FINAL REPORT

To the Minnesota Department of Natural Resources
Natural Heritage and Nongame Wildlife Program
Division of Ecological Sciences

11/7/2003

BALD EAGLE HABITATS AND RESPONSES TO HUMAN DISTURBANCE IN MINNESOTA

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ABSTRACT

Removal of the bald eagle (*Haliaeetus leucocephalus*) from the U.S. endangered and threatened species list has been proposed but delayed, pending consideration of habitat needs and the development of a population monitoring plan for the species. This project was conducted to evaluate the species' habitat use in the state of Minnesota where a large population of bald eagles nests across several different ecoregions and in the presence of varying levels of human activity.

A total of 24 habitat and human-presence variables were measured at a sample of 120 active nest sites and 162 random sites across the state. Variables were chosen *a priori* based on a review of previously published studies and the biology of the species. Variables included characteristics of the nest tree and surrounding vegetation, several physical habitat characteristics, and neighboring human presence, including buildings, roads, and land uses. Measurements within 100 m were conducted on site and within 1,000 m via remote sensing/aerial photography.

Variables were considered individually, that is, on a univariate basis, from a descriptive standpoint. However, numerous correlations exist among variables and, in some cases, the range of values for a given variable was so small or skewed as to not provide explanatory value. Hence, the number of variables (parameters) was reduced for proper inferential analyses. As recently recommended by others, "significance testing" for sampling-based field studies of this nature is no longer considered appropriate and was not used here (although it is likely that such techniques on a multivariate basis would have yielded similar outcomes). Rather, we used discriminant function analysis to compare nest sites versus random sites and information-theoretic model selection to compare nest productivity with nest site characteristics.

Discriminant analysis separated nest sites from random sites primarily on the basis of nest tree diameter and distance from shoreline. Productivity was not explained well by any of the variables we analyzed, that is, variation in productivity did not appear to depend on the observed variation among the independent variables. Thus, within the broad range of basic requirements (proximity to water bodies, substantial trees for nest support, and an adequate prey base), eagle habitat is highly variable and not specialized. We did not find either the habitat characteristics or the physical presence of humans per se to be very explanatory or limiting for the presence of bald eagles in Minnesota. As a consequence, we have few recommendations for habitat management beyond insuring the continued existence of large-diameter trees.

The rebound of the bald eagle population did not happen with concurrent changes (increases) in habitat. Rather, it appears that both the former population decline and the recent population increases resulted from demographic (reproduction and survival) factors that were probably not related to habitat or human presence per se. As long as the public is sympathetic toward eagles and their needs, and not harassing the birds or impacting eagle reproduction and survival, nesting bald eagles and humans appear to coexist satisfactorily in close proximity. Thus, it appears that the continued welfare of bald eagles depends most importantly on protection of the birds themselves, via continuing education of the public and enforcement of existing regulations. While eagle habitat should not be ignored, we find little evidence that it is a major concern based on these data. At least in the state of Minnesota, changes of habitat that would be sufficient to impact nesting bald eagles would probably alter the very nature of the state itself!

INTRODUCTION

Gains in nesting bald eagle populations over the last two decades have led to a proposed delisting of the bald eagle from the endangered and threatened species list (Fish & Wildlife Service 1999; Bednarz 2000). Bald eagles are currently protected in the United States by the Bald and Golden Eagle Protection Act, the Migratory Bird Treaty Act, the Lacey Act, and the Endangered and Threatened Species Act. A substantial amount of protection for eagle habitat would vanish under the current delisting proposal (Bednarz 2000; Barth 1999, letters from National Wildlife Federation to U.S.F.W.S.).

Concern about eagle habitat requirements expressed by both experts and the public resulted in delaying a change in the listing status of the bald eagle. Some groups recommended that de-listing not occur unless provisions for habitat protection were first implemented (Bednarz 2000; Barth 1999). However, bald eagle habitat has been difficult to define.

Over the last decade, bald eagles have shown the ability to successfully nest in many areas that were previously thought to be sub-optimal habitat (personal observation/corresp. with U. S. and Canadian eagle experts). For these reasons, re-evaluation of bald eagle nesting habitat was deemed necessary to determine the importance of habitat features within a context of varying levels of human presence. This project examined habitat use, including degrees of isolation from human activities, for breeding bald eagles in the state of Minnesota.

For an expanded introduction for this project, including a literature review, see Guinn and Grier (2002). Some of the information in that report to the USFWS has been transferred to this final report, however, most has not, in order to provide a concise final report. This final report focuses primarily on the results and conclusions, with just enough overlap from the previous report to provide support and continuity.

PROJECT OBJECTIVES

The objectives of this project were designed to evaluate habitat features and human presence features near bald eagle nests. The initial contractual objectives were to: (1) obtain 2001 productivity, habitat, and [potential] disturbance data for a sample of bald eagle nests in Minnesota; and (2) analyze the relationship between bald eagle productivity and habitat and human disturbance variables.

These objectives were subdivided into several tasks: Objective 1: (1) conduct survey flights at a subset of all eagle nests identified in 2000; (2) obtain remote sensing measurements for each sample nest and for other random sites; (3) obtain on-site habitat measurements for each sample nest. Objective 2: (1) conduct GIS-based spatial analysis of data; and (2) employ information-theory model selection analysis to investigate the relationship between productivity and habitat and [potential] disturbance features.

Added objectives included gathering data on available, potential habitat by taking identical measurements at a number of randomly selected habitat sites and eventually publishing these findings through a dissertation and professional journal articles.

MATERIALS AND METHODS

STUDY AREA

Minnesota offers a unique opportunity to study nesting bald eagles. The state has a large breeding population of bald eagles (n ~ 700 breeding pairs), four distinct habitat regions, varying amounts of human activity near nest sites, and a history of monitoring bald eagle populations. It was essential to examine a large number of nests in a large study area to eliminate potential biases that have resulted from past studies which investigated smaller land areas and/or had small sample sizes. The habitat available for eagles in the state varies dramatically between each of four ecoregions (Figure 1): the Laurentian Mixed Forest, the Eastern Broadleaf Forest, the Prairie Parkland, and the Tallgrass Aspen ecoregions (Henderson et al 1997).

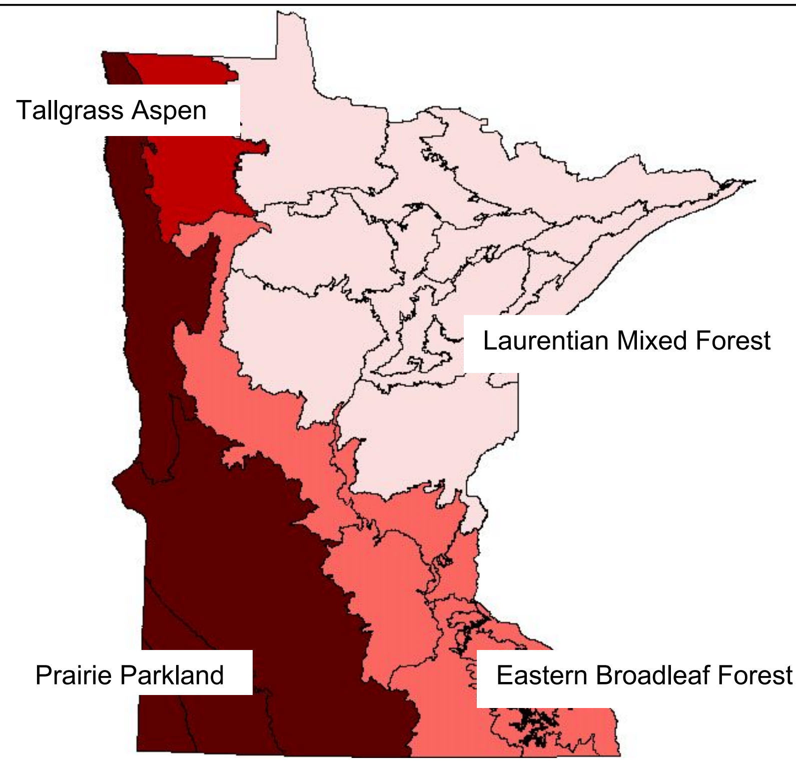

Figure 1. Geographic ecoregions found in Minnesota.

During the year 2000, The Minnesota Department of Natural Resources (Nongame Wildlife Program) sponsored the Millennium Bald Eagle Survey (M.B.E. Survey), an initiative to gain information and the locations of all known eagle nests in the state (Baker et al 2000). Sample nests (Fig. 2) for our study were selected from the group of all active nests observed during the M.B.E. Survey. For analytical purposes, active nests were stratified according to the four ecoregions. The vast majority of known eagle nests in Minnesota were located in the Eastern Broadleaf and Laurentian Mixed Forest ecoregions. Nests in the Prairie Parkland and Tallgrass Aspen ecoregions were relatively few in number. Therefore, the nests included in the sample set were every known, active nest in the Prairie Parkland (~40 nests) and the Tallgrass Aspen (~20 nests) ecoregions and a random *sample* of the total known, active nests in the Eastern Broadleaf (~60 nests) and Laurentian Mixed Forest (~60 nests) ecoregions.

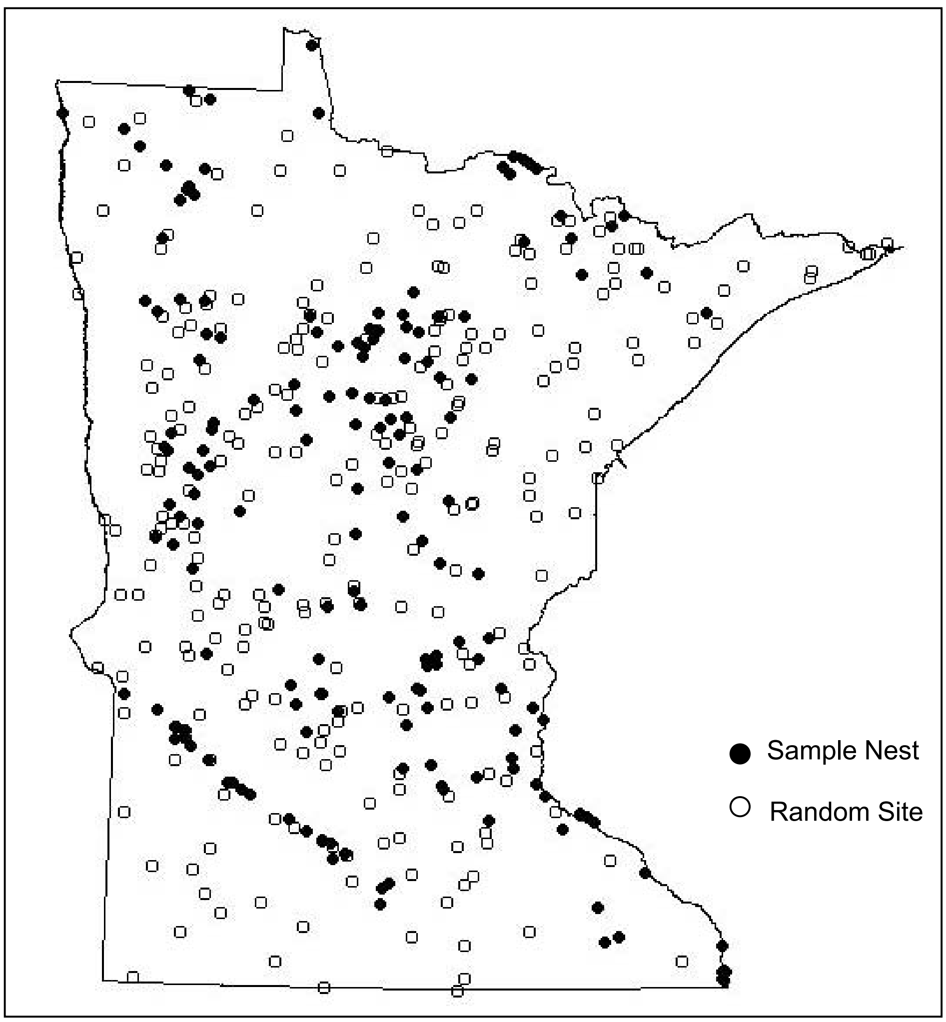

Figure 2. Sample nests and random sites selected in Minnesota.

