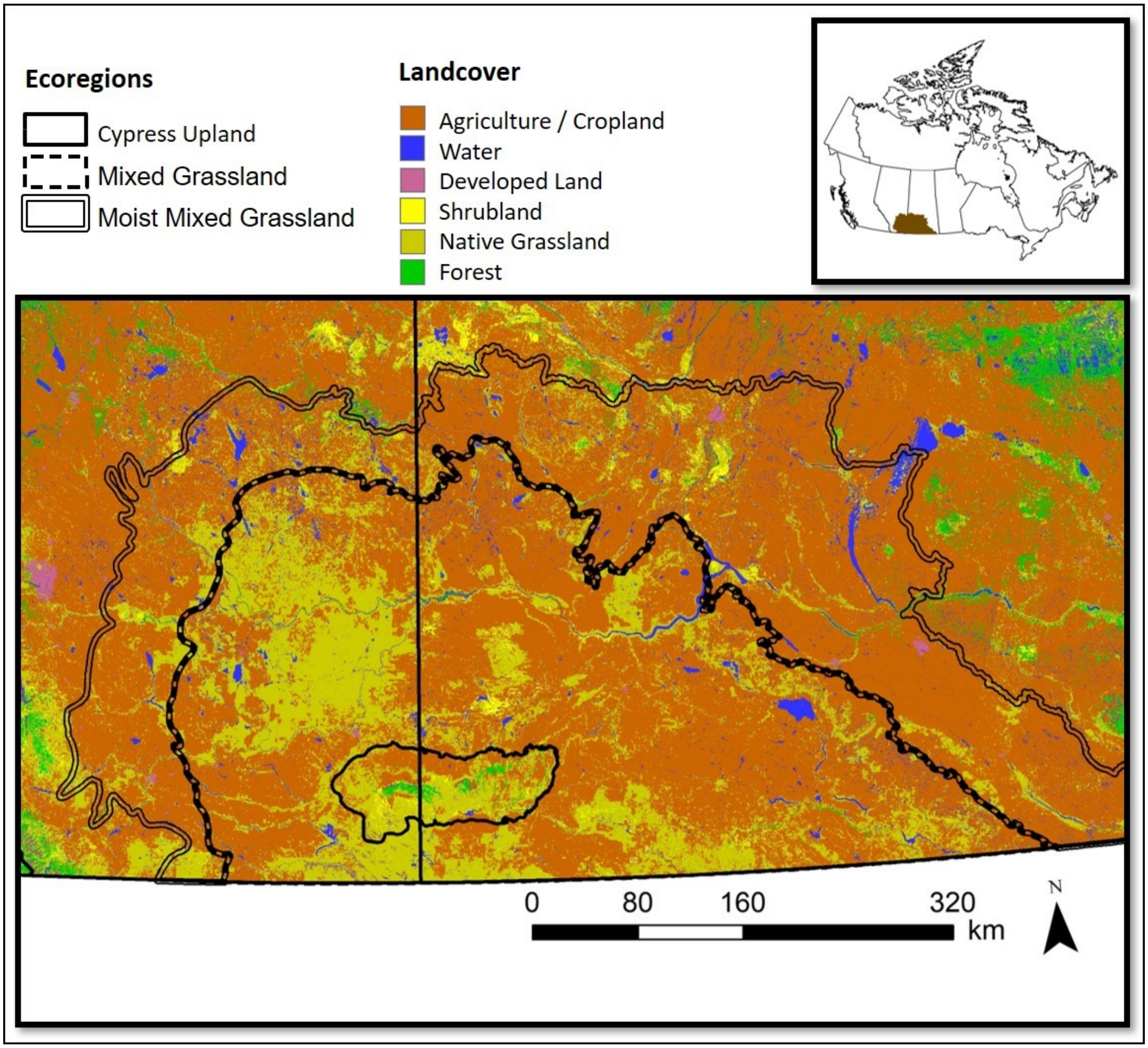

**Figure 1.1** - General land-cover characteristics where Ferruginous Hawks were studied in southern Alberta and Saskatchewan, showing the extent of land conversion and forested land within each of the prairie ecoregions.

The mixed-grassland prairie ecosystem in North America has been degraded over the past century with a > 64% decline in coverage. Initial changes to the landscape were influenced by overhunting and a vast reduction in large fauna including bison (*Bison bison*), plains wolves

(*Canus lupus*), and the plains grizzly bear (*Ursus arctos*) (Atkinson 2009), followed by rapid increases in domestic livestock (Wick et al. 2016). Native vegetation in the mixed grassland is dominated by needle-and-thread grass (*Hesperostipa comata*), wheatgrasses (*Agropyron* spp.), blue grama (*Bouteloua gracilis*), and June grass (*Koeleria macrantha*) (Alberta Environmental Protection 1997, Natural Regions Committee 2006). Sagebrush (*Artemisia* spp.) are common shrubs in southeastern Alberta and southwestern Saskatchewan. Tree species throughout the region include aspen and cottonwood (*Populus* spp.), willow (*Salix* spp.), and boxelder (*Acer negundo*). Mean annual precipitation varies from 250-350 mm and mean summer temperature is 16˚C (Environment Canada 2014). Dominant landuses consist of cattle ranching and crop production. Petroleum development is widespread in southern Alberta and localized within southern Saskatchewan. Crop fields consist primarily of wheat, oilseed, and other grains. Vegetation in tame pastures consist mostly of crested-wheat grass (*Agropyron* cristatum) and alfalfa (*Medicago sativa*) while roadside ditches consist mostly of crested-wheat grass and smooth brome grass (*Bromus inermis*). Much of the study area is fragmented by primary and secondary highways and numerous dirt and gravel roads used for agriculture and petroleum industry activities.

### *1.1.3 Objectives and Thesis Outline*

My goal was to investigate the influence of anthropogenic development on Ferruginous Hawks, at the level of 3rd-order selection, using high-resolution satellite telemetry. In Chapter 2, I compute sizes of breeding home-ranges and core use areas of Ferruginous Hawks, measure land-cover types and elevated perch features throughout each range type, and through mixed model analysis identify which features are a barometer of range quality. In Chapter 3, I develop Resource Utilization Functions to explore large-scale land-cover use by hawks on breeding home-ranges and to understand how human-altered features, including elevated perches, cultivated habitats, and proximity of roads, relate to intensity of hawk use. I then test for potential influences of micro-scale characteristics within the foraging radius of a perched hawk on space use. These influences include perch type, ground cover conditions, and relative prey abundance. For analyses at both scales, I account for the distance-to-nest which may otherwise mask other influences on perch location. To address these objectives, I tracked 48 adult male hawks during the breeding season, with GPS satellite transmitters (39 GSM/GPS and 9 Argos/GPS), between 2012-2017. Telemetry data were collected over 1 to 5 breeding seasons per individual and provided accurate and comprehensive documentation of home-range size and resource use. In Chapter 4 I summarize my conclusions and outline management implications that can be deduced from my research.

# Chapter 2: Home-range structure of Ferruginous Hawks: Correlates that affect range size and quality

## 2.1 Introduction

The spatial and temporal dynamics of an animal's home range – the area in which it conducts regular activities (Burt 1943), vary according to physical characteristics of the individual (Harestad and Bunnel 1979) and its environment (McNab 1963, Marzluff et al. 1997b, Ofstad et al. 2016, Walton et al. 2017). For breeding birds of prey, features of habitat near the nest, as well as competition for prey and essential resources by neighboring conspecifics, may influence space use. Specific factors that affect home-range size of raptors include prey type (Peery 2000), distribution, and accessibility, which can all be influenced by land-cover type, (Moss et al. 2014), topography (Slaght et al. 2013), and the density and layout of perches. Larger raptors tend to have larger home ranges (Peery 2000), and home-range size has been indirectly related to reproductive success [(Leary 1996, Peery 2000, Moss et al. 2014); but see Michel et al. (2017)].

The relationship between environmental factors and the size of a raptor's home range [i.e., 3rd-order selection (Johnson 1980)] are critical to understand because they may relate to habitat quality, and our ability to manage for and protect higher quality habitats is necessary for species conservation. Comparatively large home ranges of raptors may indicate poor-quality habitat, low prey abundance, or widely-distributed critical habitat (Newton 1979, Watson et al. 2014b, Kouba et al. 2017). Hence, adults with large home ranges may experience lower fitness (i.e., lower survival and/or breeding success) than those with smaller, high-quality home-ranges

(Howell et al. 1978, Marzluff et al. 1997b, Leary et al. 1998, Ganey et al. 2005, Moss et al. 2014). In some ecosystems, more time spent in ranging activities over larger areas increases exposure to anthropogenic risks (Solaro 2018). From a conservation perspective, the potential consequences for these individuals from increased energy needs and exposure to risks could include reduced current reproductive success (Stout et al. 2006) or fewer future breeding attempts (Krüger 2005, Catry et al. 2016).

Our ability to define a raptor's home-range size and to analyze its characteristics relies on accurate estimates of its movements. Today, transmitters used on raptors allow researchers to associate movement patterns with exogenous environmental conditions (Lanzone et al. 2012, Vidal-Mateo et al. 2016, Rus et al. 2017), make comparisons of habitat use by individuals over multiple seasons (Miller et al. 2017, Buechley et al. 2018, Watson et al. 2018), and investigate fine-scale use patterns (Marsh et al. 2014, Apolloni et al. 2017, Duerr et al. 2019). Concurrent with these technological advancements was the improvement of home-range mapping techniques, advancing from the minimum convex polygon (MCP) (Mohr 1947, Southwood 1966) to Kernel Density Estimates (KDE), which are superior because they are computed using the entire frequency distribution of data, calculate multiple centers of animal activity, lack sensitivity to outliers, and use a non-parametric methodology (Worton 1987;1989, Seaman and Powell 1996, Seaman et al. 1999, Kernohan et al. 2001).

Breeding home-range size of the Ferruginous Hawk, specialist raptor in arid landscapes, has been relatively understudied compared to other raptors in western North America (Ng et al. 2017), and no studies have attempted to gain insight into Ferruginous Hawk habitat quality on the basis of home-range size. This type of study is particularly needed in the southern Canadian

Provinces that historically supported one of the most productive populations of Ferruginous Hawks range-wide but has declined in the past 20 years from unclear causes (Ng et al. 2017).

Home-range research on this species in the 1970s was limited by pre-Global Positioning System (GPS) technology and small sample sizes. For example, Smith and Murphy (1973) reported breeding home-range information based on focal observations of Ferruginous Hawks in a raptor breeding ecology study in the eastern Great Basin. Similarly, during his behavioural study of hawk habitat and prey densities, Wakeley (1978b) recorded observations of two hawks in Idaho and reported range size. Janes (1985) investigated the interspecific interactions between grassland raptors including the *Buteos* [Ferruginous, Swainson's (*Buteo swainsoni*), and Red-tailed (*Buteo jamaicensis*) Hawks], focusing on territorial defense, habitat use, and home-range size using focal observations. McAnnis (1990) and Leary et al. (1998) reported the first Ferruginous Hawk home-ranges tracked via VHF telemetry for small numbers of hawks ($n$ = 7, and $n$ = 6, respectively). These studies, in the Pacific Northwest, USA, provided the first reliable home-range size estimates and varied from < 5 km$^2$ to 136.4 km$^2$ for the 95% contour MCP. More recent research in the Pacific Northwest, using GPS satellite telemetry, found home ranges averaged 314.5 km$^2$ (J. W. Watson, Washington Department of Fish and Wildlife, pers. comm). Because of the limitations of outdated methodologies used to assess Ferruginous Hawk home ranges, there is a need to obtain highly accurate and comprehensive location data for Ferruginous Hawks through use of GPS satellite telemetry that can be applied to studies of range quality.

Prior research on environmental factors that may influence nesting behaviour in Ferruginous Hawks, and thus relate to nesting habitat quality, fall into two categories: land cover and elevated perches. Land cover, and particularly the degree to which native habitat has been altered by cultivation, has been found to influence Ferruginous Hawk distribution and feeding behaviour (Schmutz 1984;1987;1989). Ferruginous Hawks breeding in Canada have been shown to nest in higher densities within habitats composed of 10-60% cultivated land, but in lower densities where cultivation is < 10% or over 60% (Schmutz 1989, Ng et al. 2017). Thus, moderate amounts of cultivated land appear to benefit hawk nesting at the landscape scale. Much of the research on elevated structures and their use by Ferruginous Hawks has been conducted in the context of providing nest structure (Smith et al. 2011, Keough et al. 2015), but these structures are also important for perching. For example, males in Idaho hunted from perches ~30% of the time and showed a preference for wooden fence posts relative to distribution poles and other perches on the landscape (Wakeley 1978c, Nugent 1995).

In this study, I used high-resolution satellite telemetry to determine how land cover, surface geometry (topographic position index), and human infrastructure (elevated perches) related to range size of breeding male Ferruginous Hawks in southern Alberta and Saskatchewan. My goal was to evaluate factors related to hawk ecology and document range sizes, as a possible indicator of habitat quality, in relation to composition, in order to provide previously undocumented information on both range size and structure with the intention of delineating important conservation areas in the Canadian Ferruginous Hawk breeding range. To accomplish this, I characterized Ferruginous Hawk ranges at two scales, referred to hereafter as the core area (50% contour) and the home range (95% contour). I used the term "ranges" when referring to both contour levels. I hypothesized that at both scales, decreasing range size would be characterized by a higher proportion of cultivation and higher density of elevated perches. I also predicted that specific land cover and perch types that explained core-area size and home-range size would differ and reflect the primary function of those range types (i.e., daily foraging in proximity to nests in core areas vs. ranging activity throughout the season in the home range).

## 2.2 Materials and Methods

### *2.2.1 Study Area*

A survey team conducted data collection across the mixed and moist mixed grassland ecoregion in an area > 200,000 km$^2$ (Figure 2.1). Ferruginous Hawks typically nest in habitat in rural areas composed of native grassland or crop fields, with relatively little change in elevation that ranges from 600 m to 1300 m above sea level (Ng et al. 2017). In my study area, relatively few trees were found outside of creek and river valleys, and upland vegetation was predominantly grasses, such as blue grama (*Bouteloua gracilis*), needle and thread grass (*Hesperostipa comata*), and wheat grasses (*Elmyus* spp.). Ferruginous Hawks nested on lone trees or within small bluffs, artificial platforms, electrical transmission infrastructure, oil/gas shacks, windmills, and occasionally on the ground or on hillsides (Ng et al. 2017). Cottonwood (*Populus* spp.) and trembling aspen (*P. tremuloides*) were the most dominant nest tree species. Trees and hilltops were used as perches in native habitats while transmission towers, distribution poles, fence posts, and oil/gas infrastructure provided potential perches in areas developed by the petroleum industry. Land use varied within the region, and included cattle ranching, cereal and oilseed crop production, and petroleum development. Oil and natural gas extraction were the main energy development activities in the study area, with well density in some portions of the study area > 0.8 well sites/km$^2$ and cumulative length of roads > 1.0 km per km$^2$ (Alberta Environmental Protection 1997).

### *2.2.2 Field Data Collection*

#### *Hawk Capture*

A survey team conducted nest and occupancy surveys in mid-April 2012-2017 to document activity at historical nests and to locate new nests. From a yearly sample of > 250 active nests, we selected sites for hawk capture, equally divided among the two main cover types (i.e., native prairie and cultivated farmland) and along a gradient of anthropogenic features (i.e., transmission lines, oil and gas infrastructure, and roads) that increased progressively from undeveloped to developed landscapes. Final selection of capture sites was limited to broods that survived past hatch and by permission to access land. Hawks were captured using either a dho-gaza net with a Great Horned Owl (*Bubo virginianus*) lure (Bloom et al. 1992) or a bal-chatri trap baited with a gerbil (*Meriones unguiculatus*) (Berger and Mueller 1959). I preferred the first method because it was easier to target individuals, but it was logistically more involved. The lure was set up between several break-away dho-gaza nets that were placed into a "V" shape < 15 m from the nest. Hawks were captured when they stooped the owl and became entangled in the nets. Females typically flushed from the nest when setting the nets (J. L. Watson, pers. obs.). Thus, to limit exposure of young nestlings to the elements and potential adult abandonment, we set up in early morning, under low-wind conditions, and when young were ≥ 10 days old (i.e., old enough to autothermoregulate). We used the bal-chatri capture method opportunistically when male hawks were perched in accessible locations, if weather conditions were appropriate to protect the lure animal (i.e., no rain or extreme temperatures).

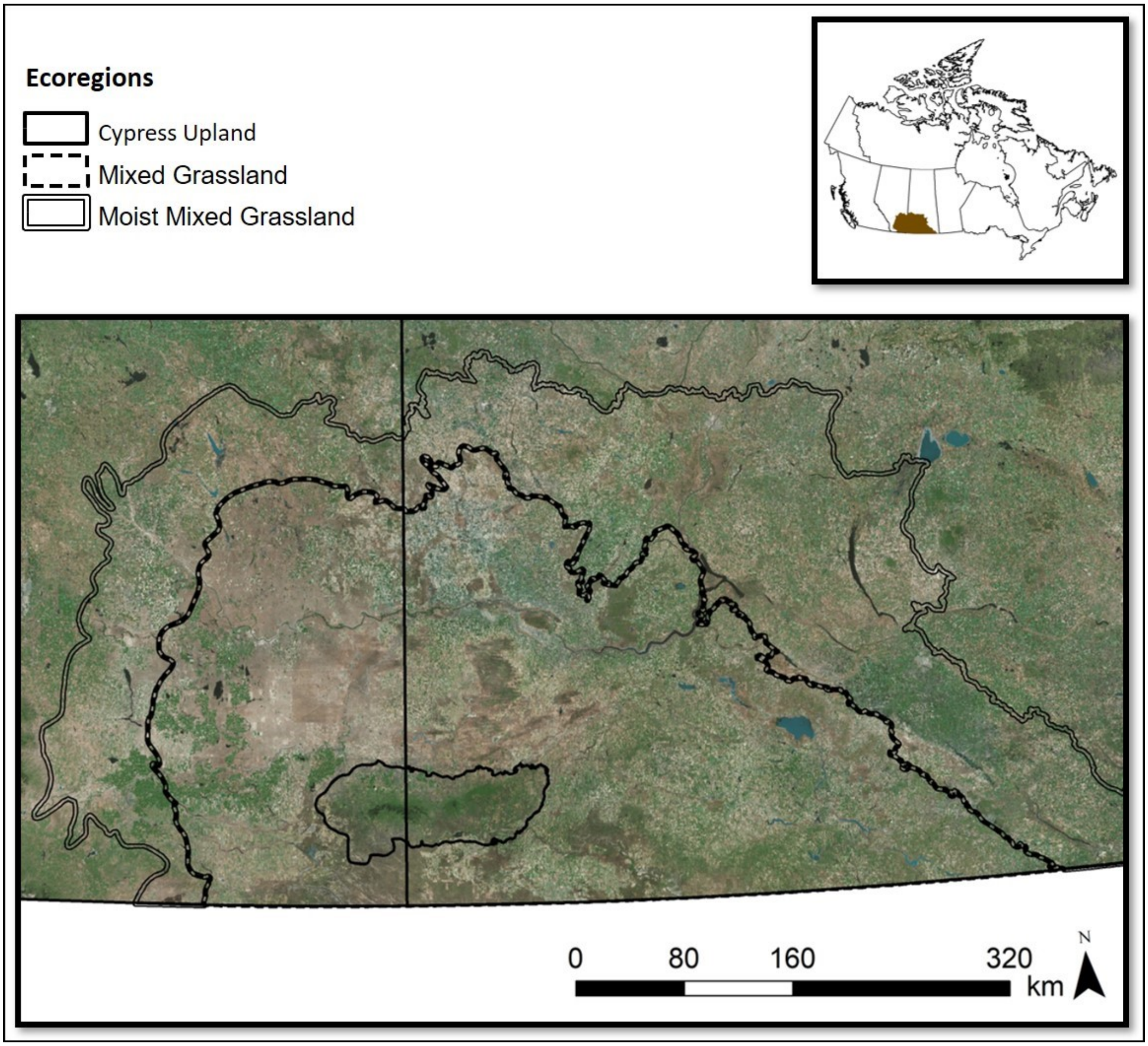

**Figure 2.1** - The mixed and moist mixed grassland ecoregions of southern Alberta and Saskatchewan, Canada where Ferruginous Hawks were captured and studied from 2012-2017.

