NORTH DAKOTA GAME AND FISH DEPARTMENT

Final Report

Distribution and Abundance of Swainson's and Ferruginous Hawks in North Dakota: Development of Habitat Models to Assist in Conservation Planning

Project T-3-1

January 1, 2006 – December 31, 2006

Terry Steinwand
Director

Submitted by
Michael G. McKenna
Chief, Conservation and Communications Division

January 2006

HABITAT USE OF LARGE RAPTORS AT TWO SPATIAL SCALES

IN NORTH DAKOTA

by

Clara M. McCarthy

B.S. SUNY College of Environmental Science and Forestry, Syracuse, NY, 2000

A Thesis

Submitted to the Graduate Faculty

of

St. Cloud State University

in Partial Fulfillment of the Requirements

for the Degree

Master of Science

St. Cloud, Minnesota

December, 2006

This thesis submitted by Clara M. McCarthy in partial fulfillment of the requirements for the Degree of Master of Science at St. Cloud State University is hereby approved by the final evaluation committee.

Chairperson

Dean
School of Graduate Studies

HABITAT USE OF LARGE RAPTORS AT TWO SPATIAL SCALES IN NORTH DAKOTA

Clara M.McCarthy

European settlement of the North American grasslands has led to losses and fragmentation of native grassland, increases in woodland, and declines in raptor prey populations. Ferruginous hawks (*Buteo regalis*) and Swainson's hawks (*B. swainsoni*) are grassland associated raptors which have shown recent declines in human-altered landscapes. Red-tailed hawks (*B. jamaicensis*) are habitat generalists that are increasing in North Dakota. I surveyed for nesting hawks on 118 townships east of the Missouri River in the 2004 breeding season and 54 townships west of the river in 2005. I found 31 ferruginous hawk nests, 175 Swainson's hawk nests, and 155 red-tailed hawk nests. Ferruginous hawk nests were surrounded by the most prairie and Swainson's hawk nests were surrounded by the most cropland. I combined information on nest sites, land cover, and colonial mammal prey to develop and test landscape (92.16 km^2) and local (3.14 km^2) scale models predicting presence of hawk nests and used landscape models to predict distribution across the state. I used an information-theoretic approach to examine the effects of land cover and prey separately. Binary and paired logistic regression models were evaluated using ΔAIC_c. Landscape models suggested that ferruginous hawks, which had been the most adapted to the open prairie, were also most negatively affected by increases in cropland, woodland, and fragmentation and decreases in colonial mammal prey. The models predicted high densities in the Northwestern Glaciated and Great Plains, where land use was mainly grazing and hayland. Highest densities of Swainson's hawks were also predicted in these areas. Swainson's hawks, which were originally inhabited the interface between plains and woodland, appeared to have adapted fairly well to some agricultural landscapes. Models showed that these hawks were associated with planted grassland but avoided dense woodland. Red-tailed hawks were the most widespread hawk and nested in all surveyed ecoregions. Land cover associated with red-tailed hawks was too general to create significant landscape models, but models predicted higher abundance when colonial mammals were present. Nest sites had higher amounts of fragmentation than random points, indicating red-tailed hawks may have benefited from increased fragmentation resulting from European settlement.

Great horned owls (*Bubo virginianus*) are another generalist that appear to be increasing in the northern Great Plains, most likely due to increases in woodland. I studied land cover use of breeding great horned owls in the Northwestern Great Plains ecoregion of southwestern North Dakota. I surveyed 54 townships and found 36 nests on 24 townships. Binary and paired logistic regression models were evaluated using ΔAIC_c.

Townships where owl nests were detected had a lower amount of native open habitat and higher amounts of woodland and wetland, although this relationship was not strongly reliable. Averaged model prediction for the subset of best models correctly classified 70% of the townships (68% of townships with nests detected and 73% without). This suggested that owls were benefiting from increased woodland and loss of native habitat in southwestern North Dakota. However, scarcity of wetlands may limit population densities through prey abundance. Nesting habitat was not significantly different from random sites, indicating that this generalist species was able to colonize habitat with fairly low tree cover and wetland availability. Great horned owls appeared to be thriving in the current mixed landscape of southwestern North Dakota.

10 / 06
Month Year

Approved by Research Committee:

Marco Restani Chairperson

ACKNOWLEDGMENTS

R. Murphy (U.S. Fish and Wildlife Service); S. Dyke, S. Hagen and P. Isakson (North Dakota Game and Fish Department); and D. Svingen (U.S. Forest Service) provided the impetus for this study. I thank my graduate committee of M. Blinnikov, M. Restani, and N. Voelz for advice and constructive comments throughout this project. They and R. Murphy also commented on the draft manuscript. S. Hagen, L. MacDonald, W. Newton, M. Sovada, and T. Sklobar provided technical assistance. J. Cornwell, T. Ludwick, R. Flagen, R. Murphy and B. Tresnor kindly assisted with field surveys. Helpful project administration came from B. Kjellberg, L. Donnay, M. McKenzie, and R. Rothaus. Financial support for this project was provided by the North Dakota Game and Fish Department through Federal Aid funds under the State Wildlife Grants program and the U.S. Forest Service, Dakota Prairie Grasslands (Agreement No. 04-CS-11011800-039). Partial funding came from St. Cloud State University and the North Dakota Falconer's Association. The U.S. Fish and Wildlife Service and U.S. Geological Survey provided housing and other logistical support.

TABLE OF CONTENTS

Chapter I

HABITAT USE OF FERRUGINOUS, SWAINSON'S, AND RED-TAILED HAWKS AT TWO SPATIAL SCALES IN NORTH DAKOTA

INTRODUCTION

The North American grasslands are among the most extensively altered biomes in the world, with losses of native prairie as high as 60 – 99% (Samson and Knopf 1994, Houston and Schmutz 1999). European settlers converted native grassland to agriculture and increased woodland cover by planting trees and suppressing fires. Since settlement, grassland habitat has been further decreased by economic policies favoring conversion of marginal land, pastures, and hayfields (Samson and Knopf 1994). As a consequence of the habitat changes, grassland birds have shown consistent, widespread declines whereas ranges and populations of species that are associated with woodlands or are generalized in their habitat affinities have increased (Houston and Bechard 1983, Sargeant et al. 1993, Samson and Knopf 1994, Igl and Johnson 1997, Houston and Schmutz 1999, Grant et al. 2004, Sauer et al. 2005). Populations of colonial mammals, such as Richardson's ground squirrels (*Spermophilus richarsonii*) and black-tailed prairie dogs (*Cynomys ludovicianus*), have also declined through widespread habitat loss and poison control measures (Schmutz 1989, Cook et al. 2003, Sovada et al. 2005).

These habitat changes have affected raptor species by altering abundance and distribution of nest sites and prey, the two primary factors limiting raptor populations (Newton 1979). Ferruginous hawks (*B. regalis*) have declined as much as 90% in areas of prairie Canada since European settlement (Houston and Bechard 1984). More recently, migration and Christmas Bird Counts indicate that local declines and population decreases continue (Hoffman and Smith 2003). Several raptors associated with grasslands appear to be declining across their ranges, including northern harriers (*Circus cyaneus*), burrowing owls (*Athene cunicularia*), and Swainson's hawks (*Buteo swainsoni*) (Kirk and Hyslop 1998, Peterjohn and Sauer 1999). Although Swainson's hawks have adapted well to some agricultural landscapes (Schmutz 1989, Schmutz et al. 2001), this species became extirpated from large areas of California in the mid- to late-1900s (Risebrough et al. 1989) and has suffered significant population declines in southeast Oregon (Littlefield et al. 1984). Declines in reproductive success of both ferruginous and Swainson's hawks in Canadian grasslands appeared linked to decreases of their prey, specifically Richardson's ground squirrels (Kirk and Hyslop 1998, Houston and Schmutz 1999, Schmutz et al. 2001, Houston and Zazelenchuk 2004). In contrast, increases in woodland has increased habitat for generalist raptors such as red-tailed hawks (*B. jamaicensis*) (Sargeant et al. 1993, Sauer et al. 2005). Ferruginous and Swainson's hawks are Level I "Species of Conservation Priority" in North Dakota (Dyke et al. 2004), whereas red-tailed hawk populations in the state appear to be steadily increasing since 1966 (Sauer et al. 2005).

Breeding populations of ferruginous, Swainson's, and red-tailed hawks have coexisted by partitioning nest sites and prey (Schmutz et al. 1980, Bechard et al. 1990, Restani 1991). Ferruginous hawks nested in open plains, Swainson's hawks nested in the interface between plains and woodland, and red-tailed hawks were associated with greater tree cover. Europeans have decreased open, native prairie and increased tree cover in the interface between plains and woodland, which appears to have benefited Swainson's hawks and red-tailed hawks because these species were originally absent from large expanses of prairie (Schmutz 1984). Ferruginous and Swainson's hawks, which had more similar nesting sites, had less dietary overlap than ferruginous and red-tailed hawks (Schmutz et al. 1980, Gilmer et al. 1983, Restani 1991). In North Dakota east of the Missouri River, Richardson's ground squirrels and Northern pocket gophers (*Thomomys talpoides*) were the primary prey for ferruginous and Swainson's hawks (Gilmer and Stewart 1983, 1984), and Richardson's ground squirrels made up a major component of red-tailed hawk diets (Gilmer et al. 1983). Black-tailed prairie dogs, which replaced ground squirrels west of the river (Jones et al. 1983), were important prey for ferruginous hawks in parts of their range (Cook et al. 2003).

Current distribution and habitat use of ferruginous and Swainson's hawks in North Dakota is largely unknown (Dyke et al. 2004). My objectives were to combine information on nest sites, land cover, and prey to develop and test models predicting presence of hawk nests. I considered five variables to investigate the effect of land cover: native prairie, three land cover types that have replaced native prairie (cropland, planted grassland, and woodland), and land cover fragmentation. I created models at landscape and local spatial scales. The landscape scale covered a township (92.16 km^2) and the local scale approximated the nesting territory (3.14 km^2). I predicted ferruginous and Swainson's hawk nests would be found at higher densities in areas of low cultivation and woodland and that red-tailed hawk nesting habitat would be less affected by type and distribution of land cover. I used distribution and abundance of colonial mammals (Richardson's ground squirrels east of the Missouri River and black-tailed prairie dogs west of the river) to create landscape and local models to investigate the effect of prey. I predicted that hawk distribution would be positively related to distribution and abundance of colonial small mammals. Finally, my models also allowed me to predict hawk distribution across the entire state and to suggest management actions to maintain and increase hawk habitat.