Random Sites were selected based on two main criteria. Potential sites were (1) restricted to being within 1 km of a major water body, the range in which nearly all nests are known to occur (Corr 1974; Whitfield et al. 1974; Fraser et al. 1985; Gerrard et al. 1975; Livingston et al. 1990) and (2) required to include trees larger than 20 cm in diameter. To meet the first criterion, a grid of 1 km^2 cells was developed to overlay the entire state using ArcView GIS (ESRI 1999, Neuron Data, Inc.). A 1 km buffer (Figure 3) was then selected to border all major water bodies. Any grid cell that contained an amount of the buffered area (i.e. all areas of land within 1 km of a major body of water) was considered a potential random site. From that set, Random Sites were selected using ArcView Spatial Analysis Extension corresponding to the number of Nest Sites within each ecoregion. Each habitat cell was then examined manually and omitted if it did not include usable eagle nesting substrate (e.g. if the cell is entirely water or in the middle of a metropolitan area with no trees). The closest tree to the mid-point of the grid cell was designated to symbolize the "nest tree" of a Random Site. Habitat measurements were initiated from that "nest tree" point and all relevant measurements were taken.

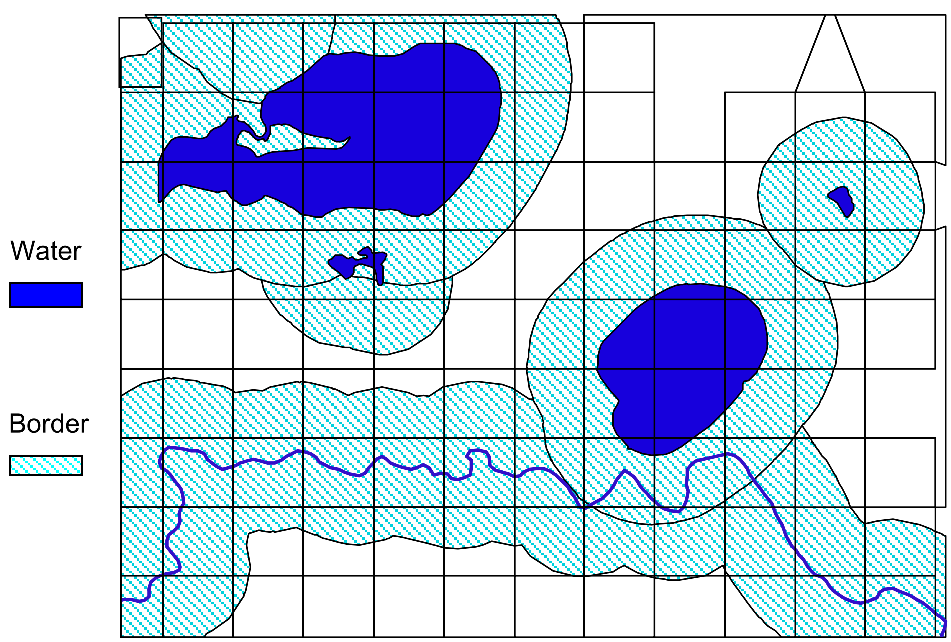

Figure 3. Water body buffer and grid system for selection of random sites.

SCALE OF PROJECT

Data concerning the habitat features of each Nest Site were gathered at two scales: a 100 m radius plot (primary zone) and a 1,000 m radius plot (secondary zone) (Fig. 4). Several habitat and human presence variables (discussed later) were measured at each Nest Site. Primary zone evaluation consisted predominantly of measurements of trees within 100 m of nest trees. Analysis of the larger secondary zone consisted of evaluating land-use activities and human presence using aerial photographs and land-use maps (MNDNR Data Deli Online GIS Data) of each selected Nest Site and Random Site.

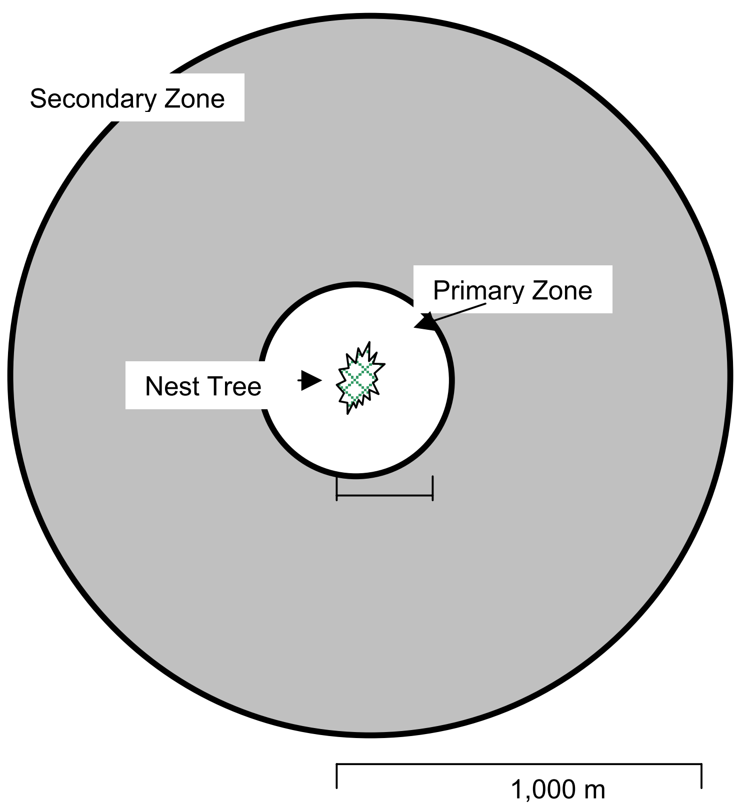

Figure 4. Scales for evaluation of bald eagle nest site habitat.

At each Nest Site and Random Site, measurements were taken within a total of four-10 m radius circular plots (Figure 5). The initial plot used the nest tree (or the mid-point of a Random Site) as the center of the circular plot. The other three plots were chosen at a random compass

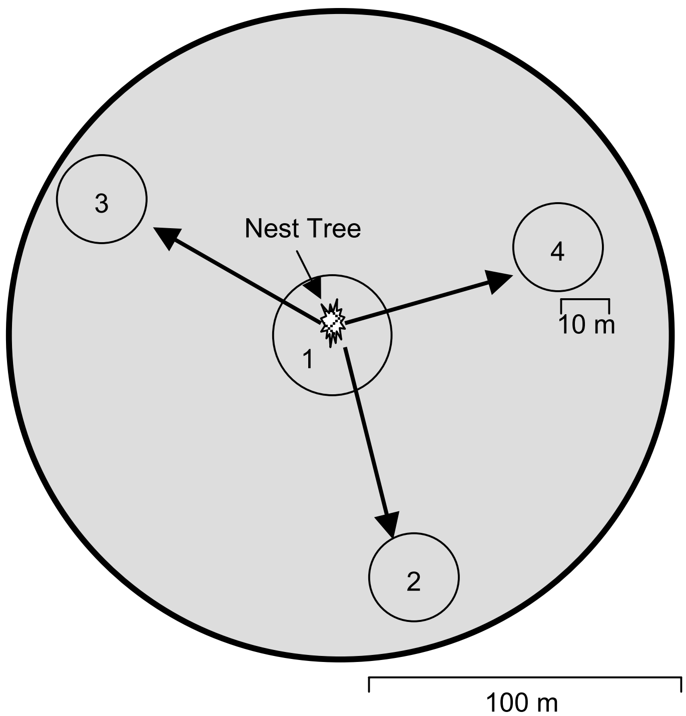

Figure 5: Sampling strategy for measurements of the primary zone. Stand measurements were taken at additional sites (numbered 1, 2, 3 and 4). *Not to scale.

direction and random distance within 100 m of the nest tree. Compass degrees were selected randomly using a random numbers table to determine the direction of each additional site from the nest tree. Distance was constrained to >10 m (to avoid overlapping with site #1 measurements) and <100 m (the limit of primary zone evaluation). Measurements taken within each primary zone are listed in Table 1.

TABLE 1: Measurements at Primary Zone.

FEATURE	DESCRIPTION
Latitude & Longitude	Measured at the base of the nest tree or the middle point of random habitat sites using a hand-held Garmin GPS 3+. Waypoint averaging of locations used to accurately determine the location of each site.
Ground to nest	Measurement of distance from the ground at the base of the nest tree to the bottom of the nest. Measurement taken with Brunton Survey Master Clinometer to nearest foot and converted to meters.
Nest to top	Measurement of distance from the top of the nest to the top of the nest tree. Measurement taken with clinometer to nearest foot and converted to meters.
Species	Species of nest tree.
Height	Measurement of the distance from the base of the tree to the top of the highest branch. Measurement taken with clinometer to nearest foot and converted to meters.
Diameter at Breast Height	Diameter of tree at 1.4 m from the ground. Measured in centimeters using Ben Meadows Company 5 m/160 cm Diameter Tape
Canopy Elevation	Average height measurement of overall canopy in area taken measured using a Bruno Clinometer. Comments on slope of terrain and height of canopy compared to nest and nest tree.
Nest Site	Measurements are taken of trees greater than 20 cm dbh within a 10m radius of the nest tree. Measurements taken of each tree are: species, height, and Diameter at breast height, as above.
Additional Sites	Additional sites are chosen at a random distance and direction from the nest tree. Measurements are taken of trees greater than 20 cm dbh within a 10 m radius extending from the random point. Measurements taken of each tree are: species, height, and diameter at breast height.
Human Presence	Comments on location, size, distance, and type of human activity in area.
Distance to Active Nest	Distance to nearest known or visible active nest.
Shoreline Distance	Distance of closest known or visible shoreline.
Shoreline Description	Comments on closest visible shoreline.