*Satellite Telemetry*

I targeted male hawks for transmitter attachment to obtain ranging behaviour because male Ferruginous Hawks are responsible for most activities away from the nest (e.g., foraging and territory defense) during the breeding season (Wakeley 1974, Laux et al. 2015). Sex of targeted hawks was determined using a combination of observed behaviours (e.g., copulation, nest provisioning, and nest attentiveness) and verified after capture with morphometric data, as females are larger and heavier than males (Table 2.7) (Liguori et al. 2020). I used two different types of transmitters: solar ARGOS/GPS (Global Positioning System) PTTs (platform transmitter terminals) and solar GSM (Groupe Special Mobile)/GPS 20-70 for the duration of this study. Data downloading was via ARGOS satellites for ARGOS transmitters that were pre-programmed to collect hourly locations during the period of expected daily: 0400 h to 2100 h local time from 16 April through 15 September. Data downloading for GSM transmitters that acquired fixes dynamically ≤ 1/min, depending on the level of solar charge, was via the digital cellular network. Units had built-in activity, speed, and altitude sensors, and location accuracy for GPS fixes was ± 18 m horizontal and ± 22 m vertical (Microwave Telemetry Inc., Columbia, MD, USA) and had the potential to function for ≥ 3 yr. Transmitter units weighed 30 g, which is less than the 5% of body mass recommended by other avian researchers (Caccamise and Hedin 1985) and required by provincial and federal permits. Units were affixed to hawks with a Teflon-ribbon harness, attached backpack-style, with the four ribbons sewn together at the keel with dental floss intended to last through the life of the transmitter (Buehler et al. 1995).

### *Estimation of Core Areas and Home Ranges*

I estimated ranges, for tagged individuals captured between 2012 and 2017, using ArcGIS (ArcMap 10.1.3, Environmental Systems Research Institute, Inc., Redlands, CA, USA). I omitted flight locations (i.e., speed > 0 kph) from breeding datasets, between the time of capture (initial telemetry deployment date) and initiation of fall migration to include only locations that were within the breeding range. In addition to ranges being calculated for individuals in their capture year, ranges were also calculated for individuals with functioning transmitters that returned to breed in a second, third, fourth, or fifth season. Data used for range estimates for these returning individuals included fixes between their date of arrival on the breeding range following spring migration and the date of departure for fall migration following the breeding season. I used two methods to estimate ranges: 1) Minimum Convex Polygon [(MCP); (Anderson 1982)] and 2) Kernel Density Estimate with fixed smoothing parameter [(KDE); (Worton 1989, Kernohan et al. 2001)] (Figure 2.2). I estimated MCP's and KDE's using the ArcMet 10.3.1. extension within ArcMap [Movement Ecology Tools for ArcGIS (ArcMET), www.movementecology.net, accessed 10 Dec 2018]. I used the MCP Range tool to estimate MCP's with 50%, 95%, and 99% percentiles for each hawk in each breeding season. For KDE estimation, I used ArcMET's 'KDE UD' model toolset with the h-ref smoothing parameter, which chooses a smoothing factor based on the spatial variance of input points, to create a utilization distribution (UD) with 30 x 30 m grid cells. I then used the 'Create Percent Contours' tool to estimate percent volume contours at 50%, 95%, and 99% based on the KDEs for each hawk during each breeding season.

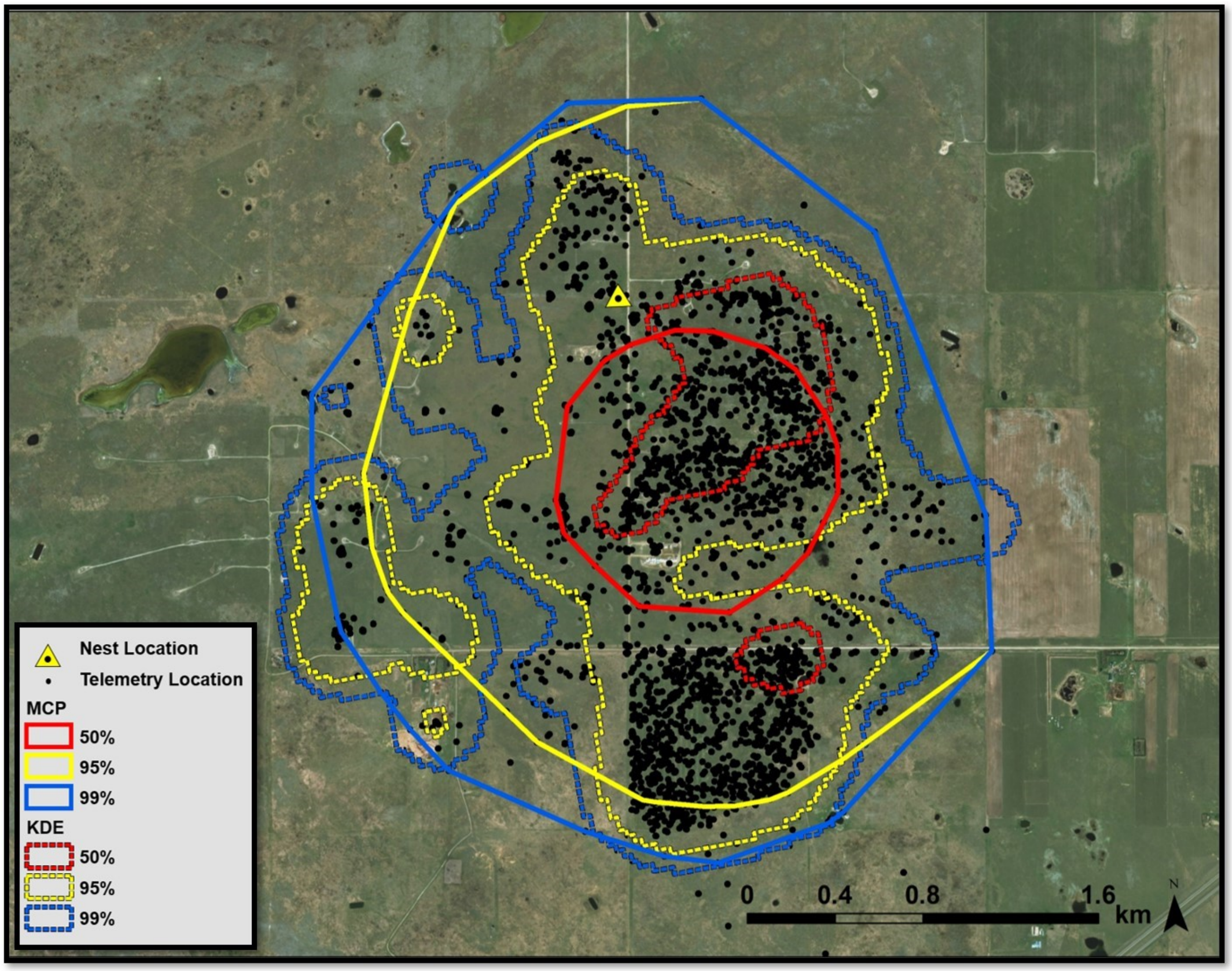

**Figure 2.2** - An example of minimum convex polygon and kernel density estimate range boundaries for a breeding, male Ferruginous Hawk using global positioning fixes collected between 2012 and 2017 on the Canadian prairie.

### *Ground-truthing and Extraction of Features*

The survey team ground-truthed locations of features within a 5-km buffer of all nest locations of tagged hawks. We recorded data by hand on printed maps which used SPOT5 imagery (2006 coverage) as a backdrop. Five kilometers was used as a buffer distance because preliminary review of data showed that it encompassed most of the movements made by male hawks during the breeding season, and surveying beyond this distance was also logistically unfeasible. Habitat and land-cover types (i.e., native grassland, cultivated land, water body, tame grass, tame hay, and idle field) were designated for each type that was larger than 50 m x 50 m. Industrial features (i.e., oil well, gas well, compressor stations, and other petroleum facilities) were overlaid on top of the SPOT5 imagery using IHS Energy spatial data (2012; www.ihs.com) and their presence was confirmed in the field. The survey crew documented the status (i.e., active or inactive) of all wells and energy infrastructure. The crew documented the surface type of all roads (e.g., paved or gravel) as well as the width of roads and ditches (m). We drew locations of fencelines, distribution lines, and transmission towers on maps. We documented other elevated features that provided potential perches for Ferruginous Hawks including houses, corrals, barns, shrubs, and trees. I did not summarize environmental covariates on 4 ranges that we did not ground-truth. I digitized all ground-truthed data from paper format into vector spatial layers using ArgGIS 10.3.1. The final GIS product for each breeding season (2012-2017) included three resource layers that I used in statistical analyses: land use (polygon), fencelines (linear), and distribution lines/roads (linear).

### *2.2.3 Statistical Analysis*

#### *Environmental covariates*

I measured and summarized explanatory variables within 50% volume contours (core areas) and 95% volume contours (home ranges) for each bird. I selected Kernel Density

Estimates for comparison over MCP because they more accurately represented an animal's home range. I used the intersect tool in ArcGIS on volume contours and layers of ground-truthed variables to calculate the total area (km$^2$) and proportion of land-cover types within each contour to derive the suite of environmental covariates (Table 2.1). I used the Agriculture and Agri-food Canada's (AAFC) landscape layer (AAFC 2000 Land cover) to validate accuracy of ground-truthed data < 5 km. For perch covariates, I calculated the total length (km) of distribution line, fencelines, oil and gas wells, roads, and the number of transmission towers within each home range (Table 2.1). I calculated the Topographic Position Index (TPI) or terrain ruggedness of the study area using a Digital Elevation Model (DEM) from GeoGratis (http://geogratis.cgdi.gc.ca/) which identified each pixel on the landscape with respect to its local neighborhood (Jenness 2007). Based on this TPI layer, I categorized the landscape into nine bins ranging from low to high ruggedness that contained proportional values ranging from 0.009 to 0.99. I pooled categories 7-9 (0.62-0.99) as "high" ruggedness and then calculated the proportion of cells within each range that fell within this category. I used a log (x + 1) transformation for linear features and counts to be able to include '0' values in models. I compared habitat proportions using logit, arcsine, and raw versions of the covariates and determined that the raw form performed best.

### *Model building*

I tested for correlations among environmental covariates and excluded highly correlated variables from data suites ($r > 0.65$). Due to the variation in range size and shape, some portions of ranges were beyond the bounds of the 5 km ground-truthing plots. Hence, larger or more irregularly shaped ranges could potentially be under-sampled compared to smaller, regular-shaped ranges, introducing bias. To address this potential bias, I included 'proportion of range ground-truthed' as a variable in models, and sequentially removed ranges with the lowest proportion until this variable did not produce a significant effect on range size. I excluded these removed ranges from subsequent analyses. At the core-area level, the majority of individuals had nearly 100% of their ranges ground-truthed, and the 'proportion of range ground-truthed' did not have a significant effect on home-range size, so no individuals needed to be removed from analysis. At the home-range level, the 'proportion of range ground-truthed' did have a significant effect on home-range size, resulting in removal of 29 individual ranges from 18 individuals from subsequent analyses.

I tested additive effects and interactive effects of explanatory variables on range size using linear mixed effects models (LMM) fit with restricted maximum likelihood (REML). I used the lme4 package in R (Bates et al. 2015), and modeled range size with the identity link and transmitter ID as a random effect to control for the expected variation among individuals. I included year as a fixed effect in all models to control for differences between years. I used Akaike's Information Criterion (AIC) to identify the overall best model based upon model parsimony and ecological relevance (Burnham and Anderson 2002). I derived the best models and supporting models ($\Delta$AIC < 2 from the top model), by progressive removal of covariates from the saturated models.

**Table 2.1** - Covariates tested for inclusion in a linear mixed-effects model of adult male Ferruginous Hawk range size.

| Model | Covariate | Abbreviation |
|---|---|---|
| Base Model | Year | Year |
| | Transmitter ID[1] | TRANSMITTER_ID |
| Land cover and Geography | Proportion of Native Grass | NG1 |
| | Proportion of Cropland | CROP |
| | Proportion of Tame Hay | TAME HAY |
| | Proportion of Tame Grass | TAME GRASS |
| | Proportion of Water Body | WATER BODY |
| | Proportion of Other | OTHER |
| | Proportion of Idle Field | IDLE FIELD |
| | Topographic Position Index[2] | TPI |
| Human Infrastructure | Fencelines[2] | FENCE |
| | Distribution Lines[2] | DIST |
| | Transmission Towers[2] | TX |
| | Oil/Gas Wells[2] | OIL/GAS |

[1] Random effect

[2] Log transformed covariate

I used RStudio (Version 1.2 1335, www.rstudio.com, accessed 6 June 2019) for all analyses. I reported the standardized regression coefficients (β) ± SE, test statistic (t-value), and p-value (*P*) for each independent variable in the top regression models and reported variable significance at α 0.05. I used the effects package to plot predictor effects (Fox and Weisberg 2018, Fox and Weisberg 2019).

## 2.3 Results

*Range Characteristics*

I captured 78 breeding Ferruginous Hawks (57 male and 21 female) across 68 territories from 2012-2017 (Figure 2.7) and tagged 57 males and 1 female (Figure 2.3). I excluded 9 males from analyses because the PTTs failed ($n = 8$) or the nesting attempt failed because a nest blew out of a tree ($n = 1$). The lone tagged female was also excluded from all analyses. Morphometrics are summarized for all captured hawks in Table 2.7

I estimated home ranges for all breeding, adult male, Ferruginous Hawks for each year in which they provided telemetry data through full breeding seasons ($n = 48$ hawks, between 2012-2017) (Figure 2.3). I tracked 24 individuals for 1 season, 13 individuals for 2 seasons, 6 individuals for 3 seasons, 2 individuals for 4 seasons, 2 individuals for 5 seasons, and 1 individual for 6 seasons, for a total of 92 home ranges. Individuals were tracked for a mean of 107 days (± 51.04 SD) per breeding season (Table 2.8). Mean size of core areas (50% contours) for the MCP and KDE methods were 3.51 $\text{km}^2$ (± 9.01 SD) and 3.54 $\text{km}^2$ (± 8.52 SD), respectively. Mean size of home ranges (95% contours) for the MCP and KDE methods were

48.67 km$^2$ (± 118.73 SD) and 36.33 km$^2$ (± 94.74 SD), respectively (Table 2.2). There was a strong, positive correlation between size of an individual's core area and size of home range, for pooled years for all individuals ($R^2 = 0.70$, $P < 0.0001$, $n = 92$).

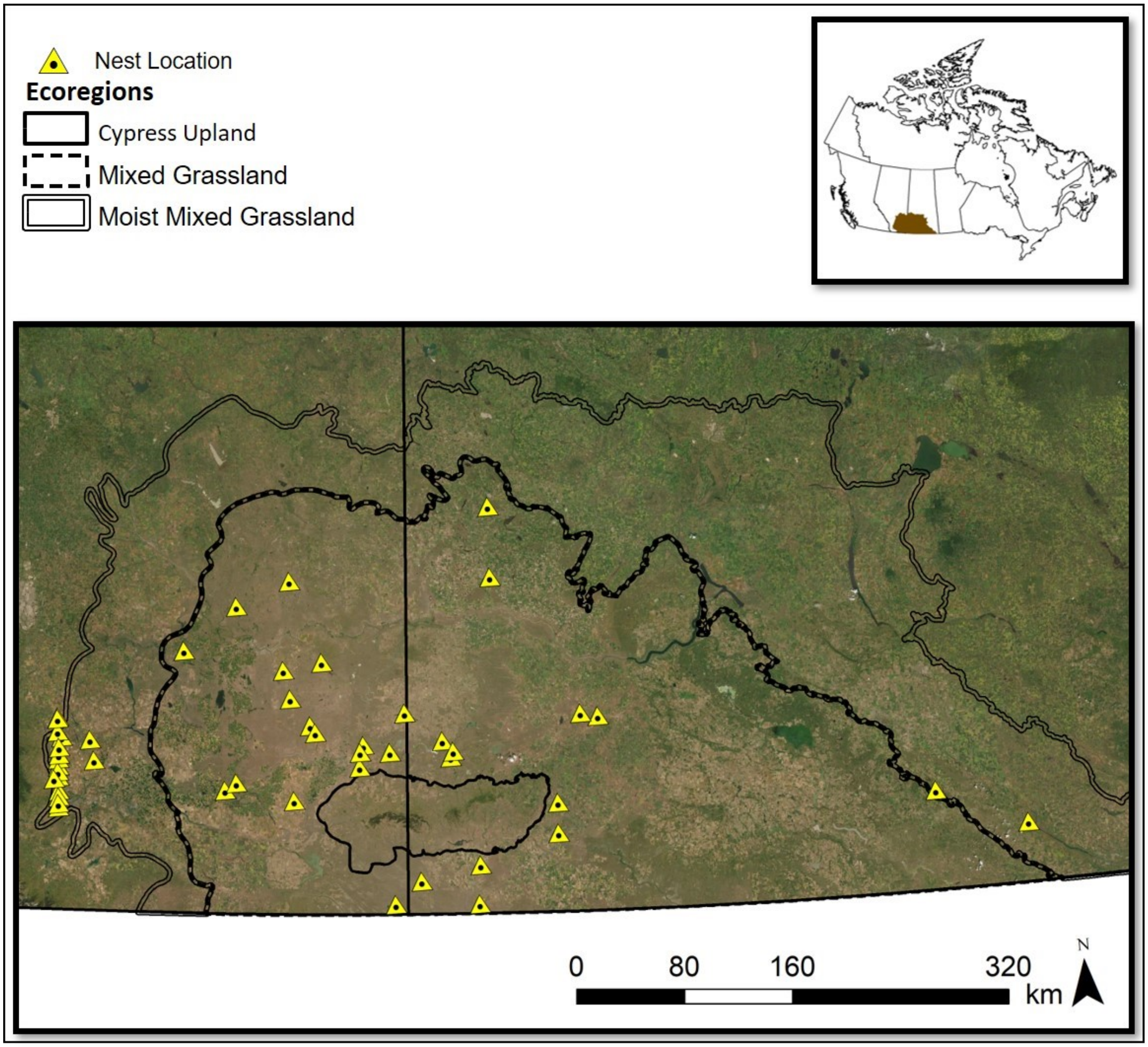

**Figure 2.3** - Locations where tagged breeding, male Ferruginous Hawks were captured, between 2012 and 2017, to assess their individual ranges within the Canadian prairies.