METHODS

Study Area

The study area was North Dakota, which from east to west included four Level III Ecoregions: Agassiz Lake Plain, Northern Glaciated Plains, Northwestern Glaciated Plains, and Northwestern Great Plains (Bryce et al. 1998). The Agassiz Lake Plain, a relatively flat area originally of tall grass prairie, was dominated by intensive row agriculture (Bryce et al. 1998). Annual precipitation was relatively high, ranging from 41 to 56 cm (Daly 1998). Human population densities in this ecoregion were some of the highest (up to 27 persons/km^2) in North Dakota (U.S. Census Bureau 2004). The Northern Glaciated Plains were originally mixed grass prairie and contained numerous seasonal wetlands underlain by thick glacial till. Woodland existed primarily in riparian and wetland margins and on the northeast aspect of sand ridges, but woody tree and shrub coverage has doubled in some areas since fire suppression and extirpation of bison (*Bison bison*) (Grant et al. 2004). Cultivation was the major land use, but the region has remained one of high waterfowl production (Sargeant et al. 1993). Annual precipitation was high (41-51 cm) (Daly 1998). Land uses of the Northwestern Glaciated and Great Plains were mainly grazing and hayland production (Gilmer and Stewart 1983). Poor soil, badland topography, and unpredictable precipitation has restricted tree growth and intensive cultivation. The Missouri Couteau was an area of ground moraines in the Northwestern Glaciated Plains where native grassland remained relatively extensive. Climate was semiarid (36-46 cm annual precipitation) (Daly 1998). These two ecoregions included 16 counties with population densities of <1 person/km^2 (U.S. Census Bureau 2004).

Field Procedures

I conducted field work east of the Missouri River in 2004 and west of the river in 2005. My main sampling unit was the township. In 2004 I surveyed 118 townships chosen for a concurrent study of Richardson's ground squirrels, which allowed me to obtain distribution of this important prey species. Townships were systematically selected through a 2-tiered, stratified sampling strategy based on the total area of each ecoregion and the proportion of native rangeland within each township (Sovada et al. 2005). I systematically selected 55 townships in a grid pattern west of the Missouri

River. Accuracy of presence/absence predictions has been shown to be higher using a grid-sampling design than random sampling (Hirzel and Guisan 2002).

In northwestern North Dakota, mean nest initiation time was estimated to be late April for ferruginous and red-tailed hawks and mid-May for Swainson's hawks (Murphy and Ensign 1996). Thus, I began surveys in late April 2004 and early May 2005 before trees leafed out and after hawks had initiated nesting. Townships visited before 25 May 2004 and 11 May 2005 were resurveyed after these dates for later arriving Swainson's hawks. Surveys were performed from sunrise to sunset on days with no precipitation and temperatures above 0ºC. I searched for hawk nests from roads (Vinuela 1997, Bibby et al. 2000) on township section lines, spending up to 3 hours within each township. Large nests were conspicuous before leaf-out and visibility was typically $\geq$1 km. I used a 45x spotting scope to observe nests for 30 minutes or until an adult could be identified to species. Nests with one or two adults were considered occupied by a breeding pair (Gilmer and Stewart 1984). I plotted nest locations onto Digital Orthophotography Quarter Quadrangle (DOQQ) images of each township. I recorded a way point at the road, a compass heading to the nest, and estimated distance to the nest to verify locations with geographic information systems (GIS) software and maps. Four townships had insufficient road coverage and were surveyed from a fixed wing aircraft, traveling at 100 kph about 150 m above ground along transects spaced 0.8 km apart.

Land Cover Analysis

I used ArcGIS and North Dakota GAP Analysis data (30 m resolution) to analyze land cover at landscape and local spatial scales (ESRI 2004, Strong 2004). I considered percentages of (1) native prairie (2) cropland (3) woodland (excluding shelterbelts and single trees due to resolution) and (4) planted grassland (which included invasions of exotics such as smooth brome (*Bromus inermus*) and leafy spurge (*Euphorbia esula*) into prairies, but I excluded shrubland because this cover type was not mapped for the entire state (Strong 2004). A fifth variable considered was number of land cover patches, a metric which estimated degree of fragmentation. Land cover used to calculate this metric included native prairie, planted grassland, cropland, and woodland. For the landscape scale, I calculated percentages of land cover types and number of patches within occupied and unoccupied townships. At the local scale, I calculated percentages and number of patches within 1-km radius buffers around nest locations and paired random sites, which were generated by Random Point Generator, version 1.3 (Jenness 2005), within each occupied township. The 1-km radius approximated the size of hawk territories because it was half the average distance between Swainson's and ferruginous hawk nests in North Dakota (Gilmer and Stewart 1983, 1984).

Prey Analysis

I examined nest distribution and abundance in relationship to Richardson's ground squirrel colonies east of the Missouri River and black-tailed prairie dog colonies west of the river. Location and sizes (ha) of colonies were obtained from a concurrent ground squirrel study (Sovada et al. 2005) and the North Dakota Game and Fish Department (Knowles, unpubl. data), respectively. For the landscape scale analysis, I recorded the number and total area of ground squirrel or prairie dog colonies in each township. I also recorded number and total area of colonies with centers within 2 km of nests and random points for the local scale analysis. I used a larger radius than that for analyses of local cover type because productivity of ferruginous hawk nests in New Mexico was higher for nests <2 km from the center of a prairie dog colony (Cook et al. 2003).

Statistical Analyses

At the landscape scale, I created binary logistic regression equations distinguishing between occupied and unoccupied townships (SPSS 2004). In the Agassiz Lake Plain and Northern Glaciated Plains, townships were chosen based on percentage rangeland because Richardson's ground squirrels were abundant in grazed grasslands (Jones et al. 1983, Sovada et al. 2005), but hawks were not restricted to nesting in rangeland. Therefore I developed landscape models using data from only the 118 townships in the Northwestern Glaciated and Great Plains, where townships were chosen in a grid pattern, in order to increase accuracy of predictions (Hirzel and Guisan 2002). This restricted sample size, but sampled townships in the excluded ecoregions were not representative of the landscapes available to nesting hawks. If sufficient numbers of occupied townships were found for a species, models were developed with 80% of the data in the two western ecoregions and were verified with remaining data from these ecoregions. I applied selected models to eastern townships to determine if my results were applicable to the entire state based on classifications and results of a Hosmer-Lemeshow goodness of fit test (SPSS 2004).

I used a multivariate analysis of variance (MANOVA) and a Bonferroni post-hoc test (SPSS 2004) to characterize land cover use at the local scale by comparing percentages of native prairie, cropland, woodland, and planted grassland within 1 km of nests of each hawk species. For each species, I modeled land cover use by creating paired logistic regression equations comparing nests and random points. Paired logistic regression was more appropriate for matched data than logistic regression (Compton et al. 2002). If sample sizes were sufficient, models were developed with 80% of the data and verified with the remaining 20%, otherwise I developed models with 100% of the data set.

Land cover variables at the landscape scale were tested for nonlinearity using the Box-Tidwell transformation. If necessary, nonlinear variables were log-transformed. For each species and scale, I created 31 candidate models that included all combinations of five variables: native prairie, planted grassland, crop, woodland, and number of land cover patches. I evaluated models using Akiake's Information Criterion (AIC). For most models, the number of samples was small relative to the number of parameters ($n/K < 40$), so I adjusted AIC values for small sample sizes (AIC_c) and calculated the difference between the AIC_c of each model and the minimum AIC_c (ΔAIC_c) (Burnham and Anderson 2002). The subset of models with $\Delta AIC_c \leq 2$ were considered the best models. I excluded models from this subset that were not significantly different from the null model based on likelihood-ratio tests (Hosmer and Lemeshow 2000) and included a model of predictions averaged over the subset using Akaike weights (w_i) (Burnham and Anderson 2002). For landscape models, I also assessed model fit with classification tables and the Hosmer-Lemeshow goodness of fit test. For Swainson's and red-tailed hawk landscape and local models, I verified the best models and the averaged model with reserved data.

I calculated Akaike weights to assess the relative likelihood of each model and determined the relative importance of each predictor variable by adding Akaike weights over all models in which the variable appeared (Burnham and Anderson 2002). I calculated odds ratios and 95% Confidence Intervals (CI) to assess the direction, magnitude and reliability of predictor variables included in the subset of best models. Variables including one in their 95% CI were considered ineffective predictors of occupancy unless strongly skewed (Hosmer and Lemeshow 2000).

In order to predict hawk occupancy across the state, I calculated percentages of cropland, planted grassland, prairie, and woodland and number of land cover patches for almost all townships in North Dakota; I excluded partial townships and those which were over 50% wetland or urban (n = 13 of 1940 townships). I calculated probabilities of nests being present on townships using either the model with the best verification results or a prediction averaged over the subset of best models if results could not be verified.

The relationship between prey and hawk distribution was considered separately from land cover because ground squirrels occurred only east of the Missouri River and prairie dogs only west of the river. At the landscape scale, I created binary logistic regression models predicting occupancy of townships for each hawk species and evaluated models using ΔAIC_c and significance with likelihood-ratio tests. For each species I evaluated four candidate models, three with one predictor (size [ha] of colonies, number of colonies, or presence/absence of colonies) and one that included size of colonies, number of colonies, and the interaction term. At the local scale, I used paired logistic regression to compare ground squirrel or prairie dog colonies within 2 km of nests and paired random points. I evaluated three candidate models with one predictor (presence/absence, area, or number of colonies) for each species. I computed odds ratios and 95% CI to assess direction, magnitude and reliability of each variable in the subset of best models for each scale.

RESULTS

Thirty-one ferruginous hawk nests were found on 25 townships, all of which were located west of the Agassiz Lake Plain (Figure I-1). All nests but one were in trees. Of 175 Swainson’s hawk nests located, 93 (53%) occurred on the Northwestern Great Plain (Figure I-1). Swainson’s hawks nests were found on 88 of 173 surveyed townships. Highest densities of the 155 red-tailed hawk nests located occurred in the Northwestern Glaciated Plains (Figure I-1).

<u>Cover Types</u>

Land cover at the local scale varied by species (MANOVA: Wilks' $\lambda = 0.84$, $F_{2,361} = 7.92$, $p < 0.001$). Species differed in the amounts of native prairie ($F_{2,361} = 15.93$, $p < 0.001$), cropland ($F_{2,361} = 10.33$, $p < 0.001$), and woodland ($F_{2,361} = 3.88$, $p = 0.022$) surrounding nests. Ferruginous hawk nests had higher percentages of prairie within 1 km than Swainson's ($p < 0.001$) or red-tailed hawk nests ($p = 0.001$) (Figure I-2). Swainson's hawk nests also were surrounded by lower percentages of prairie than red-tailed hawk nests ($p = 0.009$) and higher percentages of cropland than ferruginous ($p = 0.004$) or red-tailed hawk nests ($p = 0.001$). Woodland cover was significantly greater around red-tailed hawk nests than around Swainson's hawk nests ($p = 0.044$).