Human presence may effect bald eagles at greater distances than 100 m (Fraser et al. 1985; Anthony and Isaacs 1989). Measuring human presence within 1,000 m provides a method for a thorough evaluation of potential disturbance factors. Human presence at Nest and Random Sites were evaluated utilizing ArcView GIS to examine aerial photographs and land-use maps

(MNDNR Data Deli Online GIS data). Factors evaluated within the secondary zone are listed in Table 2.

TABLE 2: Measurements at the Secondary Zone.

FEATURE	DESCRIPTION
Distance to Forest	Distance (m) to nearest forested land as shown on land-use maps and/or aerial photographs..
Distance to Water	Distance (m) to nearest body of water as shown on land-use maps and/or aerial photographs.
Distance to Bog	Distance (m) to nearest bog, marsh, fen, or swamp as shown on land-use map.
Distance to Grassland	Distance (m) to nearest grassland as shown on land-use maps or aerial photographs.
Distance to Cultivated Field	Distance (m) to nearest cultivated field as shown on land-use maps or aerial Photographs.
Distance to Roads	Distance (m) to nearest road as shown on aerial photographs.
Distance to Structures	Distance (m) to nearest structures as shown on aerial photographs.
Distance to Brushland	Distance (m) to Brushland as shown on land-use maps and aerial photographs.
Density of Roads	Number of roads within 1000 m as shown on aerial photographs.
Density of Structures	Number of structures within 1000 m as shown on aerial photographs.
Density of Land-use Types	Number of land-use types within 1000 m as shown on land-use maps.

DATA ANALYSIS

Data analysis was conducted using PC SAS (Version 8.02, SAS Institute, Inc.) and JMP (Version 5.0.1a, SAS Institute, Inc.). Descriptive statistics were used to examine species composition, tree diameter, tree height, and distance measurements (Tables 6-9). Multivariate analyses were essential to investigate the simultaneous effects of habitat and human presence features on productivity. Discriminant Function Analysis (DFA) (McGarigal et al. 2000) was used to compare Nest Sites to Random Sites. DFA provides a method to determine if habitat variables drive a separation between Nest Sites and Random Sites. Information-theoretic model selection (Burnham and Anderson 2002) was used to select the most parsimonious models to describe the relationship between habitat features and the productivity of each Nest Site. The use of these complex and relatively recent statistical techniques was greatly assisted by consultation and advising from Wesley E. Newton, Supervisory Statistician, U. S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center and Mario Biondini, Animal Range Sciences Department, North Dakota State University.

The measured variables (Tables 1 and 2) were selected *a priori* based on a thorough review of the literature (Mathisen 1963, Andrew and Mosher 1982, Stalmaster 1987, Anthony and Isaacs 1989, Livingston et al. 1990) and our own applied experience with nesting bald eagle populations (JWG-for over 40 years with several hundred nests in Ontario). Additional screening of variables to exclude from our model sets was accomplished by testing for correlation and examining the distribution of each explanatory variable. Several variables were highly correlated and others showed highly skewed distributions with little range or spread of values, thus, providing little information. In the former case, a variable that explained another explanatory variable was eliminated from the model set. In the latter case, the variable was transformed using a $\log_e$ transformation, in an attempt to provide a distribution with a more useful spread, to better permit the detection of any possible effects. If transformation was unsuccessful in providing a less-skewed distribution, the variable was considered unlikely to provide any explanatory value and eliminated from consideration. We used these techniques to select the final variables to include in our models.

The full data set (including data for both Nest Sites and Random Sites) was used to determine differences between Nest Sites and Random Sites. Five of the original variables were eliminated based on their lack of biological importance and/or to avoid overlapping variables. In addition, five were eliminated due to inappropriate distributions. Four more were eliminated due to being highly correlated with other variables. A categorical variable, "NestorRandom", was used as the response variable for determination of a discriminant function. A discriminant analysis of the final variable set (Table 3) was used to discriminate between Nest Sites and Random Sites.

A validation set was established, setting aside 20% of the data as a Validation Set. The Exploratory Set was used to discriminate between Nest and Random Sites. Using the most important vectors from the exploratory discriminant analysis, the Validation Set was used to evaluate the discriminant function. The sites were analyzed to examine the percent of sites that are mis-classified by the discriminant function. If the discriminant function is a good approximator of the data, the mis-classification percentage should be relatively low.

Table 3. Variables Chosen for Discriminant Analysis.

Variable	**Description**
Stand Height	Height of Trees within Primary Zone
LnDBH	Natural Log of Diameter of Nest Trees and Mid-point Trees
Ln DRoad	Natural Log of Distance to Nearest Road
LnDUrban	Natural Log of Distance to Nearest Urban Area
LnDEdge	Natural Log of Distance to Nearest Terrestrial Edge
LnDNest	Natural Log of Distance to Nearest Nest
LnDWater	Natural Log of Distance to Shoreline
Land1000	Density of Land-use Types 1000 m
Houses1000	Density of Houses within 1000 m

The productivity-modeling process utilized data from only the Nest Sites, therefore the variables selected are slightly different. For modeling productivity, five of the original 23 measured variables were eliminated by our first *a priori* screening process. These variables were removed based on lack of potential biological significance and to avoid overlapping variables. In addition, seven variables were screened from our set due to inappropriate correlation and/or distribution concerns. The remaining variables (Table 4) were examined using an initial variable-interaction technique. The 11 variables and each of their two-way comparisons were examined using SAS PROC REG to determine Mallow's Selection Criterion (C_p) to identify the best fitting interactions. The "best" interactions were then analyzed by SAS PROC GENMOD to determine the log-likelihood each of model. Next the log-likelihood values were used to calculate Akaike's Information Criterion (AIC_c) values and the associated Akaike weights (W_i) to arrive at the best approximating models for the data set (Burnham and Anderson 2002).

Table 4. Variables Chosen for Initial Interaction Assessment by Mallow's C_p.

Variable	Description
LnNtoTop	Log_e Distance from Nest to Top of Tree
LnDWater	Log_e Distance to Shoreline
LnDBH	Log_e Nest Tree Diameter at Breast Height
LnStandDBH	Log_e Average Diameter at Breast Height of Trees Measured within 100 m of the Nest Tree
Nland1000	Number of Land-use Types within 1000 m
Nroads1000	Number of Roads within 1000 m
LnDHouse	Log_e Distance to Nearest Structure
Durban	Distance to Nearest Urban Area (designated by city streets)
LnDCultv	Log_e Distance to Nearest Cultivated Field
LnDGrass	Log_e Distance to Nearest Grassland
LnDActive	Log_e Distance to Nearest Active Nest

In the exploratory analysis, 80% of the data (Exploration Set) was utilized in the model-building process. The remaining 20% of the data (Validation Set) was set aside to cross validate the models. The Validation Set was chosen by selecting sites from both the extremes and the median portions of the data to enhance the evaluation of the chosen models (analogous to designing treatments in a controlled experiment). The Root Mean Square Error (RMSE) was calculated and evaluated as a comparison between the two sets. The RMSE is a single standard deviation for multiple variables in a model, estimating the common within-group standard deviation.

The response variable for these models was the productivity of the eagles at individual nests. Two years of productivity data, 2000 and 2001, were obtained. For each year, productivity ratings were determined (Table 5). A final "Productivity Rank" for each Nest Site were obtained by summing the annual productivity ratings for each nest. The result of productivity ranking is a normally-distributed response variable on a scale from 2 to 10.

Table 5. Annual Productivity Rating Strategy for Bald Eagles.

Annual Productivity Rating	Description
1	Nest Not Active
2	Nest Active, Productivity = 0 chicks fledged
3	Nest Active, Productivity = 1 chick fledged
4	Nest Active, Productivity = 2 chicks fledged
5	Nest Active, Productivity = 3 chicks fledged

IMPORTANT NOTE: *Although studies of this type have traditionally been associated with significance testing and p-values (e.g., $p > 0.05$), we agree D. H. Johnson (1999) and D. R.*

Anderson et al. (2000) that "significance values" are not appropriate for field studies of this nature. No significance values are included in this report. Rather, a different and relatively newer paradigm of data analysis, Information-theoretic Model Selection, has been incorporated.

RESULTS

NEST SITE DESCRIPTIONS

Eleven tree species and one man-made structure were used by bald eagles as nesting substrate (Table 6). Our sample nests were most frequently located in cottonwood trees. This species is particularly important in the Eastern Broadleaf and Prairie Parkland Ecoregions (Table 7). Red and white pines were also well represented as nest trees, especially in the Laurentian Mixed Forest Ecoregion, which is consistent with earlier reports of their importance as eagle nesting trees (Fraser 1981; Mathisen 1963). However other species, such as cottonwoods in the Prairie Parkland ecoregion and quaking aspen in the Tallgrass Aspen ecoregion, were used with no negative effects on productivity (Table 7). On average, nests were located in the upper 20% of the nest tree (Table 6).

Table 6. Mean Characteristics of Bald Eagle Nests (n = 115) in Minnesota.

Tree Species	n	Percent Total Nest Trees	Tree DBH (cm) Mean	SE	Tree Height (m) Mean	SE	Nest Height (m) Mean	SE
Cottonwood	39	32.5	59.95	4.83	24.66	0.76	19.58	0.72
White Pine	35	29.2	45.94	2.86	26.21	0.99	21.87	0.92
Quaking Aspen	17	14.2	49.4	15.31	21.84	1.55	18.98	1.41
Red Pine	10	8.3	43.75	8.29	25.73	1.12	21.66	1.41
Silver Maple	4	3.3	55.7	26.01	17.84	0.83	14.70	0.93
Slippery Elm	4	3.3	45.35	9.99	17.68	1.23	13.79	1.83
Green Ash	3	2.5	54.5	17.75	16.51	2.90	13.56	3.69
White Oak	3	2.5	45.94	2.86	23.83	5.08	17.79	4.11
White Poplar	2	1.7	43.8	7.6	21.80	1.37	19.65	1.37
Paper Birch	1	0.8	36.2	--	23.17	--	17.37	--
Sugar Maple	1	0.8	41.3	--	25.30	--	23.77	--
Steel	1	0.8	54	--	16.62	--	16.61	--
All Nest Structures	**120**	**--**	**51.56**	**2.97**	**23.99**	**0.52**	**19.78**	**0.48**

Table 7. Mean Productivity Ranks (SE) of Bald Eagle Nests in Various Tree Types and Ecoregions.