**Table 2.2** – Home-range sizes (km$^2$) estimated from either MCP or Kernel density methods for 48 breeding, male Ferruginous Hawks in southern Canada, 2012-2017 ($n$ = 92 ranges).

| Method | Contour | Area (mean) | Min. | Max. | SD |
|---|---|---|---|---|---|
| Kernel | 50% | 3.54 | 0.08 | 68.21 | 8.52 |
| Kernel | 95% | 36.33 | 0.82 | 665.57 | 94.74 |
| Kernel | 99% | 63.91 | 1.50 | 996.03 | 156.66 |
| MCP | 50% | 3.51 | 0.06 | 70.10 | 9.01 |
| MCP | 95% | 48.67 | 0.94 | 791.56 | 118.73 |
| MCP | 99% | 81.61 | 2.17 | 1,291.72 | 175.27 |

### *Land Cover and Elevated Perch Characteristics*

There was a strong similarity in habitat proportions between the average Ferruginous Hawk home range (95% contour) and core area (50% contour) (Table 2.3). Both contour types were dominated by about 50% native grassland, with lower proportions of moderately-disturbed or managed tame grass and hay, and similar proportions (< 20%) of more highly-disturbed cropland. Perch density was also similar between range types, but with higher density of transmission towers and oil-gas infrastructure within core areas, offset by slightly lower density of fencelines in core areas (Table 2.3).

Tests for correlations among land cover and perch types identified a significant negative correlation between native grass and cropland types for core areas and for home ranges (r < -

0.65; *P* <0.001). Thus, I removed native grass as a predictor from further analyses and maintained cropland because of the stronger relationship to home-range size.

**Table 2.3** - Mean ± (SD) proportion of land cover and density of perch types within core areas (*n* = 88 ranges; 45 hawks) and home ranges (*n* = 63 ranges; 32 hawks) of Ferruginous Hawks on the Canadian prairie.

| Covariate | Core Area | Min | Max | Home Range | Min | Max |
|---|---|---|---|---|---|---|
| Cropland | 0.19 (0.27) | 0 | 0.9 | 0.14 (0.18) | 0 | 0.74 |
| Native Grass | 0.46 (0.37) | 0 | 1.00 | 0.51 (0.33) | 0 | 1.00 |
| Idle Field | 0.07 (0.17) | 0 | 0.88 | 0.05 (0.11) | 0 | 0.47 |
| Tame Grass | 0.16 (0.23) | 0 | 0.99 | 0.17 (0.19) | 0 | 0.72 |
| Tame Hay | 0.08 (0.15) | 0 | 0.88 | 0.09 (0.13) | 0 | 0.63 |
| Water Body | 0.02 (0.03) | 0 | 0.17 | 0.02 (0.02) | 0 | 0.13 |
| Other Land Cover | 0.02 (0.06) | 0 | 0.48 | 0.02 (0.03) | 0 | 0.19 |
| Transmission Towers[1] | 2.64 (5.84) | 0 | 24.2 | 0.72 (1.2) | 0 | 5.51 |
| Oil/Gas[1] | 0.86 (1.72) | 0 | 9.28 | 0.61 (0.98) | 0 | 4.17 |
| Fenceline[2] | 3.2 (2.69) | 0 | 12.4 | 3.67 (2.93) | 0.9 | 13.8 |
| Distribution Line[2] | 0.68 (0.93) | 0 | 5.05 | 0.67 (0.63) | 0 | 2.27 |
| Topographic Position Index[3] | 0.19 (0.09) | 0 | 0.38 | 0.19 (0.05) | 0.1 | 0.28 |

[1] Count of features per area.

[2] Density, calculated as linear km of feature per km$^2$.

[3] Topographic Position Index presented as the proportion of the range with a "high" ruggedness value (0.62-0.99). Calculated using a Digital Elevation Model.

### *Mixed model Core-area Analysis*

The top-ranked model explaining size of core area included only main effects of cropland and fenceline and no interactive effects (Table 2.4). The top land-cover covariate, proportion of cropland, was positively related to core-area size ($\beta = 1.02 \pm 0.59$; $P = 0.08$; Figure 2.4 right; Table 2.5; Table 2.6), suggesting core area increased with a higher proportion of cropland. Nearly 80% (70 of 88) of ground-truthed core areas were smaller than the average core-area size (3.54 km$^2$) and averaged 16% cropland. Comparatively, the 18 core areas that exceeded the average core-area size were composed of > 30% cropland. Among all core areas, cropland averaged 19% (ranging from 0 - 90% of home-range composition). Core areas with < 10% cropland ($n = 55$) averaged 3.30 km$^2$, versus 5.38 km$^2$ for those with 10 - 60% cropland ($n = 21$), and 2.14 km$^2$ for those with over 60% cropland ($n = 12$).

**Table 2.4** - Models tested to determine factors affecting size of Ferruginous Hawk core areas (*n* = 88; 50% kernels estimated from 45 hawks) and home ranges (*n* = 63; 95% kernels estimated from 32 hawks) in southern Canada, 2012-2017. Linear mixed modeling was used to test and compare models using Akaike's Information Criterion corrected for small sample size ($AIC_c$) based on change from top candidate model (Δ $AIC_c$), and model weight ($AIC_c$ wt). Distance and count variables, along with Topographic Position Index, were log-transformed.

| **Model**[a] | **$AIC_c$** | **K** | **Δ $AIC_c$** | **$AIC_c$ wt** |
|---|---|---|---|---|
| **Core area (50% kernel)** | | | | |
| FENCE + CROP | 269.1 | 2 | 0.0 | 0.651 |
| TAME GRASS + TAME HAY | 271.4 | 2 | 2.3 | 0.205 |
| OIL/GAS | 273.8 | 1 | 4.7 | 0.063 |
| DIST + TPI | 274.2 | 2 | 5.1 | 0.051 |
| TX | 275.3 | 1 | 6.2 | 0.030 |
| **Home range (95% kernel)** | | | | |
| TAME GRASS + TAME HAY + FENCE + CROP + FENCE x CROP | 140.8 | 5 | 0.0 | 0.710 |
| OTHER + OIL/GAS + WATER BODY + OIL/GAS x WATER BODY | 142.6 | 4 | 1.8 | 0.290 |
| TPI | 155.0 | 1 | 14.2 | <0.001 |
| IDLE FIELD + DIST | 159.1 | 2 | 18.3 | <0.001 |
| TX | 159.7 | 1 | 18.8 | <0.001 |

[a] See Table 2.1 for variable definitions

**Table 2.5** - Variables affecting core area (*n* = 88; 50% kernels estimated from 45 hawks) and home-range size (*n* = 63; 95% kernels estimated from 32 hawks) for Ferruginous Hawks monitored with GPS telemetry in southern Canada, 2012-2017. Variables were identified in the top candidate model (i.e., Table 2.4). Dashes (-) indicate variables that did not enter top models. See Table 2.1 for variable definitions. Statistically significant relationships ($P \leq 0.05$) shown in bold.

| **Variable** | **Core area (50% kernel)** | | | **Home range (95% kernel)** | | |
|---|---|---|---|---|---|---|
| | ***F* value** | **df** | ***P*** | ***F* value** | **df** | ***P*** |
| FENCE[a] | 5.09 | 1, 85 | **0.027** | 2.95 | 1, 30 | 0.096 |
| CROP[b] | 2.95 | 1, 79 | 0.089 | 3.33 | 1, 40 | 0.076 |
| FENCE x CROP | - | - | - | 1.55 | 1, 36 | 0.221 |
| TAME GRASS[b] | - | - | - | 6.06 | 1, 45 | **0.018** |
| TAME HAY[b] | - | - | - | 5.58 | 1, 43 | **0.023** |

[a] Density per area.

[b] Proportion of habitat per area.

**Table 2.6** - Unstandardized and standardized parameter estimates and SE on the log scale (with 95% confidence intervals) for fixed effects explaining core-area (50%) and home-range size (95%) of Ferruginous Hawks from top mixed models. Statistically significant estimates ($P \leq 0.05$) shown in bold. Dashes (-) indicate variables that did not enter top models.

| **Variable** | **50% kernel (Unstandardized)** | **50% kernel (Standardized)** | **95% kernel (Unstandardized)** | **95% kernel (Standardized)** |
|---|---|---|---|---|
| INTERCEPT | 0.66 ± 0.35 (-0.02, 1.34) | 0.07 ± 0.13 (-0.19, 0.33) | **2.77 ± 0.40 (2.01, 3.50)** | 0.12 ± 0.15 (-0.15, 0.40) |
| FENCE[a] | **-0.49 ± 0.22 (-0.92, -0.06)** | **-0.22 ± 0.10 (-0.41, -0.03)** | -0.48 ± 0.28 (-1.00, 0.05) | **-0.46 ± 0.16 (-0.75, -0.16)** |
| CROP[b] | 1.02 ± 0.59 (-0.14, 2.18) | 0.19 ± 0.11 (-0.03, 0.40) | 4.63 ± 2.53 (-0.10, 9.34) | **0.36 ± 0.13 (0.11, 0.60)** |
| FENCE x CROP | - | - | -2.06 ± 1.66 (-5.14, 1.00) | -0.22 ± 0.18 (-0.55, 0.10) |
| TAME GRASS[b] | - | - | **-1.44 ± 0.59 (-2.53, -0.34)** | **-0.30 ± 0.12 (-0.53, -0.07)** |
| TAME HAY[b] | - | - | **-2.16 ± 0.92 (-3.95, -0.46)** | **-0.31 ± 0.13 (-0.58, -0.07)** |

[a] Density per area.

[b] Proportion of habitat per area.

Fenceline density was negatively related to core-area size ($\beta = -0.49 \pm 0.22$; $P = 0.03$; Figure 2.4 left; Table 2.5; Table 2.6), suggesting core areas decreased in size as fence density increased. Fenceline density among core areas where cropland was < 10%, 10-60%, and > 60% decreased overall from 2.96 km / range, 0.43 km / range, and 0.85 km / range, respectively. Core areas below the average size had higher densities of fencelines (3.54 km / range) relative to those above average core-area size (1.88 km / range).

No other models were > 2 AIC units of the top ranked model (Table 2.4). The effect of Year was negligible and was subsequently excluded from all analyses.

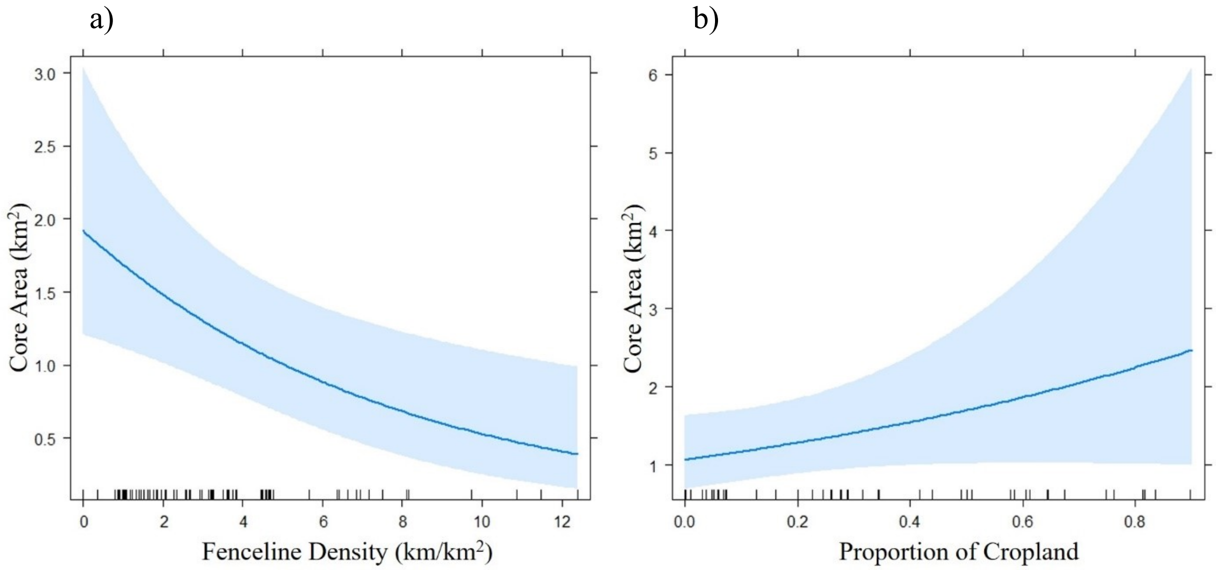

**Figure 2.4** - Predicted effects plots of a) fenceline density (km/km$^2$) and b) proportion of cropland on core-area size (50% contour) for breeding, male Ferruginous Hawks tracked with satellite transmitters.

*Mixed model Home-range Analysis*

The highest ranked model explaining home-range size included main effects of tame hay, tame grass, and an interactive effect of cropland x fenceline (Table 2.4). Proportion of tame grass and tame hay negatively affected home-range size ($\beta = -1.44 \pm 0.59$; $P = 0.02$; Figure 2.5 left and $\beta = -2.16 \pm 0.92$; $P = 0.02$; Figure 2.5 right; Table 2.5; Table 2.6) respectively, suggesting increasingly smaller home ranges with higher proportions of tame grass or tame hay. Home ranges below average size were composed of 20% tame grass versus 11% for those above average while proportion of tame hay was consistent. Home ranges below average size had slightly less cropland compared to those above average size (12% versus 17%), while all other land-cover proportions were consistent between below average and above average sizes.

The interaction between fenceline and cropland suggested that increasing fence density weakened the effect of proportion of cropland on home-range size (fenceline x cropland; $\beta = -2.06 \pm 1.66$; Figure 2.6; Table 2.5; Table 2.6). Among ground-truthed home ranges, cropland composition averaged 13% (ranging from 0 - 74%). Home ranges with < 10% cropland ($n = 38$) averaged 7.53 km$^2$, versus 11.34 km$^2$ for those with 10 - 60% cropland ($n = 23$), and 6.60 km$^2$ for those with over 60% cropland ($n = 2$). Fenceline densities for home ranges containing these three increasing levels of percent cropland were 3.40 km / range, 3.98 km / range, and 5.07 km / range, respectively. The effect of Year was negligible and was subsequently excluded from all analyses.

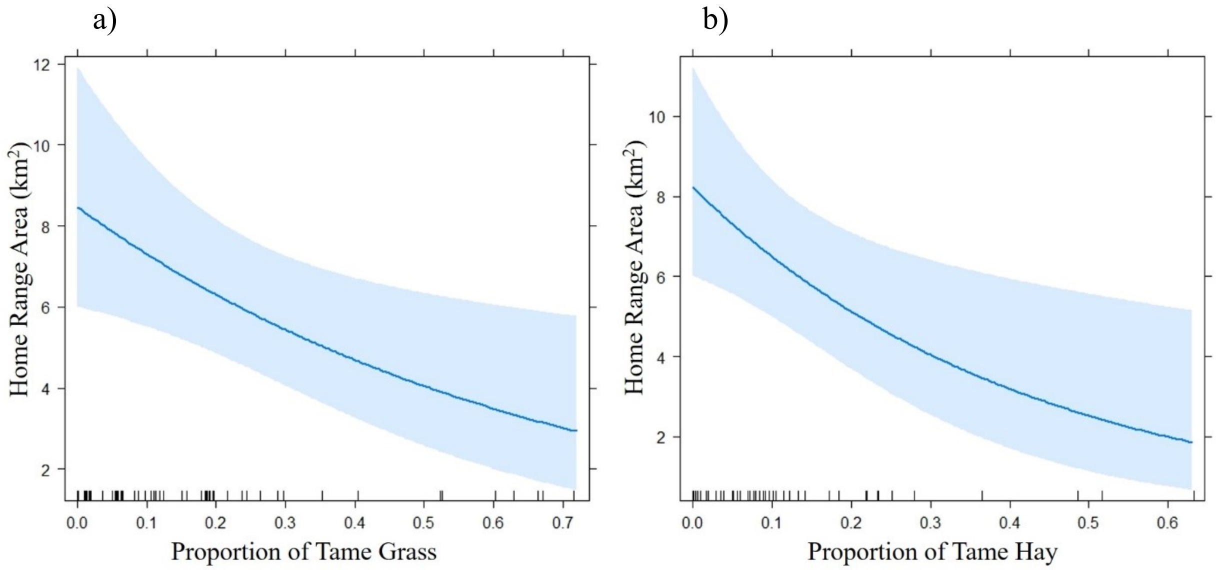

**Figure 2.5** - Predicted effects of a) proportion of tame grass and b) proportion of tame hay on home-range size (95% contour) for breeding, male Ferruginous Hawks.