I located too few ferruginous hawk nests to reserve data, thus landscape models were developed with 100% of the Northwestern Glaciated and Great Plains data set. Besides the best model ($\Delta AIC_c = 0$), no models had $\Delta AIC_c \leq 2$ (Table I-1). The best model statistically fit the data (Table I-1) and had high overall correct classifications (Table I-2). Fragmentation, cropland, and woodland were the most important variables based on Akaike weights and all had negative relationships with presence of ferruginous hawk nests (Table I-3). Odds ratios indicated that decreasing number of patches by 100 or percentage cropland or woodland by 1% increased the odds of detecting a nest by 4%, 6%, and 53%, respectively.

I applied this model to the excluded eastern townships. The expected number of occupied townships (2 of 55) was not significantly different from observed (0 of 55), based on a Hosmer-Lemeshow goodness of fit test ($\chi^2 = 2.70$, $p = 0.952$). The models predicted high probabilities of hawk occupancy in portions of the Missouri Couteau, a region in the Northwestern Glaciated Plains with small amounts of cropland and large areas of native prairie, in the southern Northwestern Great Plains, and in the northwestern portion of the Northern Glaciated Plains (Figure I-3).

Thirty-one pairs of nests and random points were used to create local scale paired logistic regression models for ferruginous hawks. Two models were included in the subset of best models ($\Delta AIC_c < 2$) and distinguished between ferruginous hawk nests and random points based on percentage woodland and planted grasslands (Table I-1). I correctly identified nests in 65% of the paired points by averaging the results of the best models (Table I-2). Presence of hawk nests was negatively related to percentage woodland, whereas the odds ratio for planted grassland included 1 in the 95% CI and therefore was not a reliable predictor of hawk nests (Table I-3).

Fifty-eight occupied and 36 unoccupied townships were used to create Swainson's hawk landscape models. Three models were included in the subset of best models and each performed significantly better than the null model (Table I-1). Occupied townships were correctly classified more often than unoccupied townships (Table I-2). Planted grassland and woodland were the most important predictor variables (Table I-3). With an increase of 1% in planted grassland or a decrease of 1% in woodland, odds of Swainson's hawk occupying a township increased by 31% and 10%, respectively. Reserve data included 30 occupied and 49 unoccupied townships. Two models correctly classified 79% of reserve townships, and Hosmer-Lemeshow goodness-of-fit tests indicated that the model containing planted grassland and woodland fit the data best (Table I-4). In the two eastern ecoregions, this model correctly classified 65% of townships (80% occupied and 60% unoccupied). Despite this, the model fit the eastern data poorly because expected number of occupied townships (26 out of 55) was significantly different from observed (15 out of 55), based on a Hosmer-Lemeshow goodness-of-fit test ($\chi^2 = 33.19$, $p < 0.001$). I used this model to predict Swainson's hawk distribution across the state. Townships with high probabilities of being occupied were concentrated in the Missouri Couteau in the center of the state and in large parts of the Northwestern Glaciated Plains (Figure I-3).

I used 140 pairs of nests and random points to create local scale models for Swainson's hawks. All models in the best subset included planted grassland and cropland (Table I-1). The averaged model correctly identified nests in 67% of paired points. The odds of a point being a nest site increased by 7% and 3%, with a 1% increase in percentage planted grassland and cropland, respectively (Table I-3). The best local models correctly distinguished >60% of nests from random points in the reserve data set (Table I-4).

Landscape logistic regression models for red-tailed hawks were developed using 46 occupied and 49 unoccupied townships. None of the candidate models were a good fit for the data based on likelihood-ratio or Hosmer-Lemeshow goodness-of-fit tests, including the best models as ranked by ΔAIC_c. Therefore I did not validate any of the models using reserved data. I used 126 pairs of nests and random points to model habitat use at the local scale and tested models on 31 pairs. Nine significant models were included in the subset of best models (Table I-1), and the averaged model correctly identified nests in 62% of paired points (Table I-2). Fragmentation, the most important variable, was included in all of these models, and had a positive relationship with presence of red-tailed hawk nests (Table I-3). Only two models correctly identified over 60% of nests in both the modeled (Table I-2) and reserved data sets (Table I-4). Variables in these models were fragmentation alone and fragmentation with cropland, planted grassland, and woodland.

Prey

Ground squirrel or prairie dog colonies existed on 101 townships, with an overall mean (SE) of 1.8 (0.2) colonies occupying an average 19 (4) ha per township. The best landscape model for ferruginous hawks included presence/absence of colonies, such that the odds of locating a nest was 231% higher on townships with colonies present (Table I-5). Paired logistic regression was able to distinguish between nests (n = 10) and random points (n = 8) based on area of colonies within 2 km of nests (Table I-5). Twenty-four Swainson's hawks nests and 16 paired random points were within 2 km of colony centers, but no landscape or local candidate model performed better than the null model based on likelihood-ratio tests (Table I-5). Presence/absence of colonies was a significant predictor of red-tailed hawk nests on townships (Table I-5). Eleven red-tailed hawk nests and five random points were within 2 km of colony centers, but paired logistic regression could not identify nests based on colony sizes.

DISCUSSION

Analysis of a combination of field and GIS data allowed me to predict distribution of hawks across the state of North Dakota based on land cover, even in areas where nest densities were low. Habitat use generally differed among species when modeled at landscape and local spatial scales, suggesting that these species partitioned habitat resources in North Dakota. For example, landscape and local models were able to distinguish between presence and absence of ferruginous and Swainson's hawk nests, but red-tailed hawk nests in North Dakota did not appear associated with any land cover variables I examined.

Effect of Cover Type

Ferruginous hawks were originally hawks of treeless plains, and nests in my study were surrounded by the largest amount of native prairie. Native prairie may have provided nest sites and available prey in the form of colonial mammals, as well as buffering nests from anthropological disturbance which could be related to mortality or nest abandonment (White and Thurow 1985). Ferruginous hawks at the landscape scale had a negative association with three variables that were related to smaller, less intact prairies: fragmentation, cropland, and woodland. Moreover, ferruginous hawks also avoided woodland cover at the local scale. Cropland was the second most important landscape variable and native prairie was negatively correlated with cropland. Other studies have shown that ferruginous hawk nest density decreased in landscapes with greater than 30% crop cover, most likely in response to abundance of ground squirrels (Schmutz 1984, 1989).

Swainson's hawks were originally restricted from extensive prairie but, unlike ferruginous hawks, neither cropland nor fragmentation were important variables in landscape models. Probability of detecting Swainson's hawk nests on townships increased with increasing planted grassland and decreasing woodland cover. However, not all areas mapped as planted grasslands were equivalent because planted grassland could have been either grazed, hayed, or planted under the Conservation Reserve Program (CRP) (Strong 2004). Although planted grassland was important at both spatial scales, cropland was a reliable variable only at the local scale. Other studies have found Swainson's hawk nests abundant at relatively low levels of cropland and at high levels of cropland at both landscape (Schmutz 1984) and local scales (Groskorth 1995). The relationship between nests and cropland at the landscape scale may have depended on the level of cultivation, whereas the binary logistic regression equation assumes a consistent relationship.

Swainson's hawk nests were surrounded by the highest amounts of cropland of the three species and were closer to cropland and planted grassland than random points. Schmutz (1987) found that more pairs within 1 km of cultivation raised $\geq$2 young than pairs nesting in intact grasslands. Cropland may be associated with shelterbelts and farmsteads which could provide nest sites. Swainson's hawks also have a wider diet than ferruginous hawks (Gilmer and Stewart 1983, 1984; Restani 1991), and may have been affected differently by losses of native grassland because they were foraging on different species.

Landscape models were unable to correctly identify presence of red-tailed hawks nests using land cover variables, which is unsurprising because the species is a habitat generalist. Increased woodland and fragmentation of native prairie appears to have benefited red-tailed hawks, most likely through increasing nest sites and availability of prey. Compared to other species, land cover surrounding red-tailed hawk nests had highest amounts of woodland cover and intermediate amounts of prairie. Local models indicated that red-tailed hawks nests were surrounded by higher amounts of fragmentation than random points. Red-tailed hawks might have foraged extensively on ground squirrels, but may have focused on more fragmented tracts of prairie than ferruginous hawks due to their use of hunting perches.

Finally, landscape models distinguished between occupied and unoccupied townships for ferruginous and Swainson's hawks significantly better than the null model. However, correct identification of occupied townships for ferruginous hawks and unoccupied townships for Swainson's hawks was low. Logistic regression models are skewed towards the more numerous category, and group membership based on a half-way cut-off is only part of the usefulness of logistic regression models because the difference between 0.49 and 0.51 is slight (Hosmer and Lemeshow 2000). Hosmer-Lemeshow goodness-of-fit tests indicate that predicted numbers of occupied townships in each group (from low probability to high probability) did not significantly differ from observed values, thus adding all probabilities on modeled townships would predict a similar number of occupied townships as I observed. Therefore, it would be more appropriate to use the models to calculate probabilities of ferruginous hawks nesting on townships and to suggest land cover changes that would increase nesting probability than to predict group membership. Predicted numbers of townships occupied by ferruginous hawks on townships excluded from model building did not significantly differ from numbers observed, supporting the application of models to the Agassiz Lake Plain and Northern Glaciated Plain. Results of the selected model for Swainson's hawks predicted occupied and unoccupied townships better than chance in the two eastern ecoregions, but observed numbers significantly differed from expected. For these regions, predicting group membership with the model may be more appropriate.

Effect of Prey

Only ferruginous and red-tailed hawk nests had significant positive relationships with presence of colonial mammals, and only at the landscape scale. Both species consumed more mammals than Swainson's hawks (Gilmer and Stewart 1983, 1984; Schmutz and Hungle 1989; Restani 1991). When present, these mammals may have been an important component of Swainson's hawk diets (Gilmer and Stewart 1984, Restani 1991), but they did not appear to affect distribution at either scale. Ground squirrels and prairie dogs were mainly found in rangeland (Jones et al. 1983, Sovada et al. 2005). In my study, however, Swainson's hawks were associated mainly with planted grassland, and therefore may have been foraging primarily on other prey species. When ground squirrel populations were low, Swainson's hawks compensated by foraging on voles (*Microtus* spp.) if they were unusually abundant (Houston and Zazelenchuk 2004).