Tree Category	Eastern Broadleaf	Laurentian Mixed	Prairie Parkland	Tallgrass Aspen	TOTAL
Coniferous	7.2 (0.58) n = 5	6.0 (0.26) n = 37	6.5 (2.5) n = 2	6.0 (-) n = 1	6.2 (0.24) n = 45
Cottonwood	6.0 (0.37) n = 19	--	5.9 (0.33) n = 17	5.7 (1.45) n = 3	6.0 (0.24) n = 39
Quaking Aspen	7.0 (0.58) n = 3	6.3 (0.61) n = 6	--	7.1 (0.52) n = 8	6.8 (0.33) n = 17
Other Deciduous	6.0 (0.82) n = 4	6.5 (0.43) n = 6	5.7 (0.61) n = 6	6.5 (0.5) n = 2	6.1 (0.3) n = 18
Transmission Lines	10 (-) n = 1	--	--	--	--
TOTAL	6.4 (0.29) n = 32	6.1 (0.22) n = 49	5.9 (0.3) n = 25	6.6 (0.43) n = 14	**6.2 (0.14) n = 120**

On average, nest trees were larger in diameter and height than nest stand trees (i.e. trees in the additional 4-10 m^2 plots) (Table 8). Similarly, nest trees were larger in diameter and height than mid-point trees of Random Sites (Table 8). The number of species observed was similar between nest trees (12 species) and mid-point trees (16 species), however their frequency distributions were much different (Table 7). Nest Sites were closer to water and closer to other active nests than Random Sites (Table 9). Human-presence variables showed minimal differences between Nest and Random Sites with a large amount of variation between sites. Nest trees were the tallest trees measured at only 65 of 120 (54.2%) sites. On the other hand, the nest tree was larger in diameter at 97 of 120 (80.1%) sites.

Table 8. Characteristics of Nest Trees, Random Sites, and their associated stand trees.

Variable or Tree Species	Nest Sites (n =115)		Random Sites (n = 166)		All Sites Combined
	Nest Tree	Stand	Midpt.	Stand	
Mean Diameter (SE)	51.56 (2.97)	31.41 (0.83)	30.33 (0.80)	27.30 (0.56)	**34.22 (0.99)**
Mean Height (SE)	23.99 (0.52)	18.55 (0.39)	17.22 (0.34)	15.97 (0.29)	**18.59 (0.30)**
Species (% of total species)	12 (31.0)	30 (78.9)	16 (42.1)	29 (76.3)	**38**
Number of Trees (% of total trees)	120 (5.1)	865 (36.8)	162 (6.9)	1206 (51.3)	**2353**

On average, Nest Sites were closer than 160 m to water (Table 9). This is substantially closer than reported distances of approximately 600 m in the Chippewa National Forest area (Fraser 1981). Fraser (1981) hypothesized that eagles avoided shoreline development in these areas, therefore, being forced to nest farther away from the shoreline. Nests were not located in areas devoid of human presence (Table 9). Nests were further from the nearest house and slightly further from the nearest road than random sites, but the density of houses was greater for Nest Sites than Random Sites and the distance to the nearest urban area was less for nests. Overall there was no clear relationship between nest sites and human presence. Large continuous forests were not necessary for nesting eagles in Minnesota, as Nest Sites were located closer to a terrestrial edge (Table 9).

Table 9. Mean Values for Variables Measured at Bald Eagle Nest Sites and Random Sites in Minnesota.

Habitat/ Human Presence Variable	Nest Sites (n =115) Mean (SE)	Random Sites (n = 166) Mean (SE)
Distance (m) to Nearest Active Nest	8876.58 (813.74)	16887.09 (1476.58)
Distance (m) to Water	159.28 (27.57)	511.98 (22.78)
Distance (m) to Nearest House	6147.60 (1455.98)	1834.27 (375.26)
Distance (m) to Nearest Road	668.88 (170.20)	558.14 (116.99)
Number of Land-use Types in 1000m	5.47 (0.12)	5.20 (0.11)
Number of Roads in 1000 m	4.58 (0.34)	5.41 (0.43)
Houses in 1000 m	12.42 (2.93)	8.87 (2.09)
Distance (m) to Urban Area	9752.03 (710.90)	11417.07 (832.52)
Distance (m) to Cultivated Fields	6128.97 (1325.73)	11043.70 (1707.08)
Distance to Terrestrial Edge	413.68 (66.04)	722.01 (184.92)

NEST SITES VS. RANDOM SITES COMPARISON

Univariate comparisons between ecoregions and Nest Sites versus Random Sites are shown in Figures 6-15. Tree height (Fig. 6) might seem important at first glance, but it is confounded with tree diameter and is misleading. This issue will be addressed later. Tree diameter (Fig. 7) and distance to water (Fig. 12) show the only valid univariate differences between Nest Sites and Random Sites that would show statistical significance overall (if that were considered a valid approach; see note on p. 13).

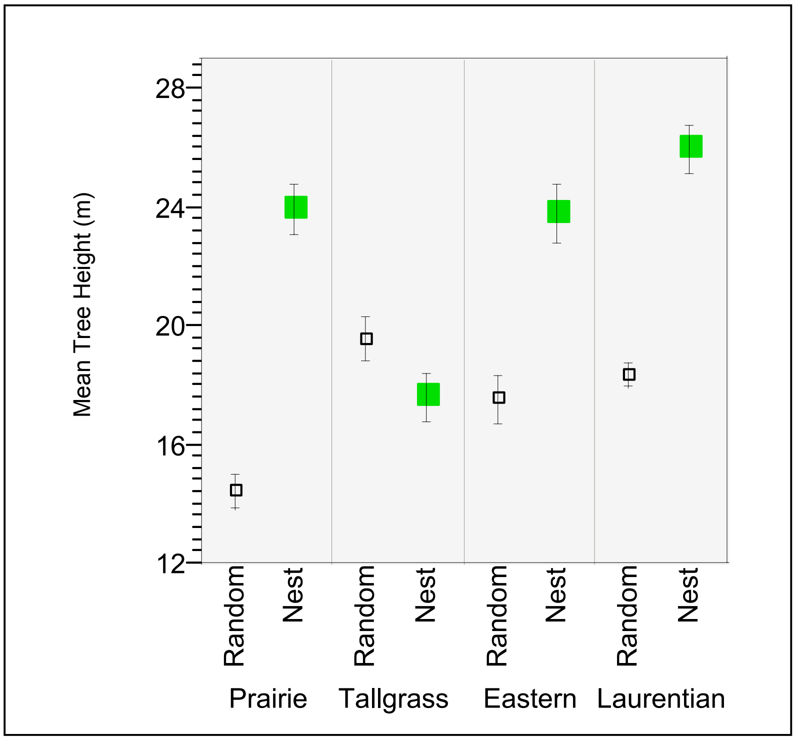

Figure 6. Tree height at Nest Sites and Random Sites within ecoregions.

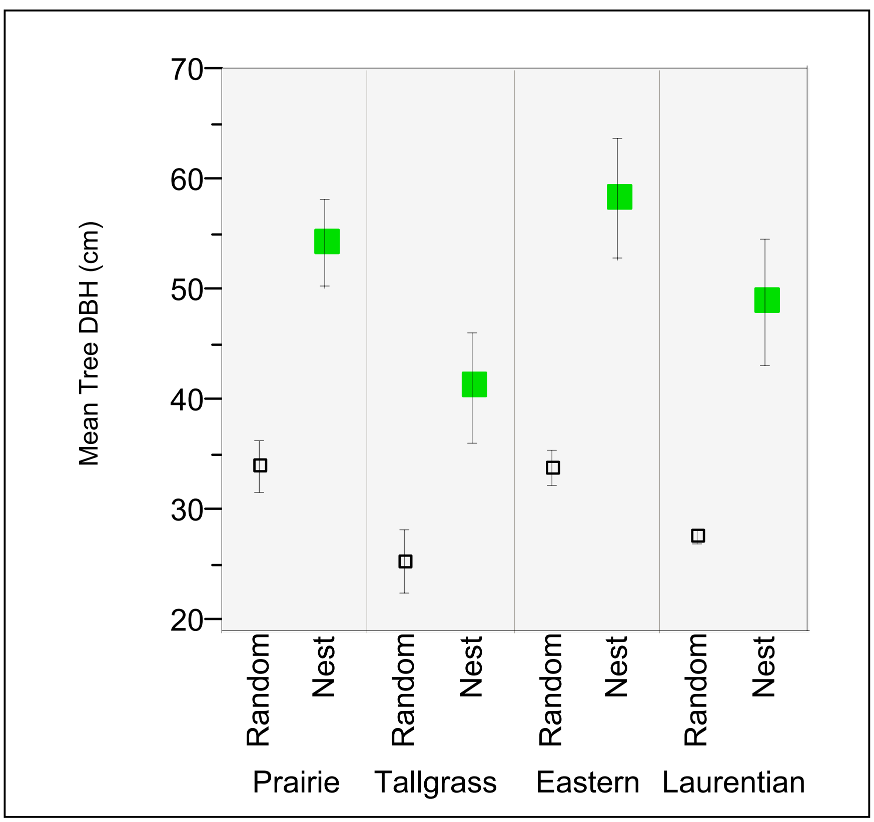

Figure 7. Tree diameter at Nest Sites and Random Sites within ecoregions.

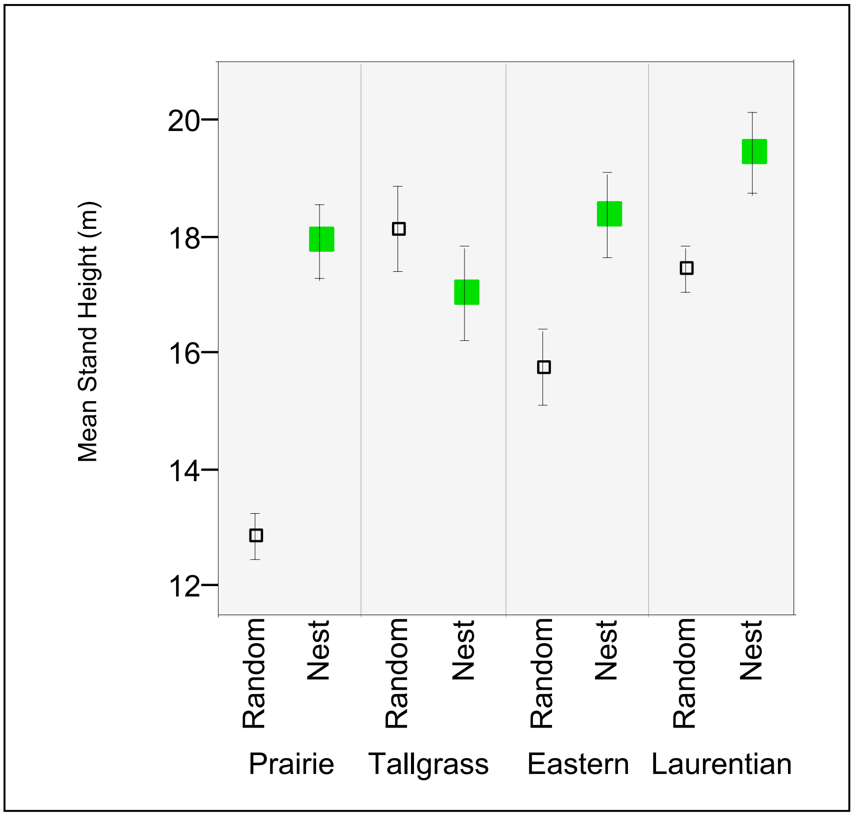

Figure 8. Height of stand trees at Nest Sites and Random Sites within ecoregions.