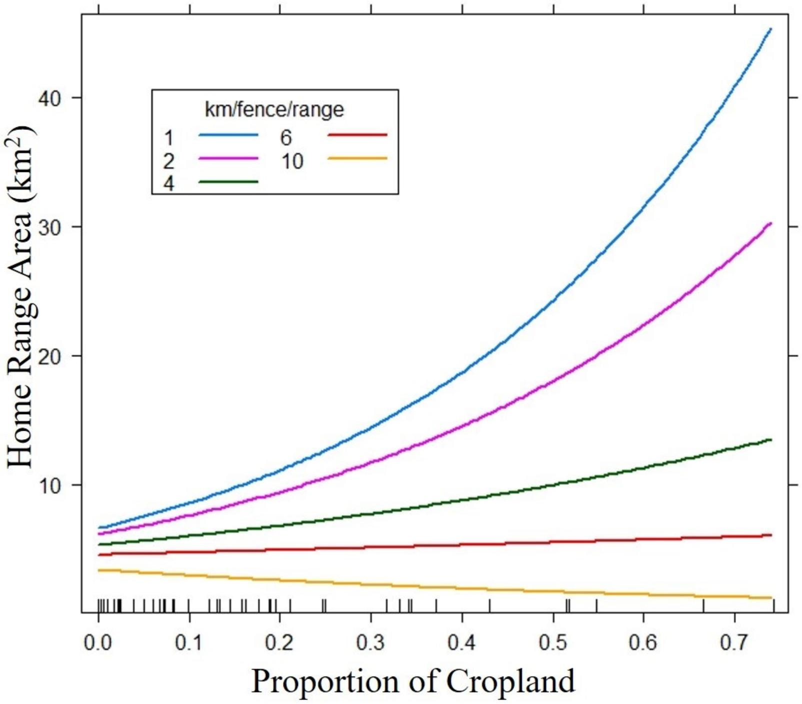

**Figure 2.6** - Predicted interactive effects of proportion of cropland on home-range size at varying fence densities.

## 2.4 Discussion

Despite the complexity of factors influencing size of Ferruginous Hawk home ranges, the four specific factors I identified through mixed model analysis at the two range scales are reasonable from an ecological perspective. My predicted association of cultivated land cover and elevated perches with smaller home ranges and higher range quality was demonstrated with the importance of cropland and fence density to core-area size but with different effects. The smallest core areas, potentially of the highest quality, had < 10% cropland but the highest density of fence posts. These results suggest there is a decreasing benefit of cropland in the core areas of Ferruginous Hawks as cultivated land increases, but an increasing benefit from fence posts. An alternative conclusion, based on the strong negative correlation that I found of native grass to cropland, is that there is an increasing benefit as the proportion of native grasses increases within the core area. My second prediction, that core areas and home ranges would be impacted differently by land cover, was supported by the increased importance of tame grass and hay with decreasing home-range size. On the home-range scale (95% contour), a high proportion of grasses that are manipulated (mowed) or have an invasive grass component appear to be important in allowing smaller Ferruginous Hawk ranges.

When considered for Ferruginous Hawks nesting in Prairie Canada, these factors may improve or reduce the quality of habitat most important to nesting because they influence spatial use and population dynamics of hawks through relationships with prey. Specifically, the influence of cropland on Ferruginous Hawks in southern Canada is most directly related to its effect on distribution and density of Richardson's ground squirrels, which have been shown to prefer native pasture over cultivated lands (Downey et al. 2006). For example, Schmutz demonstrated a decline in Ferruginous Hawk abundance within plots of increasingly cultivated land, relative to areas devoid of dense and tall crop in which they were well adapted to exploiting ground squirrels (Schmutz 1987;1989). My results supported these findings at the core-area (50% contour) scale as most of the core areas below average size had half as much cropland as larger core areas. It is important to consider that the apparent benefit of nesting on high quality ranges with high prey abundance may be outweighed by increased exposure of some raptors to anthropogenic risks during ranging behaviours (Stout et al. 2006, Solaro 2018). For example, Ferruginous Hawks on smaller ranges with higher densities of ground squirrels and more fencelines may have increased exposure to ground squirrel control (poison, shooting, etc.).

Significance of fencelines within Ferruginous Hawk core areas can likely be explained by the effect of elevated perches on Ferruginous Hawk foraging behaviour. Ferruginous Hawks are primarily ‘sit and wait’ strategists that spend much of their time hunting from perches (Wakeley 1978c). My perch density calculations were based on km of fenceline per $km^2$ rather than the absolute number of perches and thus, the true abundance of fence post perches are estimated to far exceed other perch opportunities on these landscapes. Given typical 2.4 m spacing of fence posts, average-sized core areas had over 4,500 individual fence posts relative to 24 distribution poles at standard 100m spacing. Therefore, although it is reasonable to assume hawks preferred taller perches when equally availability (Andersson et al. 2009), the importance of fence posts stands to reason because they were available among all habitat types within core areas. The fact that density of fence posts and its interaction with cropland were important at the home-range level indicated that increasing fence density moderated the effect of proportion of cropland on home-range size. This finding emphasized the importance of elevated, short perches on hawk home ranges that may improve foraging efficiency in cropland.

The association of tame grass and tame hay (i.e., non-native grazed or hayed cover) with smaller home ranges may also relate to how these land-cover types affect feeding opportunities for Ferruginous Hawks. My analysis of resource use by individual Ferruginous Hawks (Chapter 3) showed that they preferred these altered grass types (e.g., 12 out of 17 individuals showed highest use in areas with high levels of tame hay, 13 out of 26 individuals showed highest use in areas with high levels of tame grass, and 7 of 21 individuals showed highest use in areas with low levels of cropland). Ferruginous Hawk foraging locations are negatively influenced by the density of vegetation cover, likely due to its influence on prey availability (Wakeley 1978b). Over the course of the breeding season, tame grass remains shorter and less dense (i.e., like native grass), relative to cropland, which increases in structure (i.e., height and density) considerably during the growing season and is often only cut during grain harvest at the end of the season (August or September). Likewise, tame hay provides similar cover, but may be cut multiple times throughout the season, allowing relatively consistent access to habitat with low vegetative structure for increased foraging opportunities as observed by Leary et al. (1998) in Washington alfalfa fields. Interestingly, Wakeley (1978b) and Leary et al. (1998) both observed the highest prey abundance in their study areas within alfalfa hay fields and observed individuals focusing their foraging efforts within those areas until vegetative cover became too dense and prey less available from a foraging perspective. However, it should be noted that prey abundance within native habitats in the latter study was low (Leary et al. 1998) in comparison to our study, resulting in higher use of atypical habitats (i.e., cropland) and inflated range sizes due to transit between the nest site and foraging areas in their study.

Core area characteristics of Ferruginous Hawks are important to differentiate from those of the broader home range because core areas include the most important range components such as nests and alternative nests (Wilson et al. 2010, Slater et al. 2017). Because raptors are central place foragers, they spend an inordinate amount of time near their nest (Rosenberg and McKelvey 1999). Raptors tend to forage closest to the nest when prey is available (Squires et al. 1993, Thirgood et al. 2003), and less time and energy expended away from the nest may result in increased foraging efficiency, allow for better nest defense from intruders, and increased provisioning at the nest. Howell et al. (1978) found that Red-tailed Hawks with more open habitat (i.e., more fallow pasture and less canopy cover), and presumably better prey habitat and availability had higher reproductive output. Conversely, poor quality ranges (Leary et al. 1998, Moss et al. 2014) may be those with reduced foraging efficiency due to increased travel between foraging sites and the nest and poorer ability to guard the nest. I did not detect a relationship of range size to reproductive success, but I had limited reproductive information for the nests with tagged hawks. Evidence from past research on *Buteos* indicates that the dispersion and density of perches may have been more closely correlated with reproductive success than was home-range size (Janes 1984). My estimates of core-area and home-range size are the first generated for Ferruginous Hawks nesting on the Canadian Prairies, which represent the most fecund habitat for the species [based on recent breeding pair estimates of the species' two largest breeding populations; 1200 pairs in Canada (Ng 2019) and 1110 pairs in Wyoming (Olson et al. 2015)]. In comparison, Ferruginous Hawk core-area size in relatively poorer quality habitat in Washington state were an order of magnitude larger than mine, averaging 32.3 ± 12.1 $km^2$ from tagged birds (J. W. Watson, Washington Department of Fish and Wildlife, unpubl. data). For 7 males breeding in southern Idaho, McAnnis (1990) reported 50% harmonic mean as 2.2 $km^2$, which is similar in size to home ranges for male hawks in my study for 50% KDEs (3.5 $km^2$) and MCPs (3.5 $km^2$).

The importance of grasslands to Ferruginous Hawks at two scales, the core area and home range, was demonstrated by the fact that ranges were comprised of ~75% native grass, tame grass, and tame hay combined. Given that historical Ferruginous Hawk ranges were comprised of 100% native grassland, this is not surprising. Moreover, ranges in my study of 3rd-order selection (Johnson 1980) contained similar proportions (i.e., ~50%) of native grassland as predicted by a 2nd-order predictive model of home-range habitat selection for Ferruginous Hawks across the same study area (Ng 2019). However, my proportion of cropland was noticeably lower than Ng (2019) (i.e., 14% versus ~50%). In my study, tame grass and tame hay combined to make up the difference in range composition, further highlighting the importance of grassland habitat relative to cropland for breeding Ferruginous Hawks. The source of the difference in levels of cropland among ranges between Ng (2019) and this study was likely due to differences in habitat layers used in analyses. Composition of ranges in my study were based on ground-truthed information versus coarse, publicly available layers in Ng (2019), that potentially greatly inflated the importance of cropland to nesting Ferruginous Hawks. An alternative explanation as to the discrepancy in proportion of cropland between Ng (2019)'s prediction and my results could be explained by differences in characterizations of ranges used in analyses. Ng (2019) used a standardized 2500 m buffer around the nest to represent the range versus actual boundaries established by free-ranging hawks in my study. Therefore, not including the land cover at the nest (i.e., an area the hawk is obligated to use once it occupies a nest), individuals in my study may have had the ability to choose the type and amount of land cover they preferred to use for various behaviours. Regardless, results from this study provide accurate representations of Ferruginous Hawk land-cover composition within individual breeding territories.

Sizes of these 95% MCP home ranges (mean = 48.7 km$^2$) exceeded all published MCP range sizes, except Leary et al. (1998) who reported 90.3 km$^2$. Earlier reported MCP sizes range from 10-20 km$^2$ (Smith and Murphy 1973, Platt 1984, Janes 1985, McAnnis 1990, Harmata 1991, Leary et al. 1998), but numbers could be inaccurate or unfit for comparison due to outdated sampling procedures (focal observations and VHF data collection which are biased to locating hawks when they are closer to their nests versus modern satellite telemetry), small sample sizes, or because totals include home-range estimates from females that range less during nesting (e.g., Watson et al. 2018). My 95% KDE home ranges averaged 36.3 km$^2$ [similar to the

85% adaptive kernel method used by Leary et al. (1998)] and varied considerably from 0.8 to 665.6 km$^2$. Home ranges estimated from satellite tracking of Ferruginous Hawks in Washington averaged 314.5 ± 93.8 km$^2$, an order of magnitude larger than those from my study (J. W. Watson, Washington Department of Fish and Wildlife, unpubl. data), likely due to drought-stricken habitats with low-quality prey in Washington (Watson and Keren 2019). The disparity between these results emphasize the importance of this contribution to the Ferruginous Hawk literature as they provide a previously undocumented estimation of range size by an otherwise well-studied species within Canada.

My study showed that fencelines were an important factor for breeding Ferruginous Hawk space-use within the core area (50% contour) and home range (95% contour). Ranges that contained more fencelines were smaller, presumably because they had more elevated perching options, a seemingly valuable range characteristic given the Ferruginous Hawks' tendency for sit-and-wait hunting (Wakeley 1978c). The proportion of cropland was also an important predictor of range size within the core area and home range. Smaller core areas had less cropland but the influence of cropland on home-range size was moderated by the density of fencelines. Consistent with estimates of resource selection at the home-range scale (i.e., within 2500 m of the nest, as put forth by Ng 2019), both core areas and home ranges were comprised of ~50% native grassland; however, my ranges showed lower proportions of cropland (~20% versus ~50%). My results demonstrate the importance of tame grasses (i.e., non-native grazed or hayed cover) at the home-range scale as they comprised ~25% of home ranges. It is likely that Ferruginous Hawks benefited from ranges with less dense, shorter vegetation with increased elevated perch options due to the improved foraging radius (Andersson et al. 2009) and improved access to prey (Fitzpatrick 2004). Although I was unable to test for a relationship between reproductive success and range size due to inadequate reproductive data, smaller home ranges may indicate higher quality habitat (Newton 1979) and may lead to greater reproductive success for Ferruginous Hawks.

# Chapter 3: Resource use of breeding Ferruginous Hawks in human-altered landscapes in the Canadian prairies with an emphasis on the relevance of elevated perches

## 3.1 Introduction

Since European settlement, the prairie ecosystem has changed in many ways, largely due to the conversion of grassland to agricultural uses, and more recently from energy development and urbanization (Rowe and Coupland 1984). Commensurate with these anthropogenic changes are increasing risks to wildlife populations including loss of habitat, increased synanthropic predators, and increased mortality risk from increased vehicle traffic and collisions with infrastructure (Leu et al. 2008, Atkinson 2009, Benítez-López et al. 2010, Sánchez-Zapata et al. 2016, Nordell et al. 2017). Birds are not immune to these negative impacts (Calvert et al. 2013, Zimmerling et al. 2013, Loss 2016), although some species groups like raptors, may benefit from anthropogenic changes that improve nesting, perching, and hunting in urbanizing environments (Solaro 2018).

The Ferruginous Hawk is the largest hawk in the prairie ecosystem in North America (Ng et al. 2017). It has declined throughout Canada where it is listed as Threatened (SAR Public Registry), and is listed as Endangered in Alberta, a traditional nesting stronghold. Anthropogenic changes in the prairie ecosystem in the last century are believed to be a primary cause of the decline (Alberta Environment and Parks 2018). However, the exact mechanisms causing the decline are unclear because Ferruginous Hawks respond variably to anthropogenic changes. For example, early studies in North Dakota, USA, found Ferruginous Hawks avoided croplands (Gilmer and Stewart 1983, Gaines 1985), but other studies on effects of landscape change on

Ferruginous Hawks found nest distribution and abundance were positively associated with heterogeneous, cultivated landscapes (Schmutz 1989, McConnell et al. 2008, Ng 2019). Ferruginous Hawks did not show changes in reproductive success in areas of oil and gas development in Wyoming (Wallace et al. 2016), but in Utah, reproductive success was higher in areas with higher densities of active oil and gas wells (Keough et al. 2015). Hawks in Idaho subjected to controlled disturbances that simulated human presence (i.e., walking, driving, running a gasoline engine, and firing a 0.22-caliber rifle) fledged fewer young (White and Thurow 1985), but in several studies hawks nested in closer proximity to human activities, using homestead trees, haystacks, and power transmission towers, rather than remote ground nests (Lokemoen and Duebbert 1976, Gilmer and Stewart 1983, Gaines 1985).

Ferruginous Hawks often employ a sit-and-wait hunting strategy (Wakeley 1978c) and rely heavily on elevated perches where they may spend a large portion of their daily time budget perching (Wakeley 1978c;a, McAnnis 1990). Perch choice of Ferruginous Hawks may be affected not only by the distribution of perches within the home range, but also by perch characteristics that affect hunting success. For example, perch height can determine foraging radius in the surrounding viewscape (Andersson et al. 2009), and habitat types and conditions may affect prey vulnerability (Howard and Wolfe 1976, Wakeley 1978b, Bechard 1982, Schmutz 1987). Furthermore, the distribution and abundance of prey, particularly fossorial rodents that are preferred prey of this prey specialist (Ng et al. 2017), can influence perch choice (Schmutz et al. 1980).

Historically, Ferruginous Hawks often nested on the ground, and presumably used natural elevated features such as rocks and hillsides as perches (Ng et al. 2017). Over the past few decades on the Canadian prairies, the density, types, and height of elevated structures have increased dramatically, potentially altering the local distribution and behaviour of nesting Ferruginous Hawks. For example, after European settlement, fence posts became more common, and in the mid-1900s many electrical distribution power poles (< 10 m tall) were erected. Numerous treed shelterbelts were planted at farms around the same time (Gaines 1985), and more recently, much of the prairies have undergone energy sector development for oil, gas, and wind (Roch and Jaeger 2014). This has led to the construction of transmission line infrastructure that is rapidly increasing the availability of transmission towers (> 10 m tall) and subsidiary distribution pole networks within the Ferruginous Hawk's breeding range.

My goal was to investigate how Ferruginous Hawks use anthropogenic perches by examining intensity of perch use within their home ranges, and associated perch characteristics. My two objectives were to: 1) determine the types of elevated structures that are associated with higher intensity of use within home ranges; and 2) identify the perch microsite characteristics that are linked to highest use during the breeding season. I predicted that, fence posts and distribution poles would be used more intensively than other perch types because of their high abundance and wide distribution on the landscape. Additionally, I predicted that use would be higher at perches in native grassland compared to perches in mono-typic cropland due to benefits of foraging in natural habitat. I predicted higher use at perches surrounded with shorter vegetation and higher prey densities because these characteristics should increase availability of prey.

## 3.2 Methods

I conducted the study in the mixed and moist-mixed grasslands ecoregion in southern Alberta and Saskatchewan (Figure 3.1). The area consisted of native grassland interspersed with agriculture, with native vegetation predominated by blue grama (*Bouteloua gracilis*), needle and thread grass (*Hesperostipa comata*), and wheat grasses (*Elmyus* spp.). Ferruginous Hawks in this region nested most often on lone trees, artificial platforms, and to a lesser degree on electrical transmission infrastructure, oil/gas shacks, windmills, and the ground (Ng et al. 2017). Cottonwood (*Populus* spp.) and trembling aspen (*P. tremuloides*) were the most dominant tree species used for nesting. Elevated structures that potentially provided Ferruginous Hawk perches include trees and hilltops in native habitats, and transmission towers, distribution poles, fence posts, and oil/gas infrastructure in developed areas. Land use varied in the region and included cattle ranching, cereal crop production, and petroleum development. Oil and natural gas extraction were the main energy development activities in the study area, with well density in the region > 0.8 well sites/km$^2$ and cumulative length of roads > 1.0 km per km$^2$ (Alberta Environmental Protection 1997).

In 2013 and 2014, a field team captured 24 adult male Ferruginous Hawks on their nesting territories from among > 250 active nests (Figure 3.1). I stratified my selection of territories from among those in native prairie and cultivated farmland. Undeveloped and developed land provided a range of elevated structures for perches from ground level to 45 m in elevation. I tagged individuals with GSM (Groupe Special Mobile) satellite transmitters mounted as backpacks (Model GPS 20-70, Microwave Telemetry, Inc., Laurel, MD, USA). I filtered flight locations (i.e., speed > 0 kph) from breeding datasets to include stationary perching locations, and locations between the time of capture (initial telemetry deployment date) and initiation of fall migration as to include only locations that were within the breeding range.