Distribution

I found high nest densities on searched townships for all hawk species in the Missouri Couteau region of the Northwestern Glaciated Plains. Models also predicted higher occurrence of ferruginous and Swainson's hawks in this region, which was where Gilmer and Stewart (1983, 1984) found the majority of nests for both species. Land use of the Northwestern Glaciated Plains was mainly grazing and hayland (Bryce et al. 1998) and 61% of the land was rangeland (Sovada et al. 2005). Models predicted high numbers of occupied townships in these areas due to low amounts of woodland and either low amounts of cropland and fragmentation (ferruginous hawks) or high amounts of planted grassland (Swainson's hawks). Red-tailed hawks have increased in this area since the 1950s, perhaps due to increases in height and density of woody vegetation (Stewart 1975, Murphy 1993).

I located few ferruginous and red-tailed hawk nests west of the Missouri River in the Northwestern Great Plains. The ferruginous hawk nests I found were mainly in southern and north-central parts of this region where more native prairie remained. I also predicted that townships in these areas had higher probabilities of being occupied than surrounding areas. I found no ferruginous or Swainson's hawk nests on the Agassiz Lake Plain. Models calculated low probabilities for both hawks in this region because of higher woodland and either higher cropland or little planted grassland. Both species were recorded historically in the northern portion ecoregion, but ferruginous hawks may have been absent from the south (Stewart 1975). High amounts of cropland may have also affected red-tailed hawks, which are present but not abundant in this region. I located no ferruginous hawk nests on the Northern Glaciated Plain, where only 29% of the area remained rangeland and ground squirrel numbers were low (Sovada et al. 2005).

Conservation Implications

Ferruginous hawks were grassland specialists. Habitat models suggested they were affected most by losses and fragmentation of native prairie and decreases of colonial mammal populations. I located very few ferruginous hawk nests, most being found in the Missouri Couteau, and conservation efforts should focus on maintaining the population in this region. If possible, large tracts of uncultivated grassland should be protected and mammal prey, including ground squirrels and prairie dogs, should be conserved or increased. Cooperation with private landowners in North Dakota is important due to the high number of nests I found on private lands.

Although Swainson’s hawks were more abundant than ferruginous hawks, they also may have been negatively affected by increases in woodland cover and intensive cultivation. In eastern North Dakota, where coverage of hayland and rangeland was low, Breeding Bird Survey (BBS) data indicated Swainson’s hawks may be decreasing (Sauer et al. 2005), and I found lower nest densities here than farther west in the state. This species appeared to be increasing in the Northwestern Great Plains (Sauer et al. 2005) where I found Swainson’s hawk nests to be most abundant. Gilmer and Stewart

(1984) were concerned that policies encouraging intensification of agriculture would negatively affect Swainson's hawks. Marginal land should be kept out of cultivation in eastern ecoregions, while rangeland, hayland and CRP land should be expanded if possible. Extensive woodlands should be limited while shelterbelts and other small groups of trees should be maintained.

Red-tailed hawks, the habitat generalists, appeared to be thriving in North Dakota as well as across their range (Sauer et al. 2005), and therefore should be of lower management priority than either of the prairie hawks. However, some management actions targeting ferruginous or Swainson's hawks would benefit red-tailed hawks. For example, maintaining some trees for nest sites, limiting intensive cultivation, and increasing abundance of colonial small mammals.

Chapter II

LAND COVER USE OF NESTING GREAT HORNED OWLS IN THE NORTHWESTERN GREAT PLAINS

INTRODUCTION

The Great Plains grassland has been the most degraded major vegetative province in North America (Samson and Knopf 1994). European settlers converted native grassland to agriculture and increased woodland by planting trees and suppressing fires. Many grassland birds have shown widespread, steep declines due to habitat loss and the negative effects of fragmentation (Samson and Knopf 1994). Species that are increasing, such as house wrens (*Troglodytes aedon*), blue jays (*Cyanocitta cristata*) and orioles (*Icterus* spp.), tend to be associated with woodlands or human activity (Igl and Johnson 1997). Habitat changes have also altered raptor populations. For example, several grassland-associated raptors, including Northern Harriers (*Circus cyaneus*), Burrowing Owls (*Athene cunicularia*), and Swainson's hawks (*Buteo swainsoni*), appear to have declined across their ranges (Samson and Knopf 1994, Kirk and Hyslop 1998, Peterjohn and Sauer 1999). Generalist raptors such as great horned owls (*Bubo virginianus*) and red-tailed hawks (*Buteo jamaicensis*) have become more abundant in the northern Great Plains region in recent decades (Houston and Bechard 1983, Sargeant et al. 1993, Houston and Schmutz 1999, Grant et al. 2004). These raptors require trees for nesting and hunting, and were originally restricted from large expanses of prairie before European settlement. Moreover, great horned owls do not construct their own nests, and rely on other raptors and large corvids for nests. Stick nests built in previous years by other birds that have colonized prairies have probably benefited this species (Stewart 1975, Houston et al. 1998).

My objective was to assess distribution of nesting great horned owls in relation to woodland cover and grassland loss in North Dakota. I also considered distribution of wetlands in my models because they provided important prey species in the state (Gilmer et al. 1983; Murphy 1993, 1997). I assessed use at two scales. The landscape scale covered a township (92.16 km^2) and the local scale approximated home range (4.71 km^2). I predicted that great horned owl nests would be associated with increased woodland and wetland cover and with grassland loss and fragmentation.

METHODS

I studied great horned owls west of the Missouri River in the Northwestern Great Plains ecoregion of North Dakota, an area of about 50,600 km^2. Much of the original mixed-grass prairie covering this area has been replaced by dryland farming for cereal grains and alfalfa. Poor soil and dry conditions (annual precipitation range, 36-46 cm) restrict tree growth and cultivation compared to eastern grasslands (Bryce et al. 1998, Daly 1998). Rugged badlands cut by ephemeral streams and the Little Missouri River cover much of the western counties of the study area. Open ponderosa pine (*Pinus* *ponderosa*) and Rocky Mountain juniper (*Juniperus scopulorum*) woodlands cover some hillsides. Otherwise tree cover occurred as deciduous, mixed deciduous and coniferous, green ash (*Fraxinus americanus*), and aspen (*Populoides tremuloides*) mainly on hills, draws, at edges of impoundments on intermittent streams, and as shelterbelts planted in cropland and farmsteads.

I located great horned owl nests during 1 May to 6 June 2005 on 54 townships chosen systematically for a survey of ferruginous hawk (*Buteo regalis*), Swainson's hawk, and red-tailed hawk nests (see Chapter I). I searched for nests from roads using binoculars and spotting scopes, spending up to 3 hours in each township. There were roads or trails on most section lines, and visibility was often $\geq$1 km. I scanned trees, hillsides, cliffs, and haystacks for nests (Stewart 1975, Frank and Lutz 1997, Houston et al. 1998). I may have overlooked nests in abandoned farm buildings, but believe such nests rarely occurred on my study area. Nests tended by adults or that held nestlings were considered occupied. I plotted locations of great horned owl nests onto Digital Orthophotography Quarter Quadrangle maps. Four townships in remote badlands had few roads and were surveyed from a fixed wing aircraft, traveling at 100 kph about 150 m above ground along transects spaced 0.8 km apart.

I added UTM coordinates of occupied nest locations to the North Dakota Gap Analysis Project (GAP) land cover map (30-m resolution; Strong 2004). I compared land cover between each nest and a paired random points within the same township generated by Random Point Generator, version 1.3 (Jenness 2005). I used ArcGIS (ESRI 2004) and GAP Analysis data (Strong 2004) to analyze land cover at landscape (township) and local (home range) scales. I excluded 10 townships from the landscape analysis because they were surveyed after 20 May, the date I began to see owl fledglings off of nests. Local scale included the area within a 1.5 km radii buffer of each nest and random point, which corresponded roughly to 95% home range estimates for adult great horned owls in Colorado (Frank and Lutz 1997). I considered four land cover types that have been altered by settlement or which affected owl distributions in other areas: percentage native grassland, cropland, woodland, and wetland (Gilmer et al. 1983; McGarigal and Fraser 1984; Murphy 1993, 1997; Morrell and Yahner 1994; Bosakowski and Smith 1997; Houston et al. 1998; Smith et al. 1999). Native grassland included some shrub cover. Stands of trees but not shelterbelts and single trees were mapped as woodland in the GAP analysis database. Wetlands included temporary, seasonal, semipermanent and permanent wetlands and deep water habitats. I recorded the total number of patches of eight land cover types (cropland, planted grassland, native grassland, shrubland, woodland, wetland, badland, and urban) combined as a measure of fragmentation. Fragmentation has increased due to prairie conversion and may benefit foraging owls in forested areas by providing fields adjacent to wooded edges (Morrell and Yahner 1994, Bosakowski and Smith 1997).

I used data from townships and nest buffers to develop landscape and local habitat use models. Cropland was excluded from the landscape analysis because it was highly correlated with native grassland (r = -0.8). Land cover variables at each scale were tested for nonlinearity using the Box-Tidwell transformation, then nonlinear variables were log-transformed. At the landscape scale I created 16 binary logistic regressions of detection of owl nests on all combinations of four variables (three cover types and fragmentation) and at the local scale I created 31 paired logistic regressions models on all combinations of five variables (four cover types and fragmentation).

I used Akiake's Information Criterion (AIC) to evaluate candidate models (SPSS 2004, Burnham and Anderson 2002). For almost all models, the number of samples was small relative to the number of parameters ($n/K < 40$), so I adjusted AIC values for small sample sizes (AIC_c) and calculated the change in AIC_c (ΔAIC_c), the difference between the AIC_c of each model and the minimum AIC_c (Burnham and Anderson 2002). The subset of models with $\Delta AIC_c < 2$ were considered the best models (Burnham and Anderson 2002), excluding those not significant based on Likelihood-Ratio Tests (Hosmer and Lemeshow 2000). I included a model of predictions averaged over the subset of best models using Akaike weights (w_i) (Burnham and Anderson 2002).

I used correct classification tables, Hosmer-Lemeshow goodness-of-fit tests (SPSS 2004), and w_i to assess each model. I determined the relative importance of each predictor variable by adding w_i over all models in which the variable appeared (Burnham and Anderson 2002). I calculated odds ratios and their 95% Confidence Intervals (CI) to assess the direction, magnitude and reliability of predictor variables (Hosmer and Lemeshow 2000). Variables including 1.0 in the 95% CI were considered ineffective unless skewed.