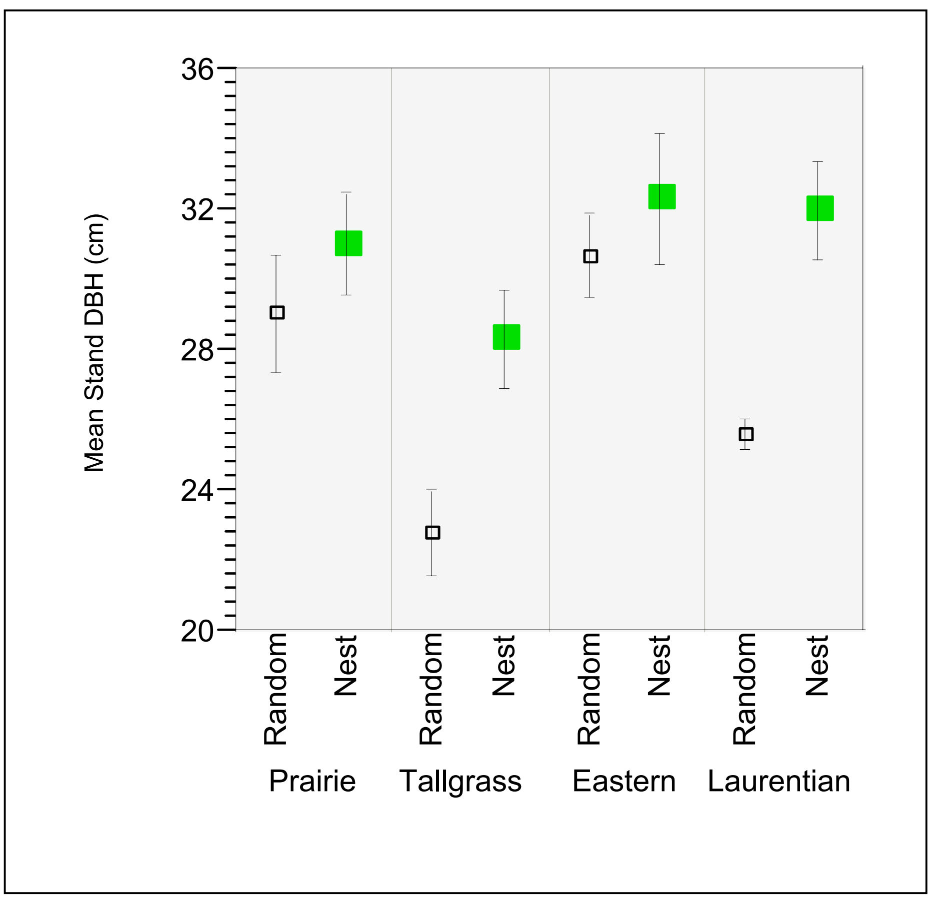

Figure 9. Diameter of stand trees at Nest Sites and Random Sites within ecoregions.

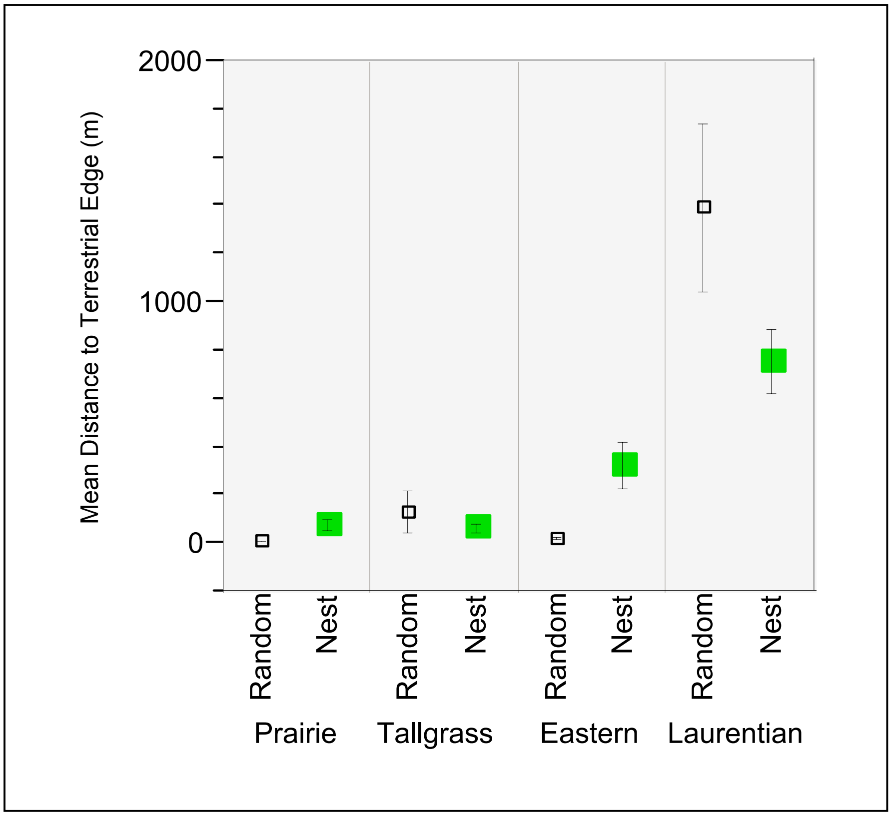

Figure 10. Distance to terrestrial edge at Nest Sites and Random Sites within ecoregions.

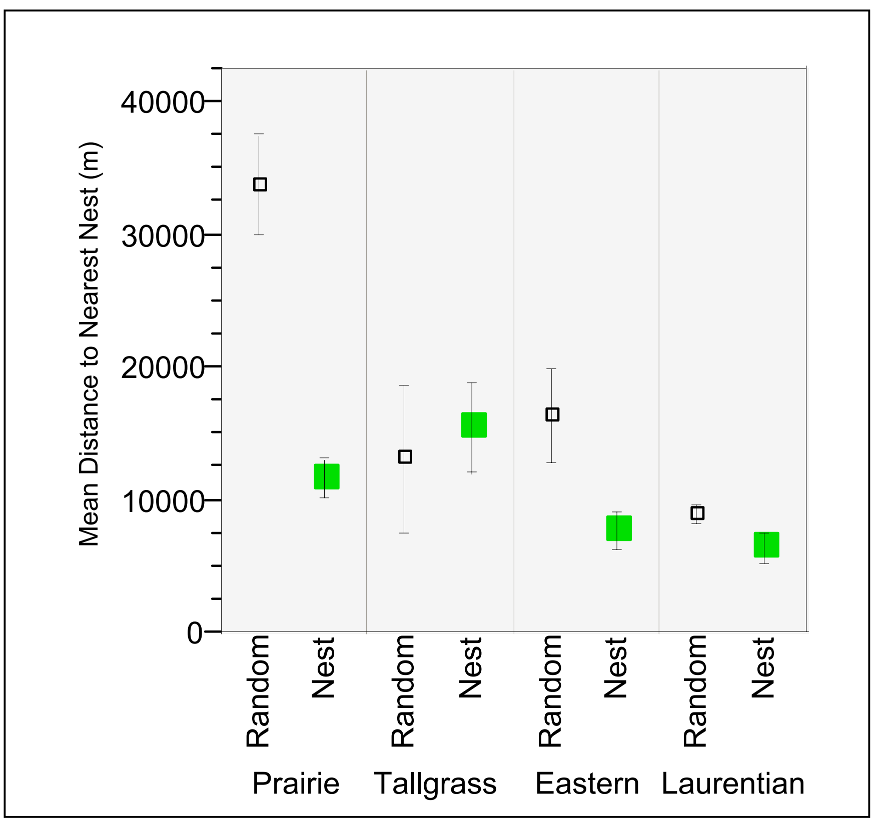

Figure 11. Distance to nearest active nest at Nest Sites and Random Sites within ecoregions.

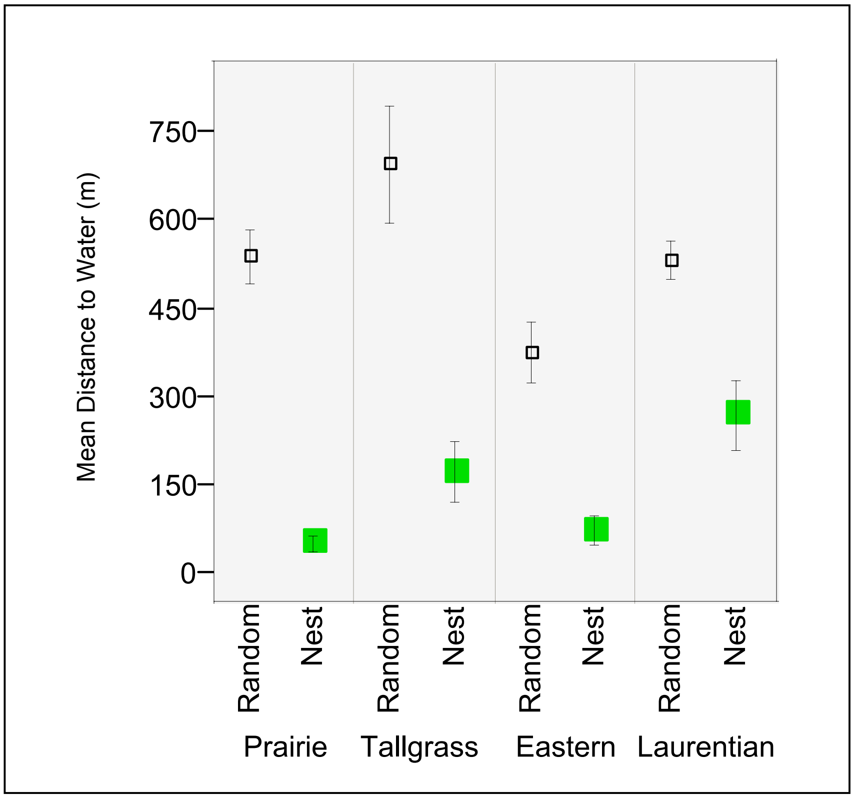

Figure 12. Distance to shoreline at Nest Sites and Random Sites within ecoregions.