### *3.2.1 Home-range Scale Macro Analysis (obj 1)*

#### *Perch and Land Cover Extraction and Ground-truthing*

A survey team identified, mapped, and ground-truthed locations of elevated structures and of roads, within a 5-km buffer of each nest location. Within each home range, I estimated utilization distributions (hereafter "UDs"), using ArcMET's 'KDE UD' model toolset [Movement Ecology Tools for ArcGIS (ArcMET), www.movementecology.net, accessed 10 May 2018]. I used an h-ref smoothing parameter, which assigned a smoothing factor and a use value, based on the spatial variance of inputted locations, to each 30 m x 30 m grid cell within each individual's 95% KDE. I used a cell size of 30 x 30 m because it matches the resolution of the satellite transmitters. Utilization distribution values for cells within hawk's datasets were fractional and summed to 1 for each hawk. After matching hawk UDs with their home-range volume contours, I created a matching fishnet (30 m x 30 m grid cells) using the Geospatial Modelling Environment 'genvecgrid' tool (GME Version 0.7.4.0, http://www.spatialecology.com/, accessed 7 Dec 2018). Next, by creating a centroid point layer to match each cell in the fishnet, using the 'Extract Values to Points' and 'Near' ArcGIS tools (ArcMap 10.1.3, Environmental Systems Research Institute, Inc., Redlands, CA, USA), I extracted UD values and four types of variables from each centroid including: distance (km) to nearest perch feature (three perch types); distance (km) to the nest (DTN); distance (km) to the nearest road; and land-cover type (nine types) (Table 3.1). Resource Utilization Functions (RUF) were then used to examine the relationships among variables at each centroid. Because ground-truthing was restricted to < 5 km from each nest (see '*Ground-truthing and Extraction of Features*' in section 2.2.2), RUFs were also limited to UDs < 5 km from nests.

**Table 3.1** - Covariates tested for inclusion in Resource Utilization Functions for breeding male Ferruginous Hawks in southern Alberta and Saskatchewan.

| Covariate | Definition |
|---|---|
| **Nest**[a] | Point location of nest site used in the year of data extraction. |
| **Perch**[b] | |
| Fenceline | Linear feature containing ~1.2-m high fence posts spaced at ~2.4-m. |
| Powerline | Linear feature containing ~7.5-m distribution poles spaced at ~100-m. |
| Transmission Tower | Individual feature with ~45-m towers spaced at ~400-m intervals. |
| **Land Cover**[c] | |
| Native Grass | Dominant grass species include needle and thread grass, green needle grass, blue gramma grass, northern wheatgrass, western wheatgrass. Clubmoss and lichen carpets ground where forbs and grass are not growing. Cannot see rows of where vegetation was planted. Cattle manure present. |
| Cropland | Active crop including; grain (i.e., wheat, barley, rye); pea; potatoes; canola. |
| Tame grass | Dominant grass species include crested wheatgrass, smooth brome, timothy, rye grass, alfalfa. Bare soil between clumps of grass, rows may be present from when tame forage was seeded. Cattle manure present. |
| Tame hay | Same dominant grass species as tame grass, rows may be present, bales in field, actively being hayed, irrigated, and cattle manure sparse or absent. |
| Idle field | Any growing vegetation are weed species, no uniformly growing monoculture, high volume of bare soil, and sometimes stubble is present. |
| Water | Open water or wetlands. |
| Perch conglomerate | Any parcel of land cover comprised of perches ≥ 30 $m^2$ (e.g., a patch of trees). |
| Major highway | Any parcel of land cover comprised of road ≥ 30 $m^2$ (e.g., 4 lane highway). |
| Other | Any parcel of land cover comprised of human structures (e.g., houses, farm equipment) or oil and gas infrastructure (e.g., pumpjack, screwjack, wellpad) ≥ 30 $m^2$. |
| **Road**[e] | Linear feature including paved, graveled, and two-track roads. |

[a] Distance from centroid to nest.

[b] Distance from centroid to perch.

[c] Land-cover type at centroid.

[e] Distance from centroid to nearest road.

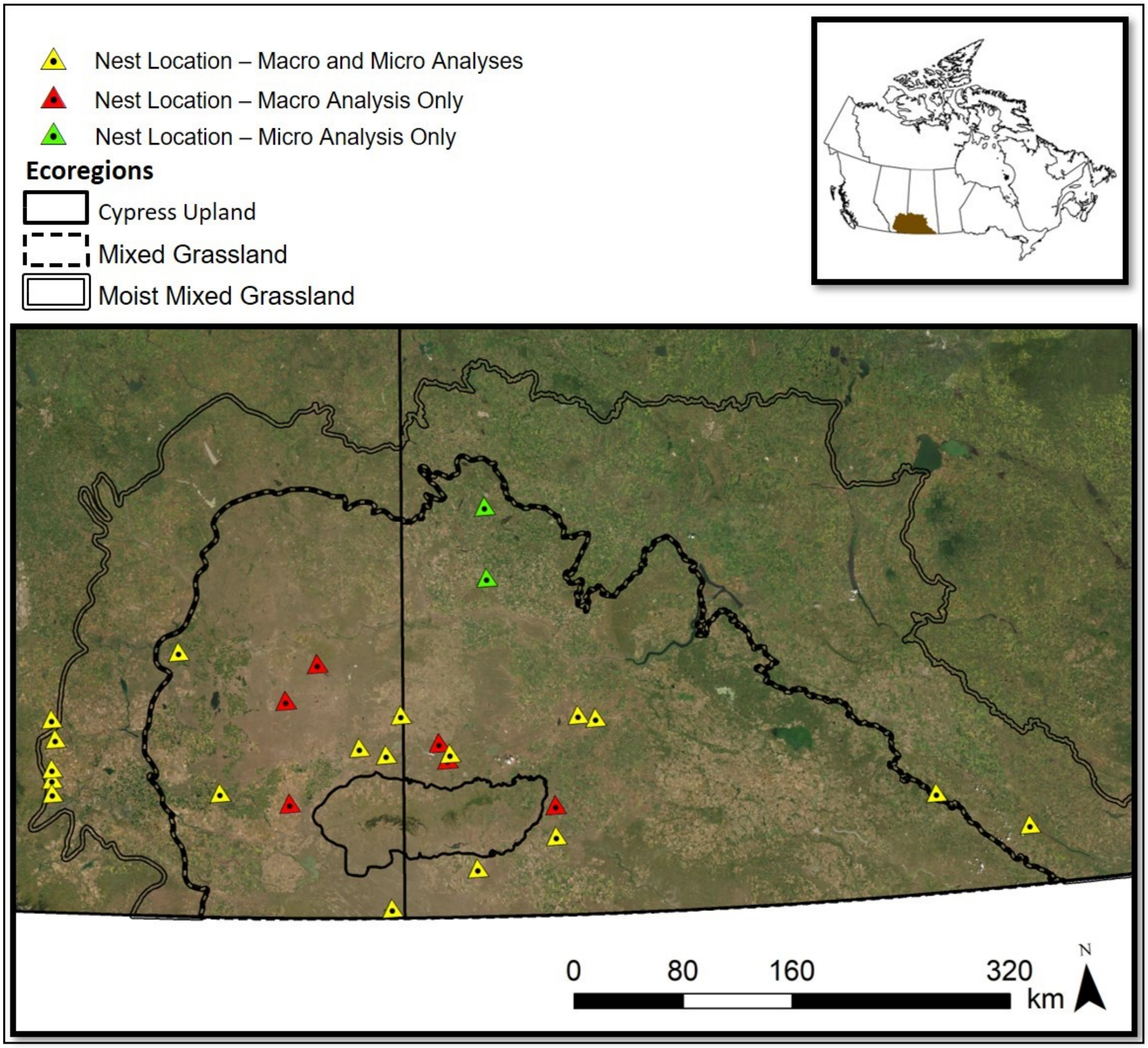

**Figure 3.1** - Locations where adult male Ferruginous Hawks were tracked with satellite telemetry in southern Alberta and Saskatchewan to assess their resource use on home ranges (i.e., macro analysis; *n* = 24), and to determine variables associated with perches they frequented (i.e., micro analysis; *n* = 20 hawks).

### *Resource Utilization Analysis*

I used Program R (R Version 3.2.3, www.r-project.org, accessed 6 May 2017) to assess individual hawk UDs for homogeneity, collinearity among covariates, normality, potential for interactions, and independence of the response variable (Zuur et al. 2010). I calculated variation inflation factors (VIF) for collinear covariates and removed VIFs > of 3 from models until all VIFs were ≤ 3 (Quinn and Keough 2002). Utilization distributions for individual hawks violated the assumption of normality so I performed a log transformation. Utilization distribution values indicated spatial dependence (i.e., spatial autocorrelation) and thus I used spatial simultaneous autoregressive lag models which incorporated spatial independence into standard linear regression models to model individual hawk UDs (Bivand 2013).

In addition to creating RUFs for individual hawks, I calculated population-level RUFs. To do this, I used coefficients and standard errors from individual RUFs to calculate the inverse variance weighted mean, standard error, z-value, and p-value for each covariate for the entire sample of hawks. The β coefficient values in RUF outputs indicated the change in the UD value for 1-unit change in a given resource with the assumption that all other resources were fixed. For consistency, I reversed signs of coefficients for distance variables so the response of the hawk (highest use closer to a feature) matched the signs (positive versus negative) of the coefficients for the non-distance covariates. Both individual and population-level RUFs were created for Ferruginous Hawks as described by Scobie et al. (2014). I also determined the percentage of GPS locations that were located on perches, roads, and the nest. The number of locations within 50 m (equal to combined error of satellite transmitters and ground-truthed layers) was divided by the total number of locations per bird and was then averaged among all hawks to estimate the relative amount of perching time spent on each of these features.

### *3.2.2 Viewscape Scale Micro Analysis (obj 2)*

#### *Perch Sample Selection*

I tracked 20 hawks for 8 to 108 days during the breeding season (Table 3.4), from which I sampled perch locations to document perch type, the adjacent land cover and vegetation characteristics, and the relative abundance of Richardson's ground squirrels (*Urocitellus richardsonii*) and other small mammal species (e.g., deer mouse (*Peromyscus maniculatus*), meadow vole (*Microtus pennsylvanicus*), sagebrush vole (*Lemmiscus curtatus*), etc.). Tracking data provided high numbers of perch locations for analysis because hawks were tagged with GSM satellite transmitters that functioned with high reliability throughout the entire breeding seasons of 2013 and 2014 (9 and 11 individuals, respectively) (Table 3.4). The sample of hawks, and thus their perch use, represented the range of land-cover types and human development used throughout the study area (Figure 3.1).

To identify perches for data collection in the field, I overlaid all stationary fixes with a 100 m x 100 m grid system using ArcGIS. I ranked grid cells by their relative use values and selected a total of 80 perches per bird from among each individual's gradient of use values. See Appendix B: 'Methods' for a detailed description of perch sample selection methods.

### *Characteristics of Perch Locations*

At each used perch location, I identified the closest elevated structure (e.g., tree, transmission tower, distribution pole, fence post, rock) < 25 m from the GPS location (i.e., within range of fix error). If there was an elevated structure within this distance, I collected data at that structure. If no elevated structure was present at that location, I collected data at the original GPS location, and these were considered "ground perches". For randomly-generated (i.e., non-used) locations, I collected data at the nearest elevated perch within the grid cell boundary, or at the original GPS location when no elevated structures were present within these boundaries. At each perch, I recorded perch type, perch height (m), and distance to the nest (m).

To document vegetation height (cm) and bare ground (%) associated with the perch, I traversed four, 50-m transects beginning from the perch. I chose 50-m as an appropriate and practical distance to sample, because the visibility of prey for a perched raptor at distances < 50 m varies significantly (i.e., 20-100%), depending on the height of the perch (i.e., 2 m to 8 m) (Andersson et al. 2009). I randomly chose the bearing of the first transect and conducted the remaining three transects at 90° from the previous transect, to sample representative vegetation structure and rodent presence in the immediate area. At a randomly selected distance along each transect, I measured vegetation height (Robel et al. 1970), and bare ground using a 50 cm x 50 cm modified version of the Daubenmire frame (Daubenmire 1959). The height (5 cm increments) at which the vegetation visually obstructed the 1-m Robel pole was documented from 4 m away from the Robel pole, and averaged across four measurements at each 90° bearing to produce a single measurement for the transect. Bare ground was evidenced by lichen, leaf litter, rocks, moss, and cattle manure along with any matted or dead grass that would allow 100%

exposure of rodents in that area. I calculated foliar cover rather than canopy cover to not overestimate exposed bare ground that was visible between small openings in the canopy (Anderson 1986). I created an index of ground squirrel abundance and other rodent prey by counting burrows 1 m on each side of each transect (2-m search radius).

### *Perch Viewscape Analysis*

Prior to model development, I tested for correlations among environmental covariates and excluded highly correlated variables from data suites ($r > 0.65$). I developed a mixed effects logistic regression model to test the relationship of the relative intensity of perch use (proportion of fixes) to environmental factors that included fixed effects perch height (relative to the ground), vegetation characteristics, distance to nest, and an index of prey abundance (PROC GLIMMIX, SAS 9.4, SAS Institute, Inc., Cary, NC, USA). I modeled perch use (i.e., events / trials or number of perch occurrences at a given perch / total number of perch occurrences in a bird's dataset) and included Bird ID (a unique identifier for each individual) as a random effect. The model directly computed robust estimates of standard errors, and standardized coefficients. Maximum likelihood was approximated with Residual Pseudo-likelihood Estimator.

## 3.3 Results

### *Home-range Scale Macro Analysis (obj 1)*

I assessed resource use within home ranges of 27 adult male Ferruginous Hawks, derived from 11,206 ± 7,091 telemetry relocations per bird monitored for a duration of 26 to 204 days (i.e., 323 to 4,189 unique hours). Home-range sizes for these individuals averaged 14.9 ± 15.4 $km^2$ (Table 3.5).

Based on perching frequency, fencelines were the most heavily used perch type (29%; -range = 1-54%) and were present within each home range, but perch frequency by some individuals on distribution poles or transmission towers was nearly 60% and 55%, respectively (Figure 3.2). On average, 5% of fixes were at the nest (range = 0.2% to 30%). I analyzed over 600,000 30m x 30m cells, throughout 27 home ranges from 24 individuals, to derive individual-level RUFs (Table 3.5).

Resource utilization functions revealed highest use of perches in areas close to nests in the more conservative individual models, as well as the less conservative population-level model that included inter-individual variation (Table 3.2). Among perches at the population-level, use was highest near powerlines and transmission towers but further from fencelines, although the coefficient for fencelines was an order of magnitude smaller than most coefficients in the model. Linear relationships of untransformed UD and distance values are presented in Figures 3.4, 3.5, and 3.6. Individual-level RUFs revealed that 55% and 78% of individuals showed the highest use at areas near powerlines and transmission towers, respectively, but showed a split response (50%) with highest use in areas near fencelines versus areas further away from fencelines. Four hawks nested on transmission towers resulting in collinearity between nest and transmission towers, so nest was removed as a covariate for these cases.

Among vegetated land-cover types, use was highest in areas with low proportions of cropland for both the population-level and for most individual models (Table 3.2). Thirty-three percent of individuals showed highest use in areas with high levels of cropland. In contrast, use was highest in areas with high proportions of tame hay at both the population and individual levels, with 71% of individuals showing highest use in areas with high levels of tame hay. Areas with high proportions of tame grass had the highest use at the population-level but a split response (50%) at the individual-level. At the population-level, use was highest in areas further away from roads, although the coefficient was an order of magnitude smaller than most coefficients in the population model. At the individual-level, 48% of individuals showed highest use in areas near roads.

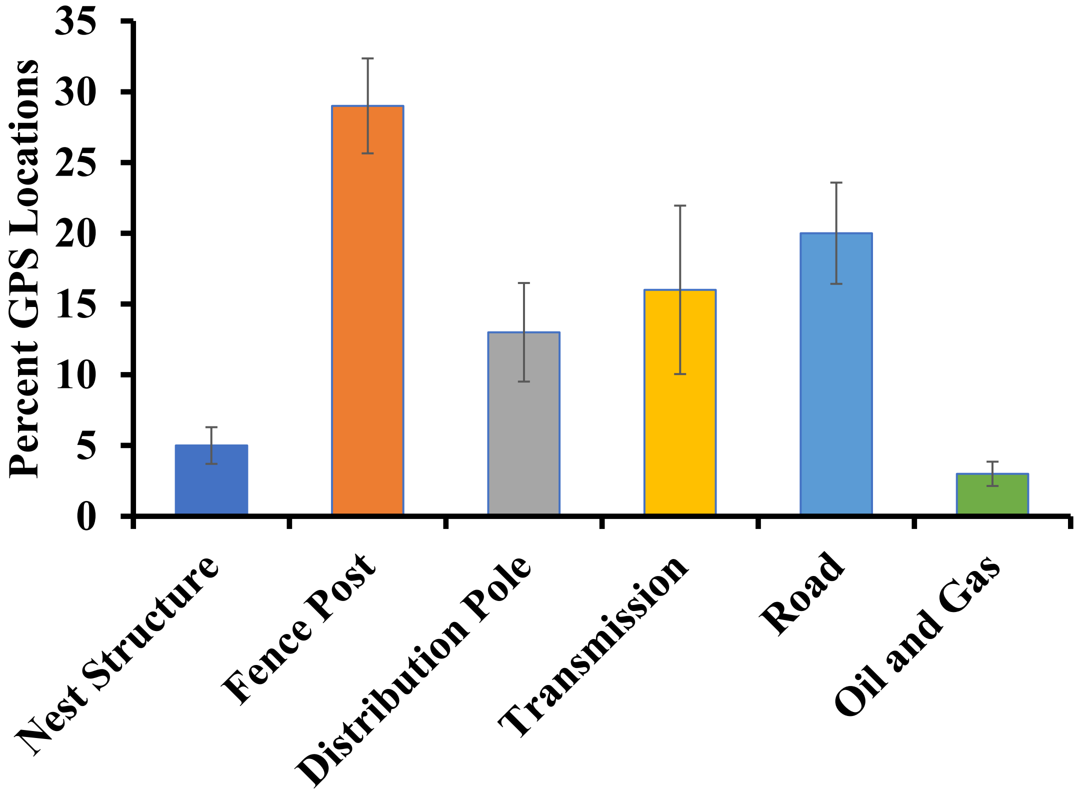

**Figure 3.2** - Average percent of Ferruginous Hawk telemetry locations within 50 m of ground-truthed elevated perches and roads calculated on 27 home ranges of breeding male Ferruginous Hawks in 2013 and 2014. Distribution pole = low voltage power pole; Transmission = high voltage transmission tower; Oil and Gas = oil and gas structure. Bars represent standard errors.