RESULTS

I found 36 great horned owl nests on 24 townships. I observed only one nest on 71% of townships in which owls were present. Nests were found throughout southwestern North Dakota and did not appear to be clustered in any one area. Fifty-three percent of nests were on shelterbelts (47%) or associated with farmyards (8%). Other nests were mainly in woodlots (14%), riparian areas (11%), or single and small groups of trees (19%). I detected one owl nest during my aerial survey of four relatively roadless townships in badland topography, but failed to plot its location accurately. This nest was not used in my analysis.

The subset of best landscape models ($\Delta AIC_c < 2$) included four models, and the Hosmer-Lemeshow goodness-of-fit test indicated that these models fit the data (Table II-1). Native grassland was the most important variable, and was included in three of the best models. I was able to correctly classify 70% of townships by averaging the results of the best models. All of the best models classified townships better than chance, with the native grassland and wetland model correctly identifying the highest proportion of townships (Table II-2). The 95% CI of the odds ratio for all variables within the subset of best models included 1.0, but all CIs were skewed (Table II-3). The odds ratio of native grassland was negatively skewed, indicating that the probability of detecting a nest increased as native grassland in a township decreased. The 95% CI of wetland and woodland had a positive skew, therefore probability of owl nests being detected on a township increased with amount of wetland and woodland. Despite this pattern, wetland

and woodland cover was a small mean (SE) percentage of land cover on townships where owls were detected (2[1]% and 3[1]%, respectively).

Woodland made up the lowest amount of land cover within 1.5 km of nests (Figure II-1). Land cover that surrounded owl nests did not differ significantly from that around random points (Figure II-1). No candidate model at the local scale was significant based on Likelihood Ratio tests.

DISCUSSION

I was able to correctly predict presence or absence of nesting great horned owls in 70% of townships based on land cover, which suggested that owls were nesting in distinctive landscapes. Townships with owls contained less native grassland than townships without owls. Owls which were associated with lower amounts of native grassland may have been using cropland and hayland to forage on mice and voles (Murphy 1997). Moreover, large areas of native grassland probably provided fewer hunting perches, the reverse of extensive woodland, which may be poor habitat because of fewer clearings and access to prey (Bosakowski and Smith 1997).

Wetland and woodland both had positive relationships with owl nests. Prey from wetlands and riparian areas was important to great horned owls in central and northwestern North Dakota (Gilmer et al. 1983; Murphy 1993, 1997). In northwestern North Dakota, owl pairs appeared to focus on wetlands as foraging sites regardless of their prevalence in the landscape (Murphy 1997). Despite wetlands being scarcer on my study area (mean coverage on townships 3%, versus 19% of a 193-ha study area in

Murphy 1997), this cover type was important to great horned owls in southwestern North Dakota. I found a positive relationship between woodland and owl presence despite limitations to the woodland cover data. All nests I found were in trees, mostly shelterbelts. Owls required trees for nesting and also preferentially foraged along fields with trees and forest edges (Morrell and Yahner 1994, Bosakowski and Smith 1997). Trees provided hunting perches (Marti 1974), and Murphy (1993) found that great horned owls in the Great Plains were most abundant where large (>0.5 ha) aspen clumps were most abundant.

The distinctiveness of nest locations appeared to be scale dependent. I was able to model land cover use at the landscape scale (townships) but not at the local scale (nests). This scale dependence may have resulted from the response of great horned owls to land cover, suggesting that owls responded to factors beyond the local scale. Occurrence of some small grassland birds appeared to be influenced by tree cover far beyond their nesting territories (Cunningham and Johnson 2006). However, unlike great horned owls, song birds may have been affected by increased predator movement related to woody cover. Once a nest site was located, the primary factor affecting owls would be food, and owls would have spent approximately 95% of their time foraging in the local area. Conversely, the scale dependence I observed may have resulted from distribution of land cover in the study area. Landscape and local scales were effectively nested and land cover may have been correlated (Cunningham and Johnson 2006). Land cover among townships may have differed more than nests and paired random points, which were located in the same township.

I did not find great horned owl nests concentrated in any one region in southwestern North Dakota. In contrast, owl nests recorded before 1972 appeared concentrated in the badlands and along the Missouri River (Stewart 1975). The population may have expanded due to loss of native grasslands and increases in woodland cover (Stewart 1975, Murphy 1993, Sargeant et al. 1993). Great horned owls are habitat generalists (Morrell and Yahner 1994, Bosakowski and Smith 1997) and my study indicated the species is capable of nesting successfully in northern prairie landscapes that are dominated by cropland and nearly devoid of woodland. Although great horned owls in my study were able to nest in areas with little woodland cover, scarcity of wetlands in southwestern North Dakota probably limited nesting densities of the owl below levels observed in other areas of the northern Great Plains (e.g., up to 0.11 occupied nests/km^2 in mixed prairie and cropland in northwestern North Dakota; Murphy 1997).

LITERATURE CITED

LITERATURE CITED

Bechard, M. J., R. L. Knight, D. G. Smith, and R. E. Fitzner. 1990. Nest sites and habitats of sympatric hawks (*Buteo* spp.) in Washington. Journal of Field Ornithology 61:159-170.

Bibby, C. J., N. D. Burgess, D. A. Hill, and S. H. Mustoe. 2000. Bird Census Techniques, 2nd ed. Academic Press. San Diego, CA.

Bosakowski, T., and D. G. Smith. 1997. Distribution and species richness of a forest raptor community in relation to urbanization. Journal of Raptor Research 31:26-33.

Bryce, S., J. M. Omernik, D. E. Pater, M. Ulmer, J. Schaar, J. Freeouf, R. Johnson, P. Kuck, and S. H. Azevedo. 1998. Ecoregions of North Dakota and South Dakota. U.S. Geological Survey, Reston, Virginia.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer, New York, NY.

Compton, B. W., J. M. Rhymer, and M. McCollough. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. Ecology 83:833-843.

Cook, R. R., J-L. E. Cartron, and P. J. Polechla, Jr. 2003. The importance of prairie dogs to nesting ferruginous hawks in grassland ecosystems. Wildlife Society Bulletin 31:1073-1082.

Cunningham, M. A., and D. H. Johnson. 2006. Proximate and landscape factors influence grassland bird distributions. Ecological Applications 16:1062–1075.

Daly, C. 1998. North Dakota Average Annual Precipitation, 1961-90. Water and Climate Center of the Natural Resources Conservation Service, Portland, Oregon.

Dyke, S., S. Hagen, and P. Isakson. 2004. North Dakota's 100 species of conservation priority. North Dakota Outdoors Magazine July 2004:3-21.

ESRI. 2004. ArcGIS, version 9.0. Environmental Systems Research Institute, Inc, Redlands, California.

Frank, R. A., and R. S. Lutz. 1997. Great horned owl (*Bubo virginianus*) productivity and home range characteristics in a shortgrass prairie. Pages 185–189 in Biology and Conservation of Owls in the Northern Hemisphere, 2nd International Symposium (J.R. Duncan, D.H. Johnson, and T.H. Nichols, Eds.). U.S. Department of Agriculture, Forest Service General Technical Report NC-190.

Gilmer, D. S, P. M. Konrad, and R.E. Stewart. 1983. Nesting ecology of red-tailed hawks and great horned owls in central North Dakota and their interactions with other large raptors. Prairie Naturalist 15:133-143.

Gilmer, D. S., and R. E. Stewart. 1983. Ferruginous hawk populations and habitat use in North Dakota. Journal of Wildlife Management 47:146-157.

Gilmer, D. S., and R. E. Stewart. 1984. Swainson's hawk nesting ecology in North Dakota. Condor 86:12-18.

Grant, T. A., E. Madden, and G. B. Berkey. 2004. Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. Wildlife Society Bulletin 32:807-818.

Groskorth, L. C. 1995. Nest-site selection by the Swainson's hawk on the Regina plain, Saskatchewan. Canadian Journal of Zoology 73:1887-1890.

Hirzel, A., and A. Guisan. 2002. Which is the optimal sampling strategy for habitat suitability modeling. Ecological Modelling 157: 331-341.

Hoffman, S. W., and J. P. Smith. 2003. Population trends of migratory raptors in western North America, 1977-2001. Condor 105:397-419.

Hosmer, D. W., and S. L. Lemeshow. 2000. Applied Logistic Regression. John Wiley and Sons, New York.

Houston, C. S., and M. J. Bechard. 1983. Trees and the red-tailed hawk in southern Saskatchewan. Blue Jay 41:99-109.

Houston, C. S., and M. J. Bechard. 1984. Decline of the ferruginous hawk in Saskatchewan. American Birds 38:166-170.

Houston, C. S., and J. K. Schmutz. 1999. Changes in bird populations on Canadian grasslands. Studies in Avian Biology 19:87-94.

Houston, C. S., D. G. Smith, and C. Rohner. 1998. Great Horned Owl (*Bubo virginianus*). In The Birds of North America, No. 372 (A. Poole and F. Gill, Eds.). Birds of North America, Inc., Philadelphia.

Houston, C. S., and D. Zazelenchuk. 2004. Swainson's hawk productivity in Saskatchewan, 1944-2004. North American Bird Bander 29:174-178.

Igl, L. D., and D. H. Johnson. 1997. Changes in breeding bird populations in North Dakota: 1967 to 1992-93. Auk 114:74-92.

Jenness, J. 2005. Random Point Generator, version 1.3. Jenness Enterprises, Flagstaff, Arizona.

Jones, J. K., Jr., D. M. Armstrong, R. S. Hoffmann, and C. Jones. 1983. Mammals of the Great Northern Plains. University of Nebraska Press, Lincoln, Nebraska.

Kirk, D. A., and C. Hyslop. 1998. Population status and recent trends in Canadian raptors: a review. Biological Conservation 83:91-118.

Littlefield, C. D., S. P. Thompson, and B. D. Ehlers. 1984. History and present status of Swainson's hawks in southeast Oregon. Raptor Research 18:1-5.

Marti, C. D. 1974. Feeding ecology of four sympatric owls. Condor 76:45-51.

McGarigal, K., and J. D. Fraser. 1984. The effect of forest stand age on owl distribution in southwestern Virginia. Journal of Wildlife Management 48:1393-1398.

Morrell, T. E., and R. H. Yahner. 1994. Habitat characteristics of great horned owls in southcentral Pennsylvania. Journal of Raptor Research 28:164-170.

Murphy, R. K. 1993. History, nesting biology, and predation ecology of raptors in the Missouri Coteau of northwestern North Dakota. Ph.D. dissertation, University of Bozeman, Bozeman, MT.