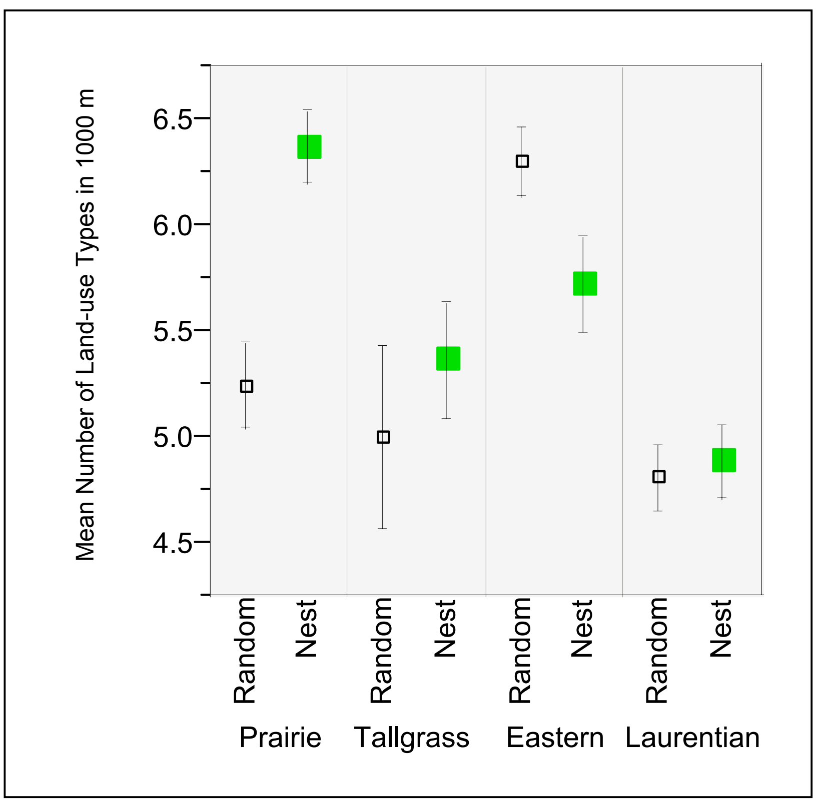

Figure 13. Density of land-use types at Nest Sites and Random Sites within ecoregions.

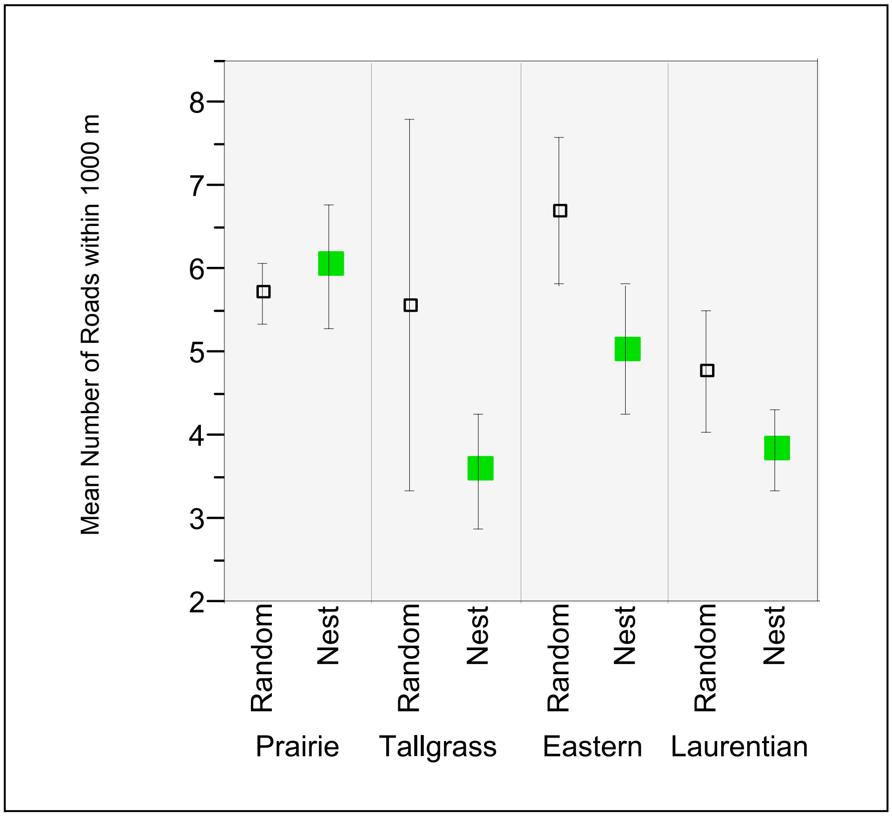

Figure 14. Density of roads at Nest Sites and Random Sites within ecoregions.

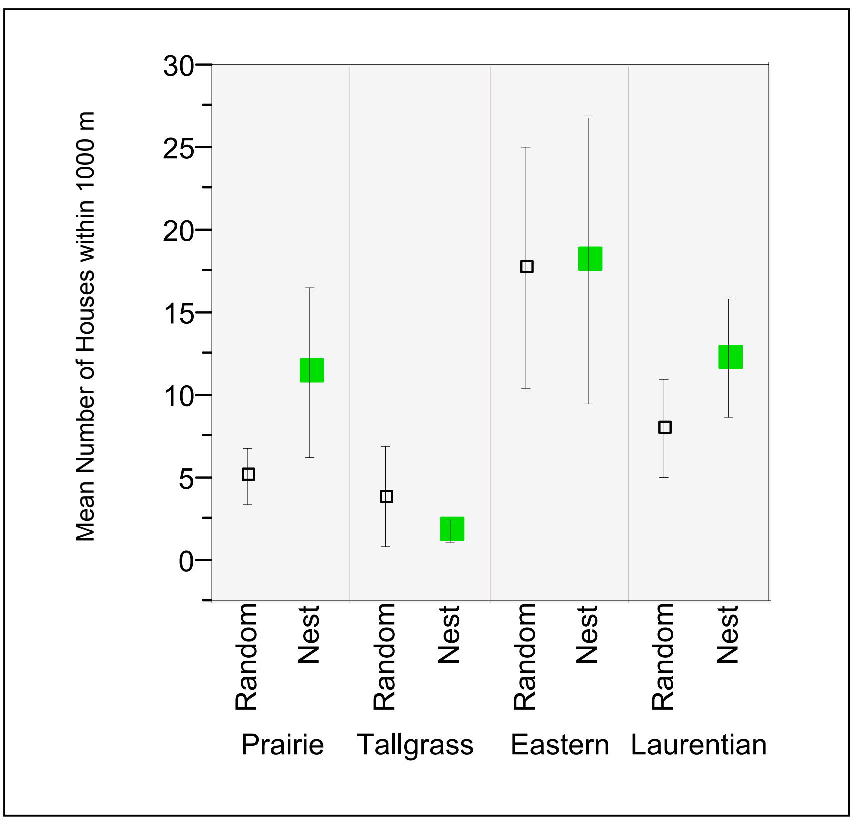

Figure 15. Density of houses at Nest Sites and Random Sites within ecoregions.

Multivariate analyses were used to examine correlations between habitat variables and productivity and to determine multi-dimensional differences between Nest Sites and Random Sites. Discriminant Function Analysis (DFA) is a technique for describing the differences between well-defined groups, in this case Nest Sites and Random Sites. DFA is comprised of both descriptive and predictive sections, making it ideal for examining separations in data sets containing a categorical grouping variable such as nesting activity. The measured variables were rigorously screened before being selected as potential discriminating variables. The measured variables and their reasons for acceptance or removal from the Discriminant Analysis is shown in Table 5.

Table 10. Acceptance or Exclusion Status of Variables for Discriminant Analysis.

VARIABLE	ACCEPTANCE STATUS FOR DFA
Species	Excluded: multiple correlations
Nest Tree Height	Excluded: multiple correlations
Nest Tree Diameter	Accepted with $\log_e$ transformation
Canopy Elevation	Excluded: difficult to measure in the field
Stand Diameter	Excluded: multiple correlations
Stand Height	Accepted with $\log_e$ transformation
Distance to Active Nest	Accepted with $\log_e$ transformation
Shoreline Distance	Accepted with $\log_e$ transformation
Distance to Roads	Accepted with $\log_e$ transformation
Density of Roads	Excluded: multiple correlations
Distance to House	Excluded: multiple correlations
Density of Houses	Accepted
Distance to Urban	Accepted
Distance to Forest	Excluded: distribution showed few extreme values
Distance to Grassland	Accepted with $\log_e$ transformation: Combined to form Distance to Terrestrial Edge
Distance to Bog	Excluded: distribution showed few extreme values
Distance to Brushland	Accepted with $\log_e$ transformation: Combined to form Distance to Terrestrial Edge
Distance to Cultivation	Accepted with $\log_e$ transformation: Combined to form Distance to Terrestrial Edge
Density of Landuse Types	Accepted

Discrimination between Nest Sites and Random Sites using the selected explanatory variables (Table 3) was possible (Figure 16). Nest Sites and Random Sites are clearly represented as separate, non-overlapping circles. The relationship between variables is represented by the length and direction of the eigenvectors. A strong association existed between Nest Sites and trees with large diameters. In other words, diameter of trees (also see Table 8 and cf. Fig. 7) was a discriminating variable with larger trees observed at nest sites. A strong association was also observed for Random Sites and greater distances to shorelines. Other variables including the distance to the nearest terrestrial edge and the height of stand trees had weak associations with nest sites.

The Validation Set was analyzed to evaluate the utility of the discriminant function. The discriminant function was successful in discriminating between Nest Sites and Random Sites (Figs. 16, 17). Discriminant Analysis was then conducted utilizing only the two most important variables (Tree Diameter and Distance to Water). These two variables were nearly as successful in discriminating between Nest Sites and Random Sites (Fig. 18) as the full model (Fig. 16). The most important differences between Nest Sites and Random Sites are diameter of trees and distance from the shoreline.