**Table 3.2** - Estimated resource utilization function coefficients for 24 adult male Ferruginous Hawks (27 home ranges) nesting in Canada, 2013-14. Resource Utilization Functions were calculated based on Utilization Distributions from fixed-kernel ranges using stationary locations and h-ref smoothing parameter.

| **RUF** | | | | | | |
|---|---|---|---|---|---|---|
| | β | SE | *P* | Hawk Response | | n |
| | | | | + | - | |
| **Intercept** | -1.449 | 0.003 | <0.00 | 0 | 27 | 27 |
| **Nest*** | 0.124 | 0.000 | <0.001 | 22 | 0 | 22 |
| **Perch*** | | | | | | |
| Fenceline | -0.001 | 0.000 | 0.001 | 13 | 13 | 26 |
| Powerline | 0.014 | 0.001 | <0.001 | 12 | 10 | 22 |
| Transmission Tower | 0.027 | 0.001 | <0.001 | 7 | 2 | 9 |
| **Land cover*** | | | | | | |
| Crop | -0.014 | 0.001 | <0.001 | 7 | 14 | 21 |
| Tame grass | 0.033 | 0.002 | <0.001 | 13 | 13 | 26 |
| Tame hay | 0.138 | 0.002 | <0.001 | 12 | 5 | 17 |
| Idle field | 0.010 | 0.002 | <0.001 | 7 | 9 | 16 |
| Water | 0.001 | 0.002 | 0.343 | 13 | 14 | 27 |
| Perch | -0.011 | 0.007 | 0.065 | 8 | 16 | 24 |
| Road | -0.001 | 0.003 | 0.393 | 10 | 14 | 24 |
| Other | 0.003 | 0.005 | 0.256 | 11 | 15 | 26 |
| **Road*** | -0.002 | 0.000 | <0.001 | 11 | 12 | 23 |

*β is negative for all distance variables

### *Viewscape Scale Micro Analysis (obj 2)*

We visited 1,436 total locations (1,037 used and 399 unused) on 20 tagged, male Ferruginous Hawk territories from 7 July - 10 October, 2013-2014. We were unable to visit 164 survey locations (i.e., 44 High, 51, Medium, 68 Low, and 1 Unused) due to access issues. Of the 1,037 used locations visited by our survey team, 31% (397) were within 25 m of an elevated perch (1 m or higher from the ground), indicating the hawk perched on the feature surveyed by our crew. The remaining 640 used locations (62%) were ground perches (Figure 3.3). Fence posts accounted for 52% (205 of 397) of elevated perches. Distribution poles were the second most heavily used elevated perch at 23% (93 of 397). The perch type ‘other’ accounted for 13% (53 of 397) of elevated perches and included farm equipment, hay bales, rock piles, and irrigation pivots. Trees accounted for 7% (28 of 397) elevated perches. Lastly, transmission towers accounted for 5% (18 of 397) of elevated perches.

All four perch type categories had higher use relative to ground perches. The most common perches on the landscape (i.e., fence posts and distribution poles 1.5-7.5 m tall) had similar effects on perch use ($\beta = 12.47 \pm 2.97$ SE; $P = 0.001$ and $12.22 \pm 1.99$ SE; $P = 0.001$). Taller and sparser structures (i.e., trees and transmission towers, minimum 15 m and $\geq 25$ m) had a larger influence on perch use ($\beta = 13.15 \pm 1.50$ SE; $P = 0.001$ and $14.14 \pm 1.83$ SE; $P = 0.001$; Table 3.3). Individuals showed higher use of perches associated with more bare ground ($\beta = 4.57 \pm 2.33$ SE; $P = 0.0498$) and higher numbers of prey burrows ($\beta = 5.63 \pm 1.95$ SE; $P = 0.004$), and at locations with lower proportion of cropland ($\beta = -11.66 \pm 3.09$ SE; $P = 0.0002$). Lastly, distance to nest was the most influential variable on perch use, suggesting hawks had a strong attraction to perches near the nest ($\beta = -22.30 \pm 0.76$ SE; $P = 0.001$).

**Table 3.3** - Factors influencing perch use for 20 adult male Ferruginous Hawks nesting in Canada, 2013-14. Data collection occurred across a range of perch types with variable amounts of use and micro site variables.

| **EFFECT** | **β**[a] | **SE** | **DF** | **t Value** | ***P*** |
|---|---|---|---|---|---|
| Intercept | -5.13 | 0.11 | 19 | -48.74 | **<0.0001** |
| Perch[b] | | | | | |
| < 2.5 m – Fence post | 12.47 | 2.97 | 1,406 | 4.2 | **<0.0001** |
| ~7.5 m – Distribution pole | 12.22 | 1.99 | 1,406 | 6.14 | **<0.0001** |
| ~15 m – Trees and tall utility pole | 13.15 | 1.50 | 1,406 | 8.79 | **<0.0001** |
| > 25 m – Transmission tower | 14.14 | 1.83 | 1,406 | 7.75 | **<0.0001** |
| Distance to nest (km) | -22.30 | 5.30 | 1,406 | -4.21 | **<0.0001** |
| Vegetation height (cm) | 4.60 | 4.45 | 1,406 | 1.03 | 0.3017 |
| Bare ground[c] | 4.57 | 2.33 | 1,406 | 1.96 | **0.0498** |
| Prey burrow count[d] | 5.63 | 1.95 | 1,406 | 2.88 | **0.004** |
| Cropland[e] | -11.66 | 3.09 | 1,406 | -3.77 | **0.0002** |

[a] Standardized coefficents.

[b] Ground (i.e., 0 m) was the reference category.

[c] Proportion.

[d] Combined count of Richardson's ground squirrel and other small rodent species.

[e] Index of land cover at survey location measured as a proportion.

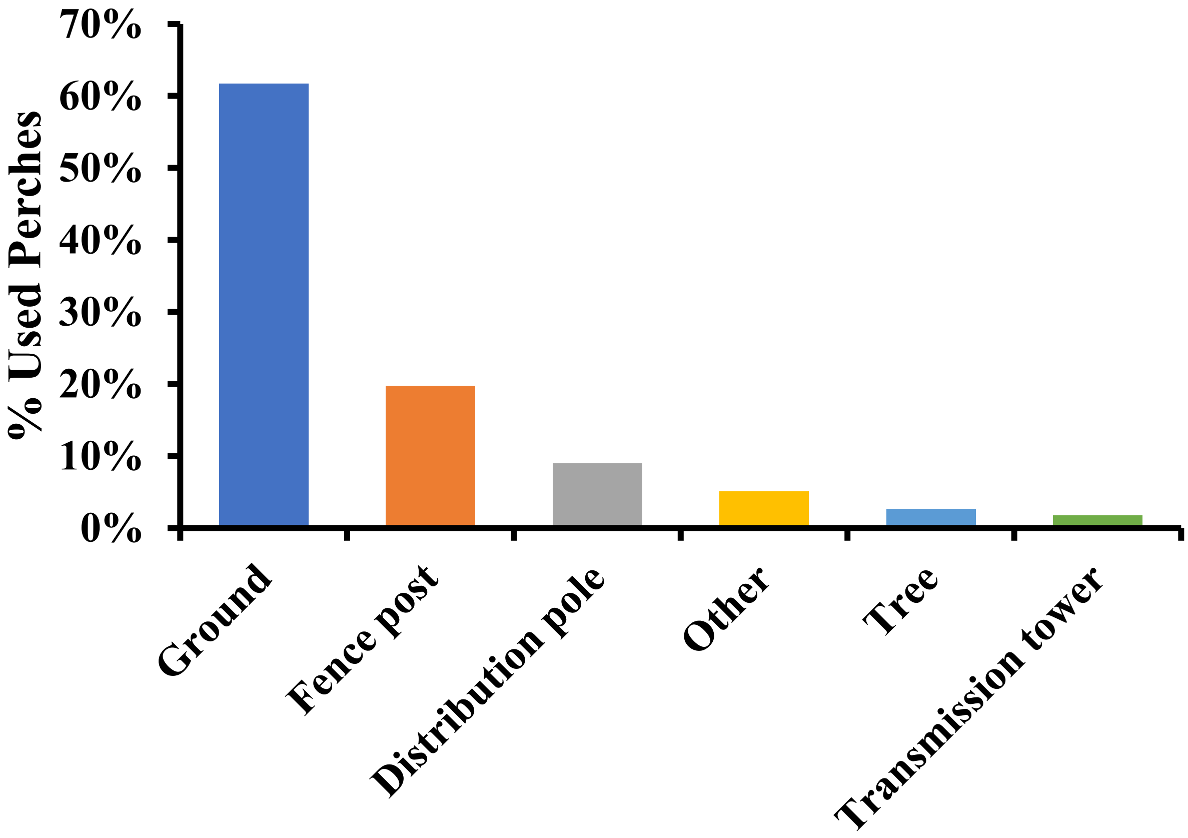

**Figure 3.3** - Perch types at 1,037 locations used by Ferruginous Hawks and studied to assess micro-scale factors affecting perching.

## 3.4 Discussion

My results demonstrate the utility of human-made elevated perches to Ferruginous Hawks, due to a combination of characteristics that likely improve foraging success including: availability and abundance of perches on the landscape, perch height, and microsite characteristics near perches. The ecological relevance of human-made perches has previously not been studied for this species within nesting home ranges, and is particularly important on the

Canadian prairies where the number of nesting pairs have declined, and the landscape is crisscrossed with a variety of linear features that are highly used by this population.

### *RUF versus RSF Analysis*

The conundrum of determining resource selection of central place foragers becomes more difficult when considering statistical constraints. Two main approaches are often used to determine how animals use habitat: resource selection functions (RSF) (Boyce and McDonald 1999), and resource utilization functions (RUF). Resource selection functions provide insight into whether an animal displays preference or avoidance of certain resources (e.g., food or habitat) using individual relocations as the experimental units (Thomas and Taylor 1990, Manly et al. 2002). In comparison, RUFs provide an understanding of the percentage of time an animal spends in a certain location (i.e., a specific habitat) relative to other locations all within a specified area (e.g., the home range) using a utilization distribution (UD) (White and Garrott 1990, Marzluff et al. 2004). Both approaches have pros and cons, and neither are consistently viewed as the superior method. Variability among resource use studies and the intricacies of the questions posed within each provide justification for the most appropriate resource use modeling approach. In some cases, a combination of the two approaches may prove most informative, but for the purposes of this thesis, I developed RUFs to relate use patterns to distribution of elevated perch structures, roads, and land-cover types within home ranges. Resource utilization functions reduce autocorrelation between resources and fix locations and minimize negative effects from location error (Millspaugh et al. 2006, Kertson and Marzluff 2011). This method, using individuals as the experimental unit, allowed me to examine variation among individuals by averaging multiple RUFs to produce population-level models (Long et al. 2009).

### *Hawk Use of Perch Types*

The abundance of perches on the landscape can be an important predictor of use by raptors (Preston 1990, Widén 1994, Malan and Crowe 1997). Fence posts, which border private and public lands and roadways, are by far the most abundant human-made elevated feature on the landscape. They accounted for 29% of all hawk perch locations. However, these features are so common that population-level use of fencelines was highest at areas further from them, while individuals showed a split response, with half showing highest use near fencelines and the other half showing highest use in areas away from fencelines. Fence posts were a unique influence on hawk perching relative to other elevated structures because of their relative density along a fenceline and across the landscape. Estimates of road densities in southern Alberta (1.07 km/km$^2$) (Alberta Environmental Protection 1997) are a reasonable proxy for fenceline density in southern Canada but likely underestimate the true density of fencelines. On most home ranges, close spacing of fence posts provided many more individual perches than could be used by hawks relative to distribution poles and transmission towers within the viewscape of a foraging hawk (see *Ecology of Perch Choice*). For other individuals, lower use was a consequence of a lower density of fencelines and fewer fence posts within their home ranges.

Relative to fencelines, taller distribution poles and transmission towers were much more sparsely distributed across the landscape, with larger spaces between the poles/towers along the line, resulting in lower perch availability. My prediction that individuals would use distribution poles more intensively relative to other perch types was partially supported at both the population and individual levels. Use in areas near distribution poles was higher relative to areas near fencelines but lower relative to areas near transmission towers. Over half of the individuals with distribution poles in their home range showed highest use at areas near poles (n = 12), yet use was highest in areas away from poles for others (n = 10). In North America, perch use of distribution poles by wintering and nesting *Buteo* hawks is well documented (Marion and Ryder 1975, Plumpton and Andersen 1997), although use of poles may be lower where trees are available (Langley 1999). Transmission towers were more limited on hawk home ranges than distribution poles, but where these structures were available, they were highly used at both the population-level and individual-level. For the minority of individuals that had transmission towers running through their home ranges, the relatively high coefficient of use at the population-level was driven by consistent perching at a few towers. Use for individuals that also nested on towers was increased by the effect of distance-to-nest as a negative correlate to perch use.

Most perch locations of Ferruginous Hawks at the viewscape scale were on the ground (62%). This result was not surprising, as ground perches are essentially unlimited in a prairie landscape, relative to elevated natural and anthropogenic features (Marion and Ryder 1975). Furthermore, ground-perching behaviour is common for this species throughout its range (Ng et al. 2017), a region that was historically devoid of human-made elevated perches, where foraging was likely limited to the ground and the sparsely available trees.

### *Ecology of Perch Choice*

My viewscape analysis showed that all elevated perch types were more heavily used relative to ground perches, and the intensity of use of elevated perches increased with structure height. Contrary to my predictions, I found similar levels of use of fencelines and distribution poles, whereas taller structures (i.e., transmission towers and trees) were more highly used. Thus, influence of perch height on hawk behaviour was greater than I expected. This result may be explained by the fact that during nesting, adult male Ferruginous Hawks may spend up to 99% of their perch time off the nest (Wakeley 1978a), and are potentially perch hunting, or capturing prey incidentally while engaging in other perch activities like resting (Fitzpatrick 2004). Perch height is a key determinant of the viewscape of a perched raptor, which is important to foraging efficiency and nest defense (Thiollay and Clobert 1990, Widén 1994, Malan and Crowe 1997, Tomé et al. 2011). Taller perch structures, from ground level to several meters above ground, provide an increasingly greater field of view, which improves predator search radius and visibility of prey (Andersson et al. 2009). For example, based on test models of predator searching, the visibility of a target on the ground at a distance of 50 m improves by ~50% when viewed from 8 m verses the ground (Andersson et al. 2009). Thus, any perches elevated above the ground, even at fence post height, may significantly improve visibility of prey.

Prey visibility is affected not only by perching height, but also by microsite factors such as the vegetation density that may also affect prey accessibility (Wakeley 1978b, Baker and Brooks 1981, Jaksié et al. 1981, Ontiveros et al. 2005). Consistent with my prediction, results showed that individuals had higher use of perches at locations with more bare ground, and higher density of prey burrows (Southern and Lowe 1968, Schmutz and Hungle 1989, Williford et al. 2007). Densities of fossorial mammals may be higher in finely textured soils (Fortney 2013), including disturbed soils which are often along roads and hence beneath fences and distribution poles. These microhabitat features may provide cues to hawks of potential prey availability near perches. The bare ground near ground squirrel burrows is a result of vegetation depletion due to squirrel foraging, but also may be modified by squirrels to improve predator vigilance (Proulx et al. 2012). For hawks, this open ground provides for greater visibility and unimpaired accessibility of prey, so hawks may have selected perches at these locations to maximize their foraging efficiency. It is important to point out that prey burrows were only an index and therefore did not represent absolute prey abundance. Prey availability, mitigated by vegetation cover, is the actual proportion of the prey population at risk of predation (Fitzpatrick 2004), and according to optimal foraging theory is where raptors can maximize their energy gain (Pyke 2010).

In vegetated habitats near perches, prey visibility and accessibility in dense vegetation may be low relative to areas with bare ground or sparser vegetation (Wakeley 1978b). Fitzpatrick (2004) showed that characteristics of vegetation, specifically the frequency and height at which grasslands were mowed had a stronger effect on raptor habitat selection than prey abundance. This may explain the relationship I found between proportion of mowed hay fields and intensity of use by individuals. Contrary to my predictions, and previous literature (Sheffield et al. 2001, Apolloni et al. 2017), vegetation height was not a significant overall predictor of use at perch sites. Fitzpatrick (2004) similarly found that perch use was more closely associated with relative density of vegetation than relative height. Timing of sampling in my study may have affected the lack of apparent influence of vegetation on perch use.

Vegetation was measured late in the season, and it may not have been reflective of the vegetation height differentials during the earlier summer when these birds were using the area (Gibson et al. 2016). It is also possible that birds perched on tall elevated structures were more likely to forage beyond the area directly below them (i.e., < 50-m radius from the perch that I sampled) and thus in different vegetation from what was sampled. Furthermore, in addition to ground squirrels, foraging hawks in my study area are known to prey on species such as small mammals, reptiles, and birds (Ng 2019), that are associated with microsite characteristics that I did not sample.

At locations where human-made elevated perches do not co-occur with areas of high availability and abundance of fossorial prey, hawk use of those perches may be driven by other environmental factors (e.g., other prey types, seasonal vegetation type, or soil/surface conditions) (Baker and Brooks 1981, Proulx et al. 2012). The complexity of these relationships was illustrated in my study area with regard to the juxtaposition of perch height and density of prey burrows. For example, transmission towers, the tallest perch type on the landscape, had relatively few burrows near them, whereas fence posts, the shortest perch type on the landscape, had a high density of prey burrows near them. Despite burrow density, the proportion of use at individual transmission towers was considerably higher relative to individual fence posts. For a perching hawk, the choice may be to alight on a tower where there is an improved foraging radius but lower squirrel density, compared to perching on a fence post and moving down a fenceline comprised of numerous perches with a similar, relatively low viewing angle.