Murphy, R. K. 1997. Importance of prairie wetlands and avian prey to breeding great horned owls (*Bubo virginianus*) in Northwestern North Dakota. Pages 286-298 in Biology and conservation of owls in the northern hemisphere. 2nd International Symposium (J.R. Duncan, D.H. Johnson, and T.H. Nichols, Eds.). U.S. Department of Agriculture, Forest Service General Technical Report NC-190.

Murphy, R. K., and J. T. Ensign. 1996. Raptor nesting chronology in northwestern North Dakota. Prairie Naturalist 28:51-58.

Newton, I. 1979. Population Ecology of Raptors. Buteo Books, Vermillion, South Dakota.

Peterjohn, B. G., and J. R. Sauer. 1999. Population status of North American grassland birds from the North American Breeding Bird Survey, 1966-1996. Studies in Avian Biology 19:27-44.

Restani, M. 1991. Resource partitioning among three *Buteo* species in the Centennial Valley, Montana. Condor 93:1007-1010.

Risebrough, R. W., R. W. Schlorff, P. H. Bloom, and E. E. Littrell. 1989. Investigations of the decline of Swainson's hawk populations in California. Journal of Raptor Research 23:63-71.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418-421.

Sargeant, A. B., R. J. Greenwood, M. A. Sovada, and T. L. Shaffer. 1993. Distribution and abundance of predators that affect duck production - Prairie Pothole Region. U.S. Fish and Wildlife Service, Resource Publication 194.

Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American breeding bird survey results and analysis 1966 – 2004, version 2005.2. USGS Patuxent Wildlife Research Center, Laurel, Maryland. [Online] Available at <http://www.mbr-pwrc.usgs.gov/bbs/bbs.html>.

Schmutz, J. K. 1984. Ferruginous and Swainson's hawk abundance and distribution in relation to land use in southeastern Alberta. Journal of Wildlife Management 48:1180-1187.

Schmutz, J. K. 1987. The effect of agriculture on ferruginous and Swainson's hawks. Journal of Range Management 40:438-440.

Schmutz, J. K. 1989. Hawk occupancy of disturbed grasslands in relation to models of habitat selection. Condor 91: 362-371.

Schmutz, J. K., C. S. Houston, and S. J. Barry. 2001. Prey and reproduction in a metapopulation decline among Swainson's hawks, *Buteo swainsoni*. Canadian Field-Naturalist 115: 257-273.

Schmutz, J. K., and D. J. Hungle. 1989. Populations of ferruginous and Swainson's hawks increase in synchrony with ground squirrels. Canadian Journal of Zoology 67:2596-2601.

Schmutz, J. K., S. M. Schmutz, and D. A. Boag. 1980. Coexistence of three species of hawks (*Buteo* spp.) in the prairie-parkland ecotone. Canadian Journal of Zoology 6:1075-1089.

Smith, D. G., T. Bosakowski, and A. Devine. 1999. Nest site selection by urban and rural great horned owls in the Northeast. Journal of Field Ornithology 70: 535-542.

Sovada, M. A., R. K. Murphy, and T. J. Ludwick. 2005. Distribution of Richardson's ground squirrel colonies in North Dakota and burrowing owl use of the ground squirrel colonies. North Dakota Fish and Game, Bismarck, North Dakota.

SPSS. 2004. SPSS Base 13.0 for Windows: user's guide. SPSS, Chicago.

Stewart, R. E. 1975. Breeding birds of North Dakota. Tri-College Center for Environmental Studies, Fargo, North Dakota.

Strong, L. 2004. North Dakota Gap Analysis Land Cover Database. USGS Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

U.S. Census Bureau. 2004. Census 2000 data for the state of North Dakota. U.S. Census Bureau, Washington, DC. [Online] Available at <http://www.census.gov/census2000/states/nd.html>.

Viñuela, J. 1997. Road transects as a large-scale census method for raptors: The case of the red kite *Milvus milvus* in Spain. Bird Study 44:155-165.

White, C. M., and T. L. Thurow. 1985. Reproduction of ferruginous hawks exposed to controlled disturbance. Condor 87:14-22.

APPENDICES

APPENDIX A

Chapter I Tables

Table I-1. The best logistic regression models ($\Delta AIC_c < 2$) distinguishing between occupied and unoccupied townships or nests and random points for ferruginous, Swainson's, and red-tailed hawks in North Dakota, 2004 and 2005. Landscape models are binary logistic regressions and local models are paired logistic regressions. Included for each model are number of model parameters (*K*), Akaike's Information Criterion adjusted for small sample sizes (AIC_c), change in AIC_c (ΔAIC_c), Akaike weights (w_i), significance of a Likelihood Ratio test, and results of a Hosmer-Lemeshow goodness-of-fit test (χ^2 and *p*-value).

Model	*K*	AIC	AIC_c	ΔAIC_c	w_i	Likelihood Ratio Test	χ^2	*p*-value
FERRUGINOUS HAWK								
Landscape (n = 118)								
Crop + Woodland + Fragmentation	5	101.6	102.1	0.00	0.50	<0.001	5.26	0.73
Local (n = 62)								
Woodland	3	37.9	38.6	0.00	0.28	0.008	--	--
Planted grassland + Woodland	4	38.7	40.0	1.41	0.14	0.016	--	--
SWAINSON'S HAWK								
Landscape (n =94)								
Planted grassland + Woodland	4	111.7	112.1	0.00	0.22	<0.001	11.57	0.17
Planted grassland + Prairie + Woodland	5	111.7	112.3	0.21	0.20	<0.001	7.74	0.46
Planted grassland + Cropland + Woodland	5	111.9	112.6	0.44	0.18	<0.001	5.60	0.69
Averaged Prediction							11.35	0.18
Local (n = 280)								
Planted grassland + Cropland	4	175.6	175.8	0.00	0.34	<0.001	--	--
Planted grassland + Cropland + Prairie	5	177.3	177.8	1.93	0.13	<0.001	--	--

Table I-1 continued.

Model	K	AIC	AIC_c	ΔAIC_c	w_i	Likelihood Ratio Test	χ^2	p-value
RED-TAILED HAWK								
<u>Local (n = 252)</u>								
Prairie + Fragmentation	4	170.6	170.9	0.00	0.10	0.017	--	--
Prairie + Woodland + Fragmentation	5	170.5	171.0	0.07	0.10	0.017	--	--
Fragmentation	3	170.9	171.1	0.19	0.09	0.016	--	--
Crop + Fragmentation	4	171.0	171.3	0.43	0.08	0.022	--	--
Crop + Woodland + Fragmentation	5	171.1	171.6	0.72	0.07	0.023	--	--
Woodland + Fragmentation	4	171.3	171.7	0.77	0.07	0.026	--	--
Crop + Planted grassland + Woodland + Fragmentation	6	171.1	171.8	0.92	0.07	0.021	--	--
Crop + Planted grassland + Fragmentation	5	171.9	172.4	1.48	0.05	0.032	--	--
Crop + Prairie + Fragmentation	5	172.3	172.8	1.93	0.04	0.040	--	--

Table I-2. Classification table for the best logistic regression models ($\Delta AIC_c < 2$) predicting ferruginous, Swainson's, and red-tailed hawks in North Dakota, 2004 and 2005.

Model	% occupied correct	% unoccupied correct	% total correct
FERRUGINOUS HAWK			
Landscape (n = 118)			
Crop + Woodland + Fragmentation	36.0	94.6	82.2
Local (n = 62)			
Woodland	--	--	58.1
Planted grassland + Woodland	--	--	74.2
Averaged Prediction	--	--	64.5
SWAINSON'S HAWK			
Landscape (n =94)			
Planted grassland + Woodland	93.1	44.4	74.5
Planted grassland + Prairie + Woodland	94.8	44.4	75.5
Planted grassland + Cropland + Woodland	87.9	44.4	71.3
Averaged Prediction	96.6	44.4	70.0
Local (n = 280)			
Planted grassland + Cropland	--	--	67.9
Planted grassland + Cropland + Prairie	--	--	66.4
Averaged Prediction	--	--	67.1

Table I-2 continued.

Model	% occupied correct	% unoccupied correct	% total correct
RED-TAILED HAWK			
Local (n = 252)			
Prairie + Fragmentation	--	--	59.5
Prairie + Woodland + Fragmentation	--	--	61.9
Fragmentation	--	--	60.3
Crop + Fragmentation	--	--	58.7
Crop + Woodland + Fragmentation	--	--	58.7
Woodland + Fragmentation	--	--	58.7
Crop + Planted grassland + Woodland + Fragmentation	--	--	60.3
Crop + Planted grassland + Fragmentation	--	--	59.5
Crop + Prairie + Fragmentation	--	--	59.5
Averaged Prediction	--	--	61.9

Table I-3. Relative importance and odds ratios (95% confidence interval) of habitat variables in North Dakota, 2004 and 2005. Odds ratios were calculated for global models.

Model	Relative Importance	Odds Ratio	95% Confidence Interval
FERRUGINOUS HAWK			
Landscape			
Fragmentation/100	0.98	0.96	0.93 – 0.99
Cropland	0.97	0.94	0.91 – 0.97
Woodland	0.95	0.47	0.23 – 0.98
Local			
Woodland	0.91	0.33	0.11 – 1.01
Planted grassland	0.33	1.03	0.97 – 1.10
SWAINSON'S HAWK			
Landscape			
Planted grassland	0.98	1.10	1.02 – 1.19
Woodland	0.92	0.69	0.47 – 1.00
Cropland	0.40	1.01	0.95 – 1.06
Prairie	0.40	0.98	0.92 – 1.06
Local			
Planted grassland	1.00	1.07	1.03 – 1.11
Cropland	0.87	1.03	1.00 – 1.06
Prairie	0.35	1.01	0.97 – 1.04

Table I-3 continued.

Model	Relative Importance	Odds Ratio	95% Confidence Interval
RED-TAILED HAWK			
<u>Local</u>			
Fragmentation/100	0.89	2.05	1.15 – 3.64
Woodland	0.51	1.10	0.95 – 1.26
Prairie	0.43	1.00	0.97 – 1.04
Cropland	0.42	1.02	0.99 – 1.06
Planted grassland	0.34	1.02	0.98 – 1.06

Table I-4. Classification table for validating the best Swainson's and red-tailed hawk logistic regression models for North Dakota, 2004 and 2005. Included are Hosmer-Lemeshow goodness-of-fit test results (χ^2 and *p*-value).