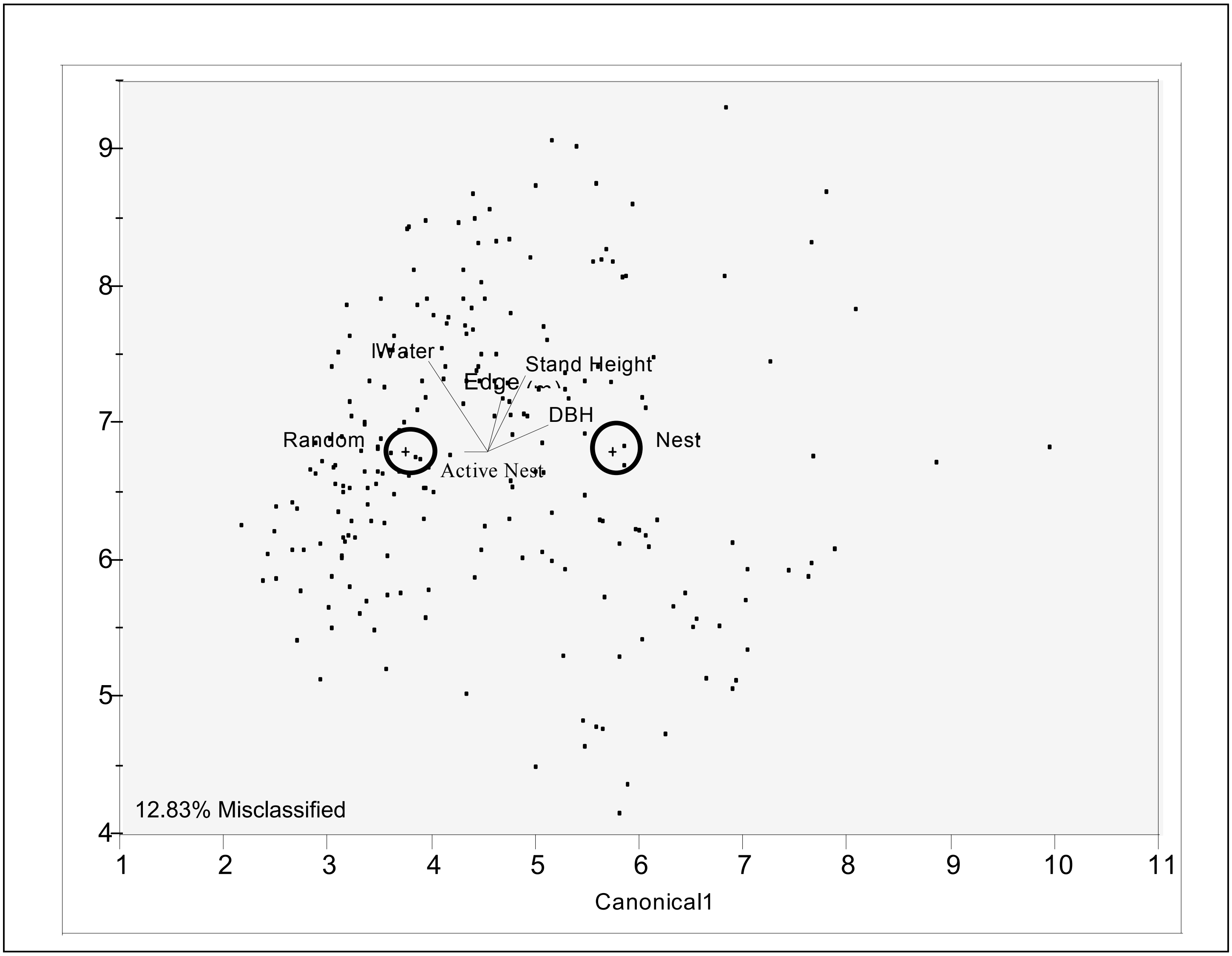

Figure 16. Canonical Plot Showing the Most Important Variables for Discriminating Nest Sites and Random Sites (Exploration Set).

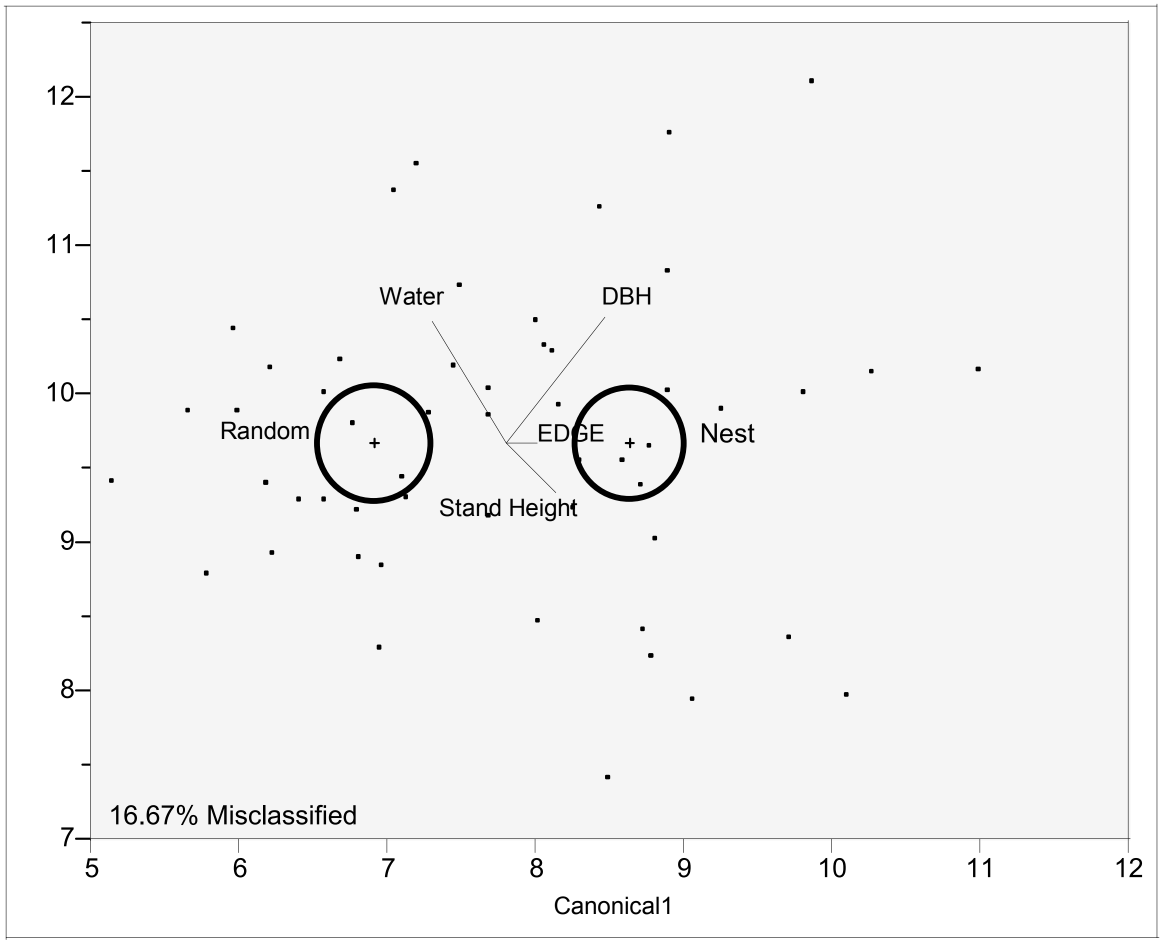

Figure 17. Canonical Plot showing the most important variables for discriminating between Nest Sites and Random Sites (Validation Set).

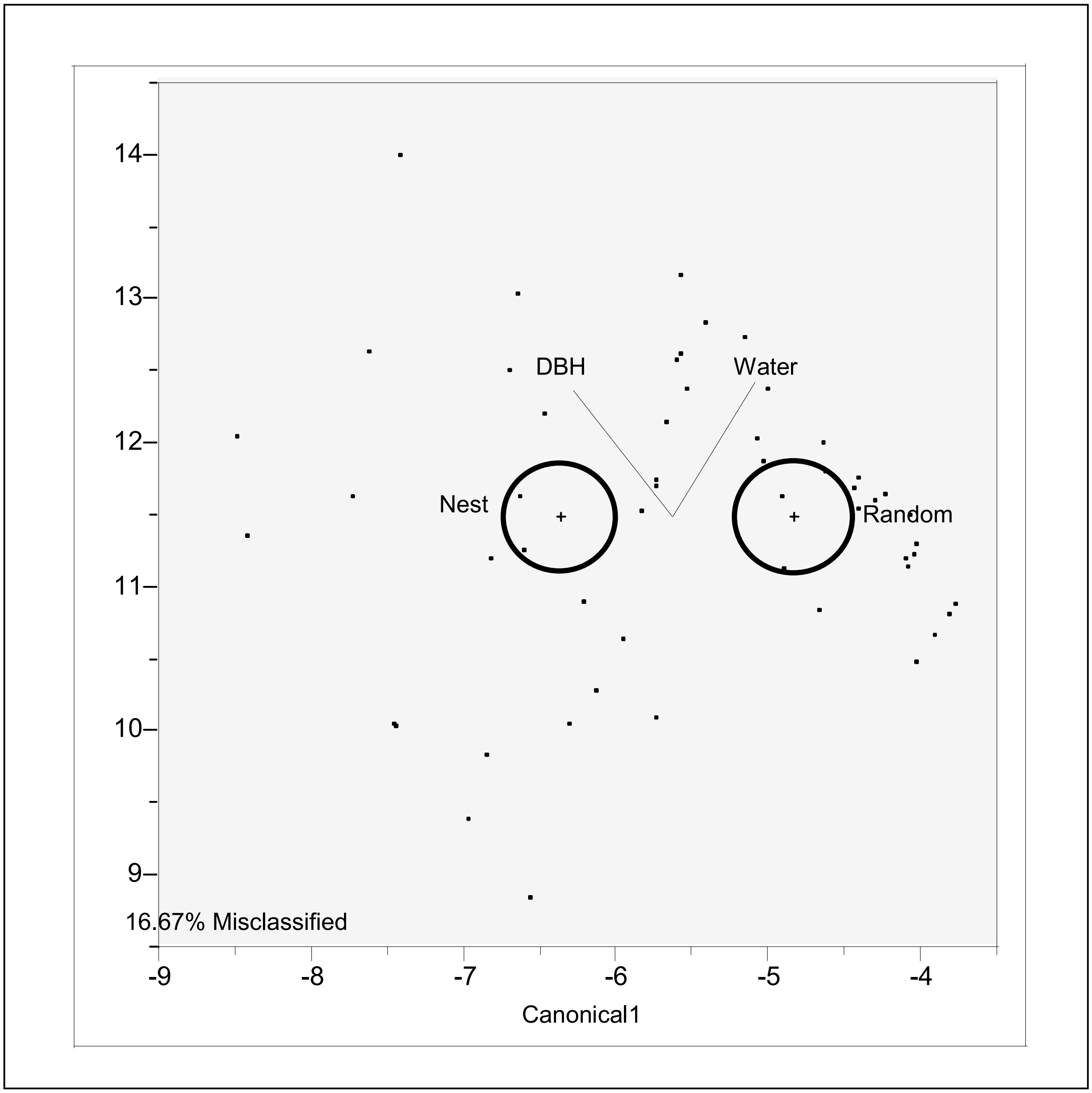

Figure 18. Canonical Plot showing distance to water and tree diameter discriminating Nest Sites from Random Sites (Validation Set).

PRODUCTIVITY MODELING

Model selection techniques were employed to determine the effects of habitat features on productivity. Table 11 shows each measured variable and reasons for exclusion or acceptance into the final model selection process. The accepted variables were examined to determine interactions of importance in describing the effects of habitat variables on productivity using

Mallow's Selection Criterion. The Candidate Set (Table 11) of modes was developed using some with these interactions.

Table 11. Reasons for Accepting or Rejecting Measured Variables for Model Selection Analysis.