The final component influencing perch use by Ferruginous Hawks at both the viewscape and home-range scales was the type of habitat associated with the perch. Hawks used perches in cropland less than perches in native grass types at both the population and individual levels, which was consistent with findings for home-range analyses (Chapter 2). At the peak of the breeding season, crops are generally taller and more dense than native grass (USDA/NASS 1997), potentially resulting in less visible and less accessible prey. There is also evidence that ground squirrel abundance tends to be lower in cropland relative to native habitat (Downey et al. 2006). In contrast, the population-level RUF showed attraction to tame hay and tame grass. Compared to cropland that is cut/harvested infrequently (e.g., wheat, barley, canola) (USDA/NASS 1997), tame hay fields are cut more frequently during the summer season, which can provide a burst in easily accessible prey (Blair and Schitoskey 1982, Garratt et al. 2012). Additionally, irrigation pivots are often used to irrigate tame hay fields, providing convenient perching structures for birds using this habitat, something that may not be available within cropland. Tame grass, which is composed of a wider diversity of plant species than mono-culture cropland, and which is grazed by cattle, may provide comparable foraging opportunities to native grass (Dechant et al. 2002). Idle fields are characterized by large amounts of bare ground, which again provides visibility and accessibility of prey. It is interesting that these human-altered land-cover types (i.e., tame hay, tame grass, and idle fields) were used more intensively than native grassland, because historically, native grasses would have predominated land cover throughout the entire home range.

# Chapter 4: Conclusions and Management Implications

### *4.1.1 Summary of Findings*

In Chapter 2, I evaluated the importance of human-made elevated perch and land-cover types that breeding male Ferruginous Hawks in southern Alberta and Saskatchewan include within their ranges at two scales: the core area (50% contour) and the home range (95% contour). Core-area kernel density estimates averaged 3.54 ± 8.52 $km^2$. Within core areas, fencelines and the proportion of cropland were the most influential characteristics, with smaller core areas containing higher densities of fenceline and lower proportions of cropland. Home-range kernel density estimates averaged 36.33 ± 94.74 $km^2$. Within home ranges, higher fenceline densities and lower proportions of cropland were again associated with smaller ranges. However, there was an interaction between these variables, suggesting that as fenceline density increased, the effect of proportion of cropland on home-range size weakened. Home ranges were increasingly smaller with higher proportions of tame grass and tame hay.

Past research has documented range size for Ferruginous Hawks in the southern part of their breeding range (i.e., the USA) (Smith and Murphy 1973, McAnnis 1990, Harmata 1991, Leary et al. 1998), but the information has not been reported for individuals from the Canadian population. Additionally, no range size information has been reported for Ferruginous Hawks tracked with satellite telemetry [but see Watson et al. (2014a)]. My results indicate smaller core-area sizes than those previously reported but generally, larger home-range sizes. However, caution should be used with past estimates that may have been derived from outdated tracking methods and range estimators, using small sample sizes, or including nest-centric females. The influence of elevated perches on breeding raptors has been described (Sheffield et al. 2001, Apolloni et al. 2017), but generally without making the linkage between perches and range size (Janes 1984). I found similar proportions of native grassland within my ranges to those predicted by Schmutz (1989) and Ng (2019) for Ferruginous Hawks from the same study area based on population-level use (i.e., second order selection). However, my analyses showed that individual Ferruginous Hawks included lower proportions of cropland in ranges compared to these earlier studies, and range size was increasingly smaller with decreasing proportion of cropland. Foraging hawks likely hunt more effectively in grassland habitats as characteristics of the vegetation are more favourable for prey capture. Additionally, the structure of grassland habitats is more consistent throughout the growing season relative to cropland, allowing for better foraging opportunities.

Chapter 3 demonstrated how breeding male Ferruginous Hawks use their home ranges with respect to land cover and perch use and investigated characteristics of perches across a gradient of use intensity throughout their ranges. In contrast to Chapter 2, where I investigated use of land-cover types based on their proportion within core areas and home ranges, in Chapter 3 I developed Resource Utilization Functions for individuals that were averaged across the sample to understand use at the population-level. Use of fencelines was not as strong as use of powerlines (i.e., distribution poles) and transmission towers. Cropland was used less relative to native grass at both the population and individual levels, a finding that was consistent with my results from Chapter 2. Hawks used tame grass and tame hay more intensively than native grassland. In my viewscape analysis, I visited 1,436 perch locations with known levels of use among 20 hawk home ranges to make comparisons between perch micro-site land cover and relative prey abundance as indexed by burrow counts. The majority of perch locations (62%)

were located on the ground and roughly half (52%) of elevated perches were fence posts. The distance to the nest was the most influential factor in perch use with higher use occurring closer to the nest. Hawks showed increasingly higher use of taller perches with transmission towers being used the mostly heavily. Perches with more bare ground and higher counts of prey burrows in the viewscape were used more intensively, but vegetation height did not influence perch use. Additionally, hawks used perches near cropland less than perches near other land-cover types.

The importance of elevated perches to raptors is well established (Wakeley 1978c, Widén 1994, Apolloni et al. 2017). Perch density is an important predictor of use by raptors (Kay et al. 1994, Widén 1994, Malan and Crowe 1997), and perch height is a key determinant of a raptor's viewscape (Andersson et al. 2009), which can lead to improved foraging success and improved nest defense (Thiollay and Clobert 1990, Tomé et al. 2011). Fence posts were the most abundant perch type within hawk home ranges and were the most frequently used type of elevated perch, indicating their consistent, widespread importance to Ferruginous Hawks (Figure 4.1). Collectively, hawks perched on fence posts more than any other perch type, but individually, hawks made much higher use of less abundant transmission towers. This suggests that when available, transmission towers are important perches for hawks. Higher use by hawks at perches with more bare ground and prey burrows indicated that prey visibility and accessibility improved Ferruginous Hawks hunting (Wakeley 1978c), in contrast to cropland where perches received lower use and the presence and structure of vegetation varied throughout the breeding season.

### *4.1.2 Management Implications*

My research is the first attempt to accurately define space use of individual breeding Ferruginous Hawks in Canada hawks by quantifying home-range and core-area sizes. This scale of examination provides the ecological connection of land cover and perch types to breeding hawk space use, specifically implications for prey acquisition. My findings support the importance of grass and hay fields compared to cropland on hawk home-range size and space use. Cultivated land is identified as a widespread threat to Ferruginous Hawk populations in Canada and although less common in modern times, cultivation is still occurring (Alberta Environment and Parks 2018). Increased range sizes in land-cover types like cropland, could have potential negative consequences for successful reproduction from effects on nest attendance and provisioning rates. Identification of suitable nesting habitat is an important task for Ferruginous Hawk recovery in Canada (Alberta Environment and Parks 2018), and should take into account range size as a potential indicator of habitat quality.

Within home ranges, my research found that human-made elevated structures in the Canadian prairies are used extensively by nesting hawks, and that intensity of use of these structures is associated with perch height, bare ground, and an index of prey abundance suggesting these structures improved foraging conditions. This indicates use of elevated perches is driven by real ecological benefits including improved opportunity to exploit prey with increased efficiency compared to when the landscape was relatively devoid of these elevated viewpoints (Wakeley 1978b, Janes 1984, Malan and Crowe 1997, Sheffield et al. 2001, Leyhe and Ritchison 2004, Tomé et al. 2011). Given that individuals were more likely to use perches located in tame hay, tame grass, and idle fields, relative to perches in cropland, the land-cover context beyond the perch itself will influence the use of that perch, and potentially foraging efficiency depending on vegetation structure. Because reproductive success of nesting raptors on home ranges is driven by the ability of breeding hawks to obtain sufficient prey for their young, the implications of improved foraging are potentially relevant to population status of Ferruginous Hawks on the Canadian prairie. Thus, informed placement of elevated perches in tame hay, grass, and idle fields where they are lacking may improve nesting conditions on home ranges experiencing poor occupancy or reproductive success.

Despite their potential benefits to Ferruginous Hawks as elevated perches, fencelines, distribution poles, and transmission towers all pose potential negative consequences. For example, collisions with both distribution lines and transmission lines have been reported among raptors and electrocution is a significant risk among distribution poles (Kemper et al. 2013, D'Amico et al. 2018). Fencelines also pose a collision risk for Ferruginous Hawks (J. L. Watson pers. obs.) and other wildlife (Jakes et al. 2018). Because fencelines and distribution lines are often placed adjacent to roadways, Ferruginous Hawks perching on these features are exposed to high risks of vehicle collisions (Schmutz and Fyfe 1987, Bishop and Brogan 2013). Transmission towers generally do not pose electrocution risk to perching or flying Ferruginous Hawks, but their large nests can span the distance between two lines and lead to electrocution (APLIC and USFWS 2005).

### *4.1.3 Future Research*

Future studies that depend on highly accurate land-cover layers should use caution with the AAFC layers and consider taking steps to assess discrepancies or consider collecting their own land-cover information. For example, there were several logistical factors that potentially influenced my range analysis in Chapter 2. Firstly, because I was unable to ground-truth > 5 km from nest sites, I could not quantify habitat composition or provide perch density for the 25 largest ranges in the dataset. Despite lacking the necessary ground-truthed layers, I was interested in looking at the composition of land cover at > 5 km from the nest using the AAFC layers. With this method, I identified the most abundant land-cover types as cropland and native grass. Furthermore, each land-cover type accounted for 45-50% (totaling ~90-100%) of the overall land cover within respective home ranges, statistics that are inconsistent with my ground-truthed habitat assessment but consistent with Schmutz (1989) and Ng (2019), studies that took place within the same study area. Ground-truthed ranges showed native grass comprising ~51% and cropland comprising ~14% of home ranges, while tame grass (17%) and tame hay (9%) made up the difference observed in Schmutz (1989) and Ng (2019). This finding suggests that: 1) AAFC layers lack the detail needed to appropriately quantify habitat on a meaningful scale; and 2) that the 95% home-range scale may be too coarse to infer which characteristics are most important for Ferruginous Hawks. Secondly, my inability to ground-truth > 5 km from nest sites restricted portions of home ranges from being included in my Chapter 3 RUF analysis. However, I suspect this had no bearing on my results because home ranges generally did not extend beyond 5 km from the nest and when they did, use was relatively low at these outer boundaries.

I recommend future studies test composition of habitat among concentric bands radiating out from the nest to confirm that habitat composition of ranges and corresponding range sizes and boundaries are driven by choices made by hawks. I did not test this method because ground-truthing in my study did not allow for comparison of apparently available habitat > 5 km from the nest. Land-cover composition within the bands could be compared to clarify whether characteristics of ranges were a result of choice or obligation (i.e., the individual had access to multiple habitat types at variable distances from the nest and chose to access those which were preferred, or the individual had no choice and was forced to access specific habitats because of either uniform habitat within range of the nest or competition that prevented use of a specific habitat type). Additionally, I did not account for conspecifics or other species [e.g., Swainson's Hawk (*Buteo swainsoni*), Red-tailed Hawk (*Buteo jamaicensis*), or Great-horned Owl (*Bubo virginianus*)] that competed for the same nesting habitat.

Future bird of prey studies focusing on resource use of grassland raptors should include a temporal component to account for changes in vegetation that occur throughout the growing season. My RUF and perch use analyses did not account for temporal dynamics of vegetation (both native and cropland). Vegetation structure may fluctuate throughout the course of the breeding season which can presumably affect when and how often hawks used specific patches of habitat (Fitzpatrick 2004). For example, it is reasonable to believe that irrigated fields or newly planted cropland may have provided different opportunities for Ferruginous Hawks depending on the time of the growing season which could have influenced my results by inflating or underrepresenting a specific habitat type. Anecdotally, I observed male Ferruginous Hawks foraging for Richardson's ground squirrels in idle fields or in cropland fields and subsequently observed the same individuals pass over the fields as they had > 1 m vegetation growth within 1 mo. Although unconfirmed, it is likely the ground squirrels were still present but inaccessible to foraging hawks at the time of the later observations.

Finally, future studies should attempt to determine through experimentation, whether there are threshold distances from the nest at which certain perch types are likely to be used, and thus how proximity might inform perch placement on territories devoid of elevated perches. Direct observational studies that assess foraging success at experimental perches, and correlate subsequent prey delivery rates at the nest would provide evidence for the benefit of elevated perches to Ferruginous Hawks.

### *4.1.4 Concluding Remarks*

My study provides new information on a threatened species in southern Canada which historically is a range-wide stronghold of Ferruginous Hawks. Causes for the decline are uncertain, but many potential drivers are being investigated (Alberta Environment and Parks 2018). Understanding range size, and resource use within home ranges is important to this process, because it frames the factors which affect birds in the fundamental management unit – the nesting territory. This knowledge gap motivated me to undertake this study, which was logistically challenging both from the field perspective, and scope of data collection and analyses. I found that Ferruginous Hawks nesting in Alberta and Saskatchewan maintained comparatively small breeding home ranges relative to other populations, some of which are in decline. This, along with relatively high occupancy of nesting terriories I studied, suggests that Ferruginous Hawk habitat in Canada still provides many of the resources essential for successful reproduction. However, the range of variation of resources within the study population allowed me to identify potential threats (cropland encroachment) and benefits (perch availability), the implications for both, contingent on ground squirrel abundance. For perches specifically, the microsite environment was influential and of no less importance than the presence of prey, a critical component for Ferruginous Hawk recovery (Alberta Environment and Parks 2018).

These findings contribute to a growing body of research investigating numerous facets of Ferruginous Hawk ecology with the goal of better understanding the mechanisms of decline through targeted research. Results from my study can be implemented in future Ferruginous Hawk recovery strategies focused on breeding populations for the species in both Canada and the USA.

**Figure 4.1** - A tagged adult, male Ferruginous Hawk perching on a fence post in southern Saskatchewan. © Janet Ng.

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## Appendix A:

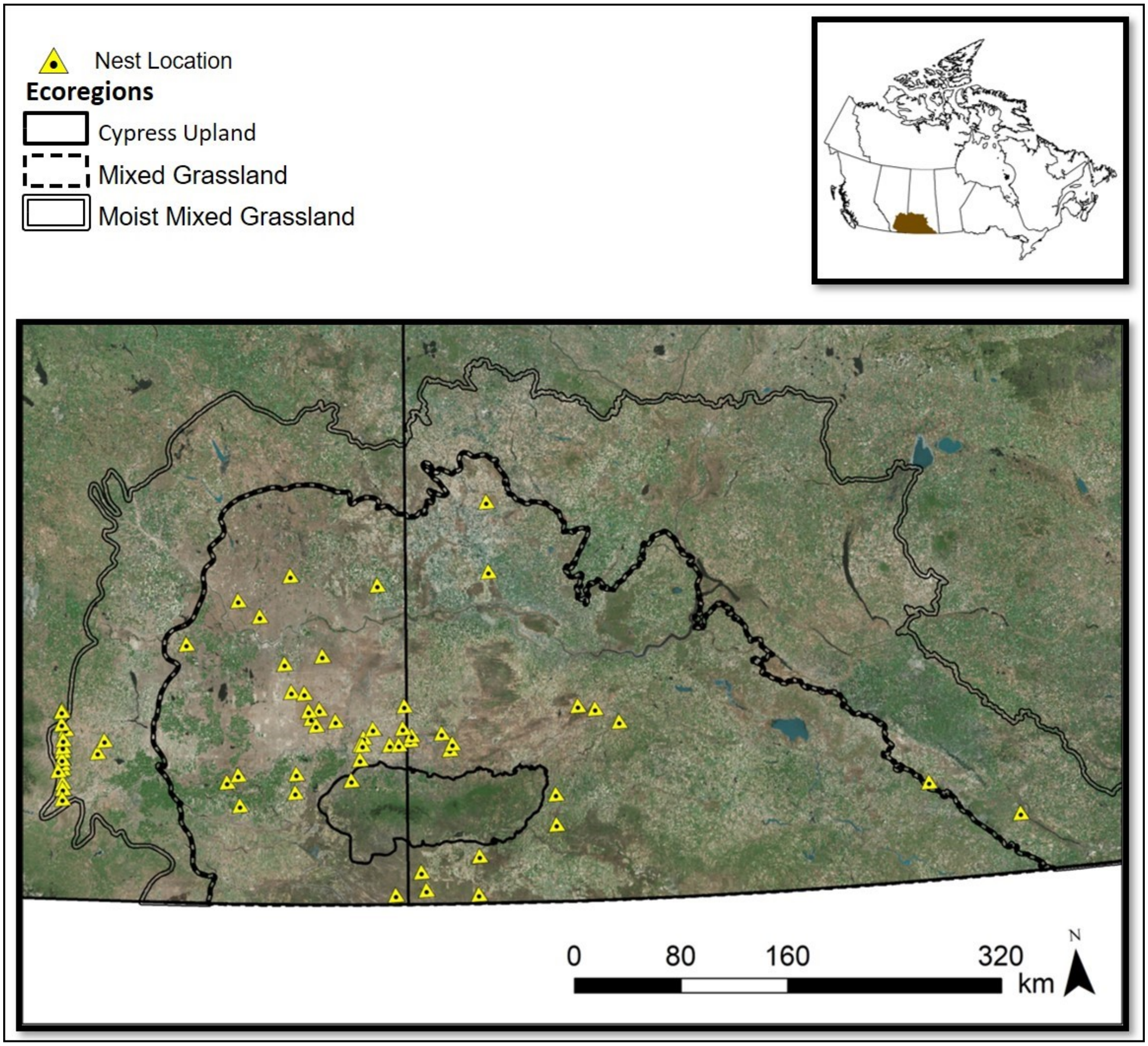

**Figure 2.7** - Capture locations for 78 breeding Ferruginous Hawks (57 male and 21 female) in southern Canada, 2012-2017.