Model	% occupied correct	% unoccupied correct	% total correct	χ^2	*p*-value
SWAINSON'S HAWK					
Landscape (n =24)					
Planted grassland + Woodland	93.3	55.6	79.2	3.34	0.912
Planted grassland + Prairie + Woodland	86.7	66.7	79.2	11.91	0.155
Planted grassland + Cropland + Woodland	93.3	44.4	75.0	9.99	0.266
Averaged Prediction	93.3	44.4	75.0	6.12	0.633
Local (n = 70)					
Planted grassland + Cropland	--	--	62.9	--	--
Planted grassland + Cropland + Prairie	--	--	60.0	--	--
Averaged Prediction	--	--	62.9	--	--
RED-TAILED HAWK					
Local (n = 62)					
Prairie + Fragmentation	--	--	58.1	--	--
Prairie + Woodland + Fragmentation	--	--	58.1	--	--
Fragmentation	--	--	60.3	--	--
Crop + Fragmentation	--	--	51.6	--	--
Crop + Woodland + Fragmentation	--	--	51.6	--	--
Woodland + Fragmentation	--	--	58.1	--	--
Crop + Planted grassland + Woodland + Fragmentation	--	--	61.3	--	--
Crop + Planted grassland + Fragmentation	--	--	64.5	--	--
Crop + Prairie + Fragmentation	--	--	54.8	--	--
Averaged Prediction	--	--	51.6	--	--

Table I-5. Logistic regression models predicting hawk presence in North Dakota, 2004 and 2005, based on Richardson's ground squirrel or black-tailed prairie dogs colonies. Shown are number of model parameters (*K*), Akaike's Information Criterion adjusted for small sample sizes (AIC_c), change in AIC_c (ΔAIC_c), Akaike weights (w_i), significance of the Likelihood Ratio test, odds ratio with 95% Confidence Interval for number of colonies/township as a predictor of hawk presence, and results of the Hosmer-Lemeshow goodness-of-fit test.

Model	*K*	AIC	AIC_c	ΔAIC_c	w_i	Likelihood Ratio Test	Odds Ratio	95% Confidence Interval
FERRUGINOUS HAWK								
Landscape (n = 173)								
Colony presence	3	12.0	12.2	0.00	1.00	0.014	3.31	1.18 – 9.29
Local (n = 62)								
Colony size	3	41.0	41.8	0.00	0.84	0.047	1.12	0.95 – 1.32
RED-TAILED HAWK								
Landscape (n = 173)								
Colony presence	3	13.7	13.9	0.00	1.00	0.017	2.12	1.14 – 3.93

APPENDIX B

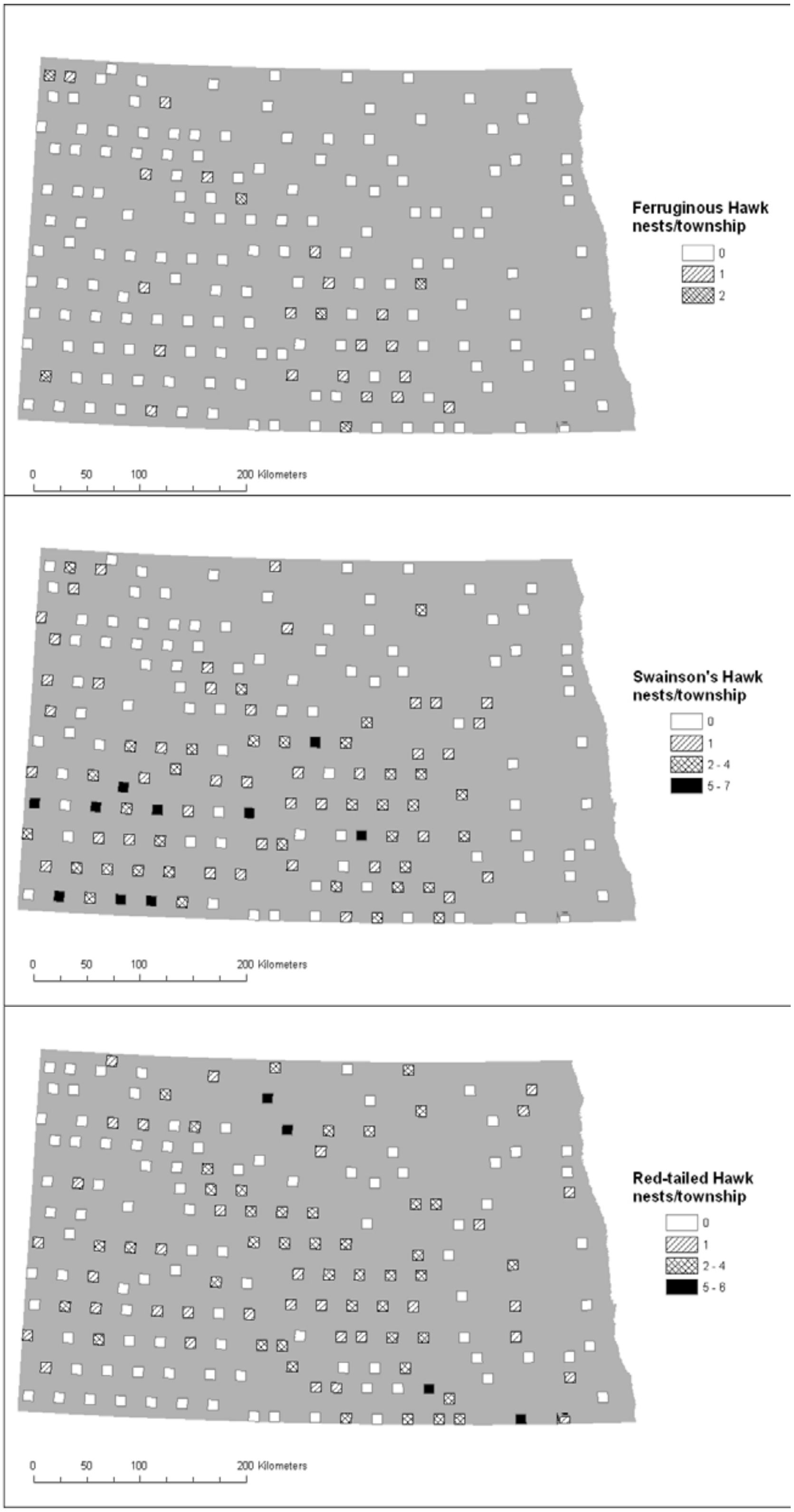
Chapter I Figures

FIGURE LEGENDS

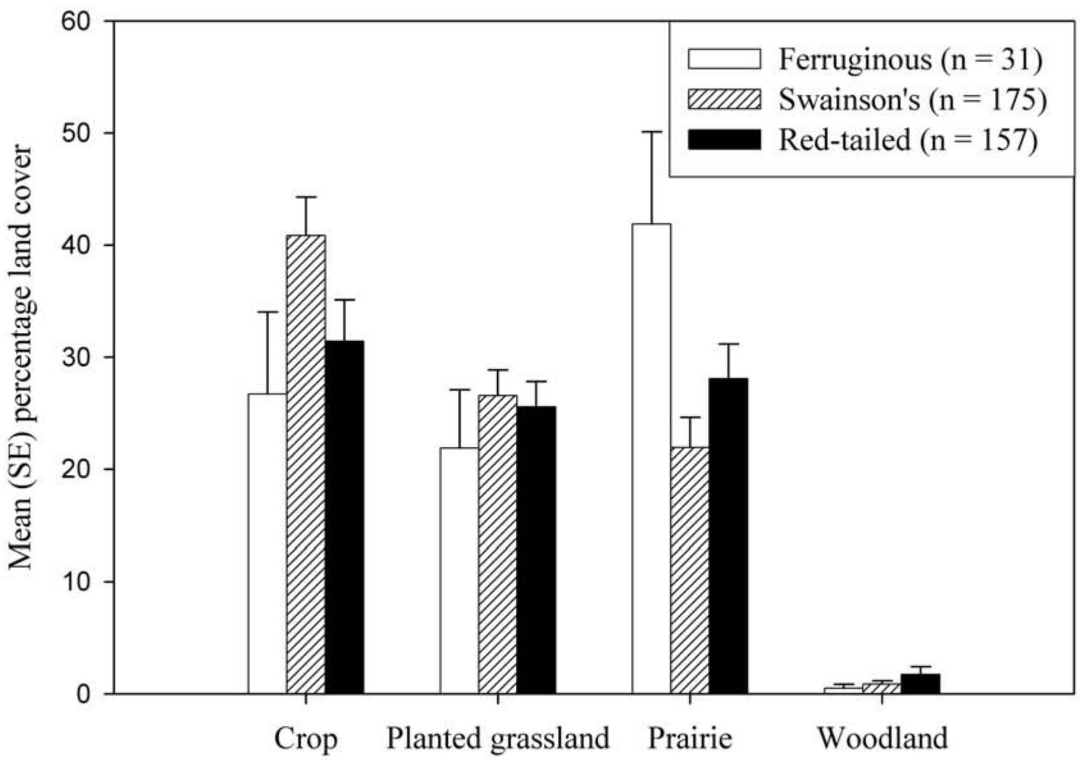
FIGURE I-1. Distribution and abundance of Ferruginous, Swainson's and Red-tailed Hawk nests located on surveyed townships in North Dakota, 2004 and 2005.

FIGURE I-2. Land cover within 1 km of Ferruginous, Swainson's, and Red-tailed Hawk nests in North Dakota, 2004 and 2005.

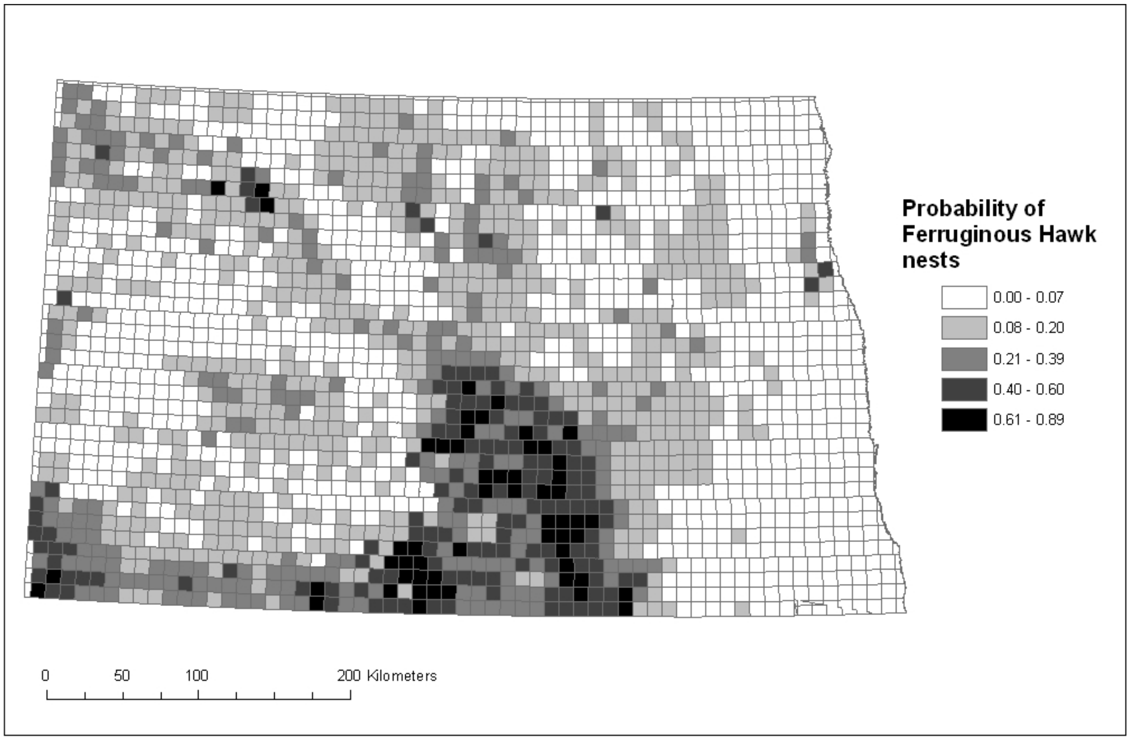
FIGURE I-3. Probabilities (0 – 1) of Ferruginous or Swainson's Hawk nests being on a township as predicted by landscape models.

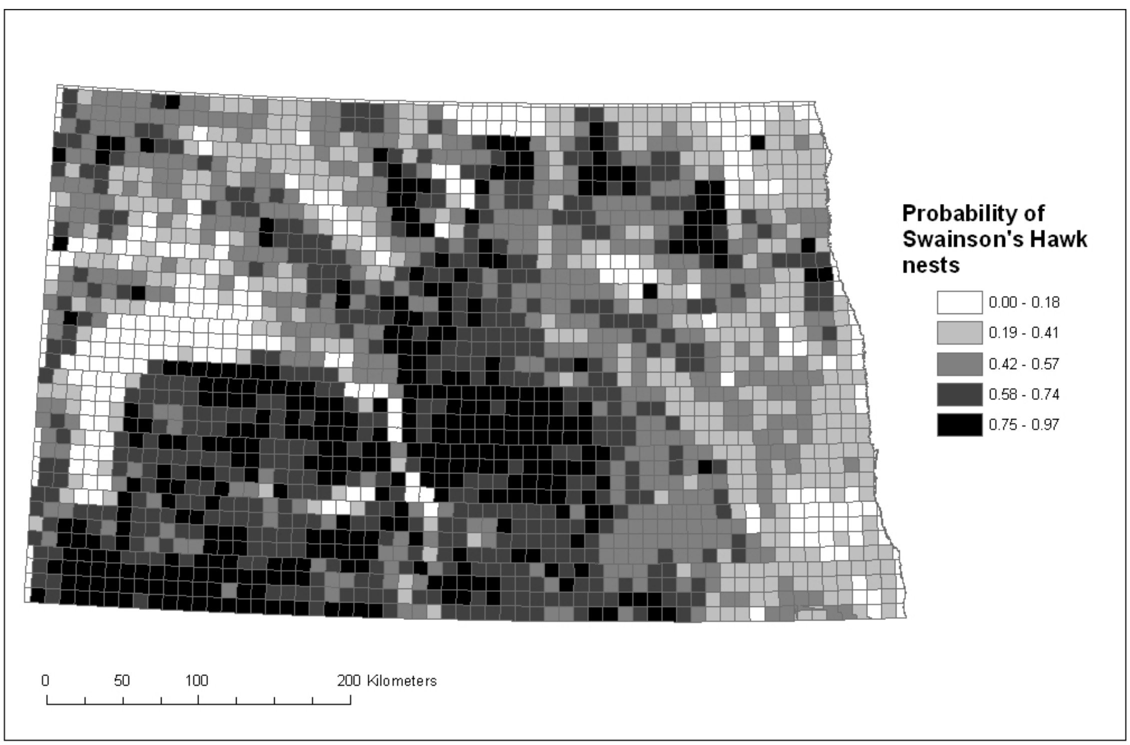


Ferruginous Hawk
nests/township
0
1
2
0
50
100
200 Kilometers
Swainson's Hawk
nests/township
0
1
2 - 4
5 - 7
0
50
100
200 Kilometers
Red-tailed Hawk
nests/township
0
1
2 - 4
5 - 8
0
50
100
200 Kilometers



60
50
40
30
20
10
0
Mean (SE) percentage land cover
Ferruginous (n = 31)
Swainson's (n = 175)
Red-tailed (n = 157)
Crop
Planted grassland
Prairie
Woodland


Probability of
Ferruginous Hawk
nests
0.00 - 0.07
0.08 - 0.20
0.21 - 0.39
0.40 - 0.60
0.61 - 0.89
0
50
100
200 Kilometers


Probability of
Swainson's Hawk
nests
0.00 - 0.18
0.19 - 0.41
0.42 - 0.57
0.58 - 0.74
0.75 - 0.97
0
50
100
200 Kilometers

APPENDIX C

Chapter II Tables

Table II-1. Logistic regression models ($\Delta AIC_c < 2$) that best distinguished between townships on which nests were detected and those in which no nests were detected in southwestern North Dakota, 2005. Shown are number of model parameters (*K*), Akaike's Information Criterion (AIC), AIC adjusted for small sample size (AIC_c), difference in AIC_c (ΔAIC_c), Akaike weights (w_i), and results of a Hosmer-Lemeshow goodness-of-fit test (χ^2 and *p*-value).

Model	*K*	AIC	AIC_c	ΔAIC_c	w_i	χ^2	*p*-value
Native grassland	3	60.4	60.9	0.0	0.13	13.1	0.108
Native grassland + wetland	4	60.0	61.0	0.0	0.13	9.76	0.282
Wetland	3	61.1	61.6	0.7	0.09	7.23	0.512
Native grassland + wetland + log[woodland]	3	60.9	62.3	1.4	0.07	3.28	0.916
Averaged Prediction						4.55	0.805

Table II-2. Correct classification tables for the subset of best models in southwestern North Dakota, 2005.

Model	% with nests correct	% without nests correct	% total correct
Native grassland	68.2	59.1	63.6
Native grassland + wetland	77.3	68.2	72.7
Wetland	59.1	63.6	61.4
Native grassland + wetland + log[woodland]	63.6	77.3	70.5
Averaged model	68.2	72.7	70.0

Table II-3. Relative importance and odds ratios (95% confidence interval) of habitat variables included in logistic regression models predicting detection of great horned owl nests on townships in southwestern North Dakota, 2005. Odds ratios were calculated for the global model of the subset of best models ($\Delta AIC_c < 2$).

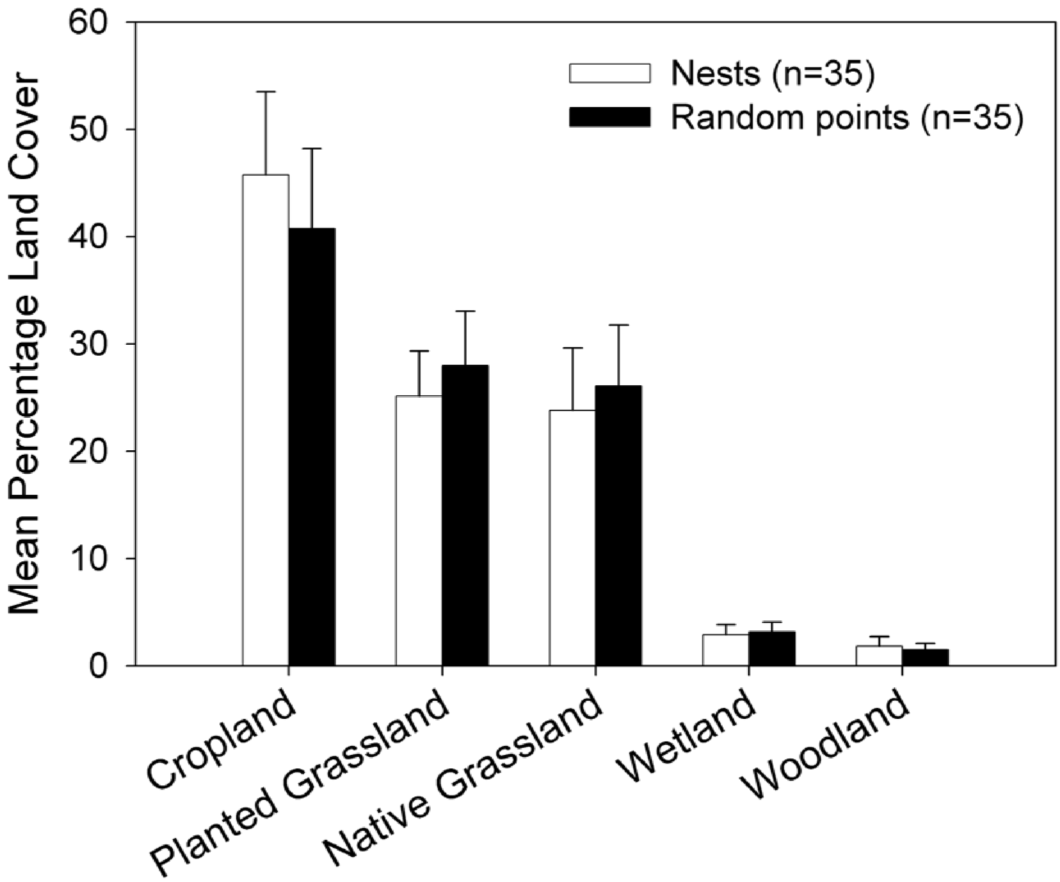
Variable	Relative importance	Odds ratio	95% Confidence Interval
Native grassland	0.61	0.95	0.90 - 1.00
Wetland	0.54	1.62	0.84 - 3.11
Log[Woodland]	0.40	2.18	0.52 - 9.23

APPENDIX D

Chapter II Figure

FIGURE LEGEND

FIGURE II-1. Land cover within 1.5 km of great horned owl nests and random points in southwestern North Dakota, 2005. Error bars indicate standard errors.


60
50
40
30
20
10
0
Mean Percentage Land Cover
Nests (n=35)
Random points (n=35)
Cropland
Planted Grassland
Native Grassland
Wetland
Woodland