**Table 2.7** - Morphometric measurements for 78 Ferruginous Hawks (n = 57 males, 21 females) captured on their breeding grounds in southern Alberta and Saskatchewan between 2012-2017.

| Measurement | Male (Mean ± SD) | Female (Mean ± SD) |
|---|---|---|
| Mass (g) | 1,239.42 ± 71.26 | 1,846.39 ± 120.54 |
| Tail (mm) | 216.13 ± 7.2 | 225.71 ± 9.5 |
| Wing Chord (mm) | 426.84 ± 9.26 | 448.18 ± 12.64 |
| Hallux (mm) | 27.16 ± 0.96 | 32.94 ± 2.1 |
| Culmen Length (mm) | 27.31 ± 1.07 | 30.01 ± 1.61 |
| Footpad (mm) | 74.8 ± 2.12 | 86.11 ± 3.38 |

**Table 2.8** - Tracking characteristics for 48 breeding, male Ferruginous Hawks monitored on their breeding grounds in southern Alberta and Saskatchewan between 2012-2017.

| Metric | Mean | Minimum | Maximum | SD | No. of ranges |
|---|---|---|---|---|---|
| Days Tracked | 107 | 26 | 204 | 51.04 | 92 |
| No. Locations | 13,783 | 459 | 48,214 | 10,391.72 | 92 |
| Max. dist. from nest (km) | 11.74 | 2.09 | 76.94 | 12.46 | 92 |

**Appendix B:**

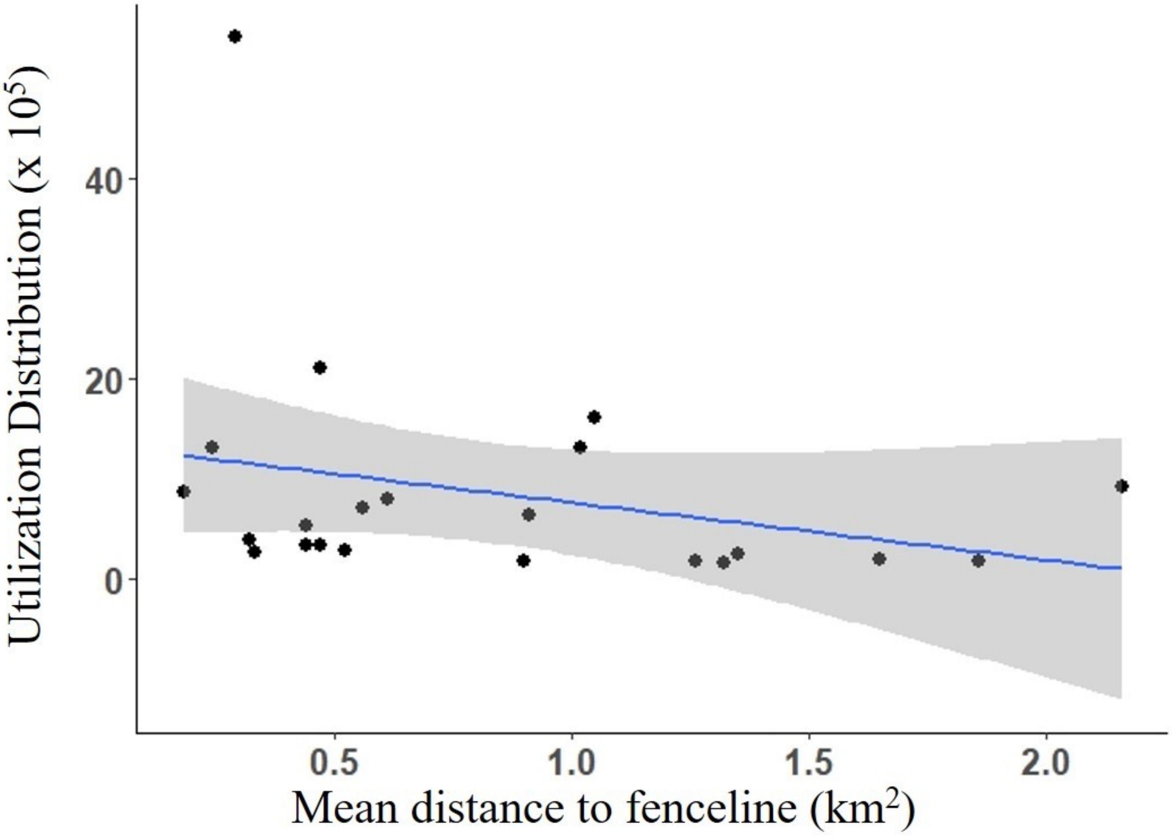

**Figure 3.4** - Linear relationship for effect of distance to fencelines on intensity of perching for 26 Ferruginous Hawks in southern Canada. Mean distance is computed from raw centroid values of individual hawks, and Utilization Distributions from Resource Utilization Functions of individuals that had fencelines within their home ranges.

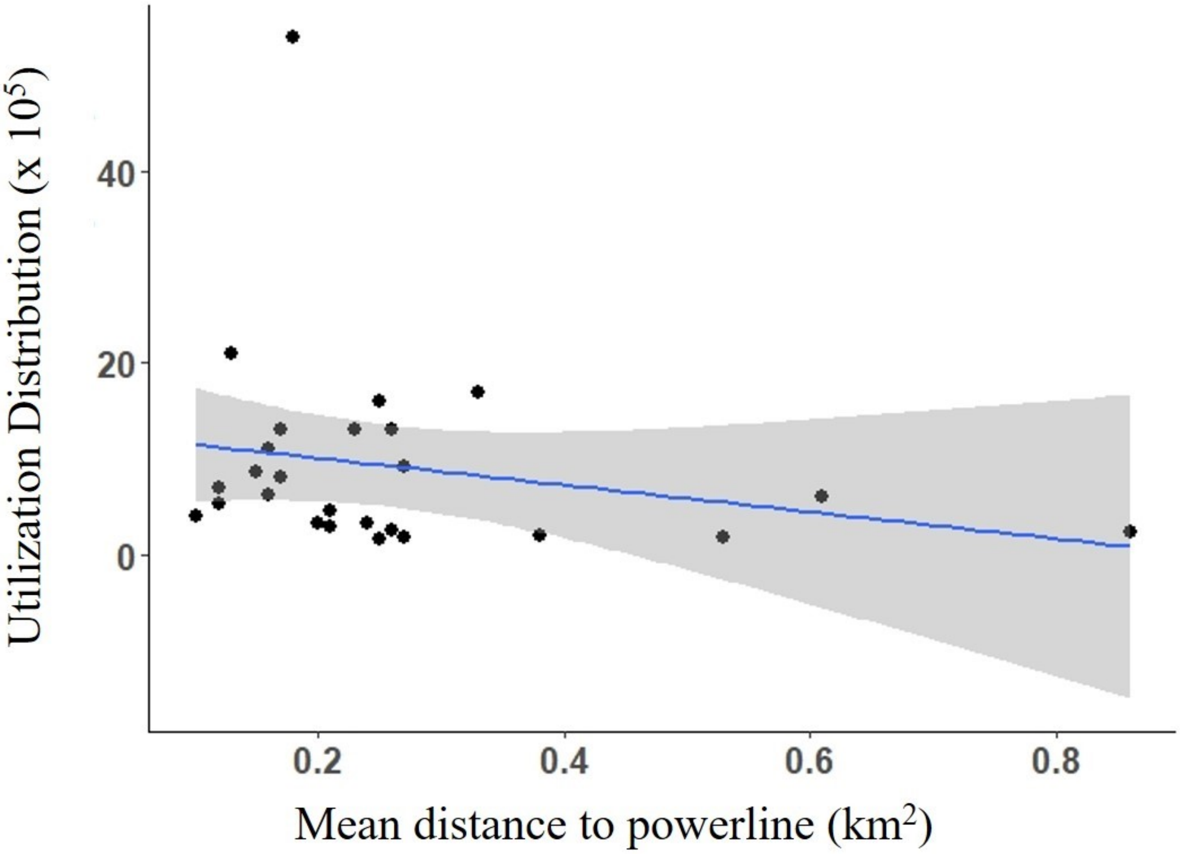

**Figure 3.5** - Linear relationship for effect of distance to powerlines on intensity of perching for 22 Ferruginous Hawks in southern Canada. Mean distance is computed from raw centroid values of individual hawks, and Utilization Distributions from Resource Utilization Functions of individuals that had powerlines within their home ranges.

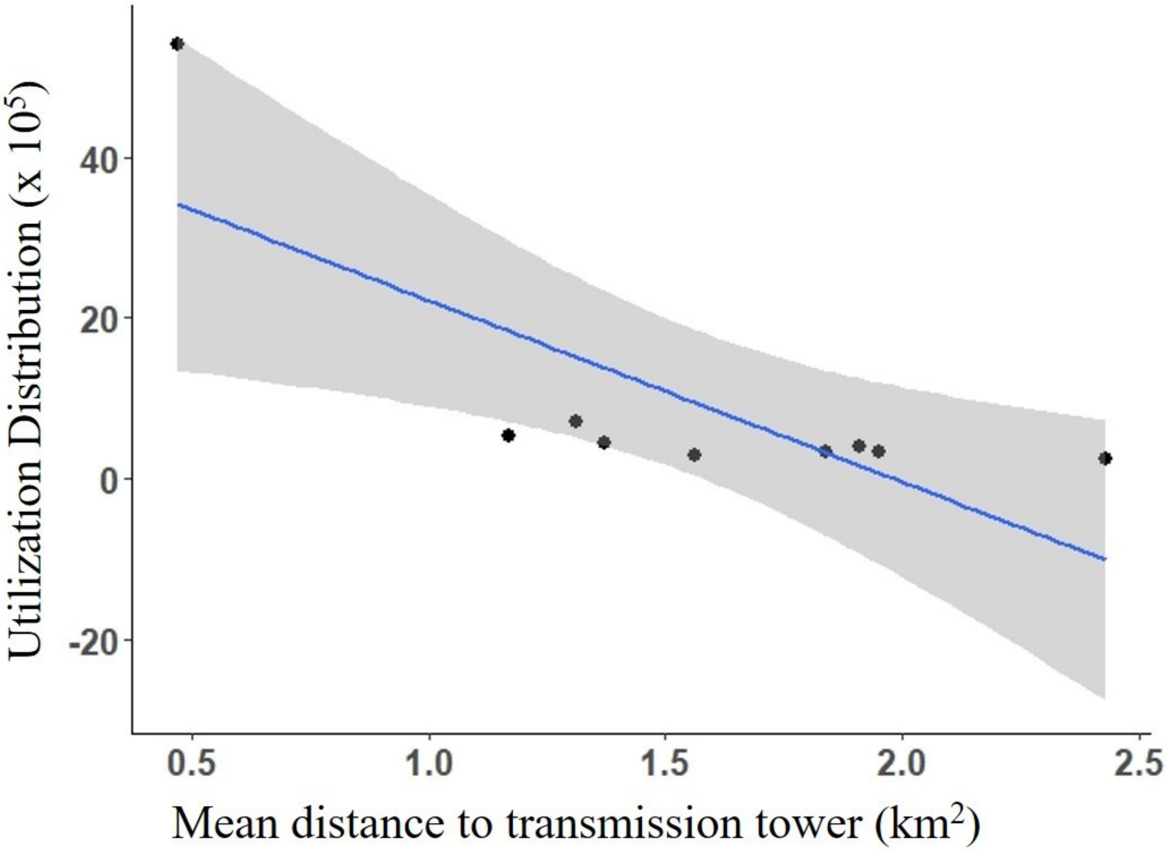

**Figure 3.6** - Linear relationship for effect of distance to transmission towers on intensity of perching for 9 Ferruginous Hawks in southern Canada. Mean distance is computed from raw centroid values of individual hawks, and Utilization Distributions from Resource Utilization Functions of individuals that had transmission towers within their home ranges.

## Methods

### *Perch Sample Selection*

To identify perches for study, I plotted all stationary fixes on each home range (i.e., constant transmitter activity sensor reading and consistent GPS fix location) and merged the fix layer with a 100 m x 100 m grid system using ArcGIS (Figure 3.7 left). To ensure that the sampling of perches within a home range was representative of a gradient of use intensity, I calculated the relative use for each cell by dividing the number of fixes per cell by the total number of fixes in the individual's dataset. Next, I ranked the cells in descending order from highest to lowest relative use for each individual. The highest ranked 20 grid cells for each individual's dataset were categorized as 'high use', and the second highest group of 20 grid cells categorized as 'medium use'. I categorized 'low use' cells by randomly selecting 20 cells from all cells containing only a single fix. I also categorized 'no-use' cells by using the 'Create Random Points' tool in ArcGIS to populate 20 empty cells (i.e., cells without stationary telemetry locations), with single, randomly generated points.

I identified one perch location within each of the 80 grid cells per individual to visit for data collection in the field (Figure 3.7 right). For 20 high use and 20 medium use cells this perch was randomly selected from among all perch locations in that cell (Figure 3.7 right). For 20 low use cells, I visited the lone perch location within the cell. For the 20 cells with no fixes, I randomly generated a single location in each cell. When these 'non-used perch' locations fell < 30 m from each other in adjacent cells, I reselected to avoid potential replication of field data collection. Use characteristics of perches selected for data collection can be found in Table 3.6.

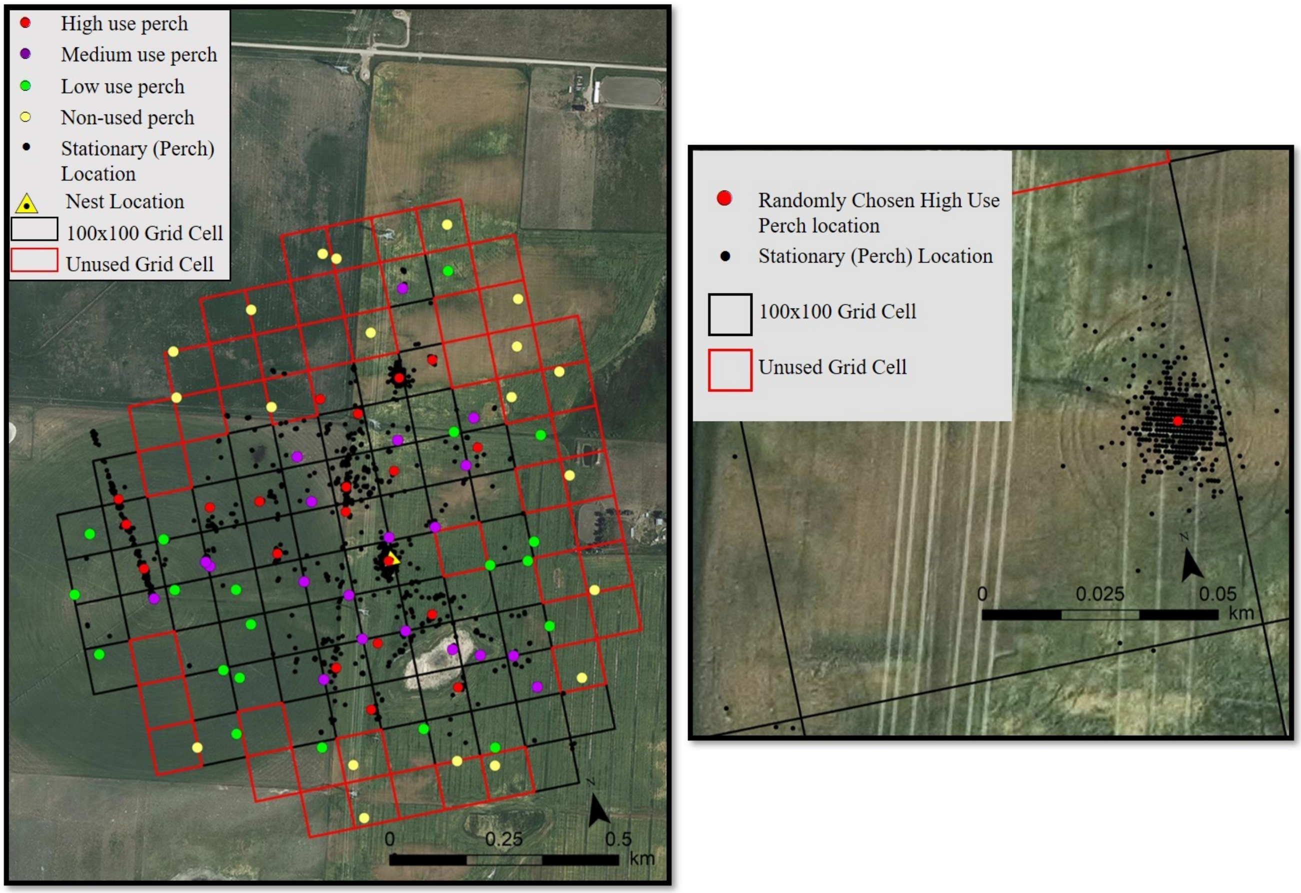

**Figure 3.7** - Ferruginous Hawk home range overlaid by a 100 m x 100 m grid used to score relative intensity of hawk use based on fix locations (left). Colored dots show locations of perches that were randomly chosen for study (right).

**Table 3.4** - Tracking characteristics for 20 breeding, male Ferruginous Hawks from which I sampled perch locations to document perch type, the adjacent land cover and vegetation characteristics, and the relative abundance of Richardson's ground squirrels and other small mammal species (e.g., deer mouse*,* meadow vole*,* sagebrush vole, etc.). Individuals were monitored on their breeding grounds in southern Alberta and Saskatchewan between 2013-2014.

| Metric | Min | Max | Mean ± SD | Total |
|---|---|---|---|---|
| Days Tracked[a] | 8.00 | 108.11 | 29.08 ± 20.53 | 582 |
| Fix Count[b] | 1,441 | 18,248 | 4,521.75 ± 3,544.51 | 90,435 |

[a] The number of days of tracking that telemetry locations were sampled from.

[b] The number of fixes per individual that sampled perch locations were derived from.

**Table 3.5** - Home range, tracking, and Utilization Distribution information for 24 adult male Ferruginous Hawks (27 home ranges) analyzed using Resource Utilization Functions. Individuals were monitored on their breeding grounds in southern Alberta and Saskatchewan between 2013-2014.

| Metric | Min. | Max. | Mean ± SD | Total |
|---|---|---|---|---|
| Home-range Size ($km^2$)[a] | 0.87 | 66.3 | 14.9 ± 15.41 | - |
| UD Value | 0.0000002 | 0.01 | 0.00004 ± 0.0001 | - |
| Number of days tracked | 26 | 204 | 71.37 ± 39.56 | 1,927 |
| Number of hours tracked | 323 | 4,189 | 1,497.52 ± 865.12 | 40,433 |
| Cell Count[b] | 1,842 | 56,612 | 23,100.15 ± 17,241.34 | 623,704 |
| Fix Count[c] | 2,385 | 27,971 | 11,205.78 ± 7,090.64 | 302,556 |

[a] 95% Kernel Density Estimate.

[b] The number of 30 m x 30 m cells per individuals' Resource Utilization Function.

[c] The number of fixes per individual that a respective Resouce Utilization Function is derived from.

**Table 3.6** - Percent use characteristics of perch locations selected for field data collection from 20 breeding, male Ferruginous Hawks monitored in southern Alberta and Saskatchewan between 2013-2014. Perches were placed into one of four categories depending on their amount of use by individual hawks; 'High' (H); 'Medium' (M); 'Low' (L); and 'Unused' (U).

| Use Category | Min. % use/location/hawk | Max. % use/location/hawk | Average % use per hawk ± SD |
|---|---|---|---|
| H | 0.58% | 44.31% | 3.06% ± 1.06 |
| M | 0.04% | 1.36% | 0.63% ± 0.22 |
| L | 0.00% | 0.45% | 0.05% ± 0.04 |
| U | 0.00% | 0.00% | 0% ± 0 |