VARIABLE	ACCEPTANCE STATUS FOR MODEL SELECTION
Ground to nest	Excluded: correlations and distribution
Nest to top	Accepted with $\log_e$ transformation
Species	Excluded: correlations, confounding factor
Nest Tree Height	Excluded: confounding correlations
Nest Tree Diameter	Accepted with $\log_e$ transformation
Canopy Elevation	Excluded: difficult to measure in the field
Stand Diameter	Accepted with $\log_e$ transformation
Stand Height	Excluded: distribution showed few extreme values
Distance to Active Nest	Accepted with $\log_e$ transformation
Shoreline Distance	Accepted with $\log_e$ transformation
Distance to Roads	Excluded: confounding correlations
Density of Roads	Accepted
Distance to House	Accepted with $\log_e$ transformation
Density of Houses	Excluded: distribution showed few extreme values
Distance to Urban	Accepted
Distance to Forest	Excluded: distribution showed few extreme values
Distance to Grassland	Accepted with $\log_e$ transformation
Distance to Bog	Excluded: distribution showed few extreme values
Distance to Brushland	Excluded: confounding correlations
Distance to Cultivation	Accepted with $\log_e$ transformation
Density of Landuse Types	Accepted

AIC_c values and their associated log-likelihood values were calculated to determine the best approximating models for the data set (Table 12). AIC provides a method for evaluating the likelihood of a model given the data. AIC uses maximum likelihood estimation to rank the models in the candidate set in order of importance. It is unlikely that one model is the single best model for the system. Therefore, it is usually necessary to acknowledge several models that represent the system well.

Table 12. The Candidate Set of Models used for Information-theoretic Model Selection.

Model	Model Description
E(y) = Bo + B1(lnStandDBH) + B2(lnDGrass) + B3 (lnStandDBH*lnDGrass)	Diameter of Stand Trees and Distance to Grassland
E(y) = Bo + B1(Nland1000)	Density of Land-use Types within 1000 m
E(y) = Bo + B1(lnDGrass)	Distance to Grassland
E(y) = Bo + B1(lnDBH)	Nest Tree Diameter
E(y) = Bo + B1(lnDBH) + B2(lnDGrass) + B3 (lnDBH*lnDGrass)	Nest Tree Diameter and Distance to Grassland
E(y) = Bo + B1(lnDBH) + B2(NLand1000) + B3(lnDBH*Nland1000)	Nest Tree Diameter and Density of Land-use Types within 1000 m

For this data set, it is appropriate to use AIC_c (a correction for smaller sample sizes) rather than AIC because the n/K ratio (ratio of number of sample and number of parameters in our models) is relatively small (Burnham and Anderson 2002). The AIC W_i are the important values for comparing the relative importance of the models. Larger values of W_i represent a greater likelihood of the model being the best in the candidate set. The number of estimable parameters in the model as designated a *K*.

Table 13. AIC-values for Models Describing Effects of Habitat Features on Productivity.

Model	Cp	r^2	Log*L*	K	AIC_c	Delta AIC_c	W_i
Diameter Stand Trees and Distance to Grassland	-1.938	0.054	-171.2599	5	353.0703	1	0.16499
Density of Land-use Types within 1000 m	-2.688	0.040	-174.883	3	355.9822	1.008247	0.166351
Distance to Grassland	-2.555	0.039	-175.2248	3	356.6658	1.010184	0.16667
Nest Tree Diameter	-2.115	0.34	-175.3402	3	356.8966	1.010837	0.166778
Nest Tree Diameter and Distance to Grassland	-2.763	0.063	-173.9562	5	358.4629	1.015273	0.16751
Nest Tree Diameter and Density of Land-use Types within 1000 m	-2.012	0.055	-174.1601	5	358.8707	1.016428	0.167701

All of the models in our candidate set fall within a very small range of AIC W_I, making determination of a single best model impossible. Though our candidate set was selected using the best available information, none of our models explained more than 7% of the variation in the system! In other words, productivity did not appear to vary in response to any of the variables we examined, even after a careful consideration of the candidate factors (alone and in combination).

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Bald eagles in Minnesota choose the largest trees (as measured in DBH) available in an area for nesting. Nest trees on average are taller and bigger in diameter than those at Random Sites and in the surrounding stand, with DBH being the more important of the two variables. Cottonwoods are more important as nest trees than previously reported. However, the species of trees does not seem to be important to eagles, rather, selection of the nest tree appears to be driven by searching for structures based on size (primarily DBH). Protection of large diameter, older growth trees may be helpful for nesting eagles as nest sites both for the present and for potential nest sites in the future. This is especially important as the eagle population grows and expands into new areas.

Large trees seem to be necessary for nesting eagles. However, most of our sample nest trees were <u>not</u> "super canopy" trees (Stalmaster 1987, Fraser 1981, Retfalvi 1965). Nest trees at our sample sites were usually one of the largest, but seldom towered above the surrounding tree stand. Our data are somewhat limited in that we only sampled trees within 100 m. If every tree in the primary zone were measured, it is likely that the nest tree would not be the tallest in the zone at many sites. On the other hand, nest trees were usually much bigger in diameter than those in the stand. If fact, once inside the tree stand, searching for large diameter trees was a useful method for finding the nest tree.

Being within a close proximity to a body of water is essential for eagles. Nest Sites were located much closer to water than Random Sites. This is a powerful trend considering that the Random Sites had an absolute limit of 1,000 m from water.

However, there seems to be no evidence of a trend relating productivity to distance from shoreline. Interactions among eagles and defense of breeding territories has been previously suggested as resulting in lowered productivity, apparently acting as a density dependent effect of increasing eagle populations (pers. corr. Lee Grim, Voyageur's National Park, others). In this analysis, Nest Sites were closer to other active nests than were Random Sites and there is little support for a trend relating productivity to distance to nearest active nest. This may be associated to the fact that Random Sites in the far southwestern part of the state were great distances from the nearest active nest. Eagles have not (yet) expanded into the southwestern part of the state beyond the Minnesota River. Additional analyses of edge-of-range nests may show that nests on the edge of a local population have higher productivity than nests within the dense core of the population, but this study was not designed to detect that situation.

There are two main limitations of this study. (1) Prey densities and availability potentially may effect productivity. It was not within the scope of this project to examine prey bases for eagles at individual nests. This factor may become especially important in areas where contaminants are a concern. We believe bald eagles to be generalists in their prey selection, therefore, not being especially effected by the losses of particular prey species at a nest site. Prey base likely does not have a large effect on bald eagle productivity, although more study of that aspect might be useful. (2) Productivity at any given nest typically varies over time. Although we obtained only two years of productivity data, we used a very large number of nests and, thus, should have detected any habitat or human presence effects that were present.

Our best approximating models explain only a small percentage of the variation in the data. This suggests that the variables measured, the best and most obvious ones for bald eagles, are not good predictors of eagle productivity. These variables were chosen after careful consideration and provide a thorough picture of eagle habitat and human presence factors. Eagle habitat is not well defined according to specific features of the habitat within the primary or secondary zones.

Eagles have proven to be more adaptable to different habitats and human presence levels than previously considered and we do not believe that habitat or the physical presence of humans per se is a limiting factor for the presence of bald eagles in the state of Minnesota. As a consequence, we have few recommendations for habitat management beyond insuring the continued existence of large diameter trees.

The rebound of the eagle population did not result from large changes (increases) in habitat factors, but most likely occurred from changes in eagle demographic factors (reproduction and survival). In our opinion, changes in habitat that would be sufficient to alter the suitability of nesting habitat for bald eagles in Minnesota would alter the very nature of the state of Minnesota itself! The essential needs for nesting bald eagles are large trees in which to place a nest in close proximity to lakes or rivers with an adequate available food source. Aside from habitat factors, although not a component of this project, it seems obvious that protection of the species depends most importantly on protection of the birds themselves, via continuing education of the public and enforcement of regulations.

An expanded version of this report is being developed into a Ph.D. dissertation by Jeremy E. Guinn with an expected completion date of May 2004.

ACKNOWLEDGMENTS

Support for this project was received from the Minnesota Nongame Wildlife Tax Checkoff, the Reinvest In Minnesota Program, the State of Minnesota General Fund, and the U. S. Fish and Wildlife Service through the Minnesota Department of Natural Resources, Division of Ecological Services. Additional support was provided by the Department of Zoology at North Dakota State University and the North Dakota BRIN Associaton.

We thank Gary Clambey (NDSU), Kyle Zimmer (NDSU/UMN), and Paul Klatt (NDSU/UND) for assistance in developing the sampling techniques used to evaluate the primary zone around nest trees. We thank Craig Stockwell (NDSU), Malcolm Butler (NDSU), Robert Arthur (NDSU), and Jeffrey Bell (NDSU/UND) for revisions of proposals and manuscripts associated with this project. Wesley Newton (NPWRC), Mario Biondini (NDSU), Michael Collyer (NDSU/ISU), and James Church (NDSU) were especially helpful in developing multivariate analyses.

We thank several agency personnel and private individuals statewide who in varying degrees facilitated the fieldwork for this project. Special thanks to Leland Grim (Voyageur's National Park), Gary Hushely (Agassiz National Wildlife Refuge), Jeanne Hall (Sherburne National Wildlife Refuge), Joan Galli (MN DNR) Brian Tangen (NDSU/NPWRC) and Thomas Dunstan (WIU), who were especially helpful in providing access to nest sites. Al Buchert (MN DNR), Joan Galli (MN DNR), and Lisa Gelvin-Innvaer (MN DNR) were involved in conducting aerial surveys of nests, which was essential for this study.

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APPENDIX 1: Scientific Names for all Species

COMMON NAME	SCIENTIFIC NAME
Bald Eagle	*Haliaeetus leucocephalus*
Cottonwood	*Populus deltoides*
Green Ash	*Fraxinus pennsylvanica*
Paper Birch	*Betula papyrifera*
Quaking Aspen	*Populus tremuloides*
Red Pine	*Pinus resinosa*
Silver Maple	*Acer saccharinum*
Slippery Elm	*Ulmus rubra*
Sugar Maple	*Acer saccharum*
White Oak	*Quercus alba*
White Pine	*Pinus strubus*
White Poplar	*Populus alba*

APPENDIX 2: Land-use Data Information

Minnesota Land Use and Cover - A 1990's Census of the Land

This data set integrates six different source data sets to provide a simplified overall view of Minnesota's land use / cover. The six source data sets covered different parts of the state, were in differing formats, and used different legend classifications. The Minnesota Department of Natural Resources developed a simplified 8-category legend and translated each source data set's original detailed classification into the 8-category system. They also standardized the data to 30-meter grid cells.

Categories

1 - Urban and Rural Development

2 - Cultivated Land

3 - Hay/Pasture/Grassland

4 - Brushland

5 - Forested

6 - Water

7 - Bog/Marsh/Fen

8 - Mining

9 - Unclassified

Source: Minnesota Department of Natural Resources. 2000. Minnesota.data, vol. 1 and 2. State of Minnesota, St. Paul, MN 55155.

APPENDIX 3: DATA FORM FOR PRIMARY ZONE EVALUATION

Minnesota Bald Eagle Nest Habitat Survey—Field Survey Data

#_____ Lat_________ Long__________ Date _____ Log.____
Nest: grnd2:_____ 2top______ cond.________ comm.____
Nest Tree: species______ height ________ dbh________ cond.___________ elev.___________________________
Nest Site:____

Surr Area: canopy______ Description ______________________________________

Site 1: dir______ dist______ ____

Site 2: dir______ dist______ ____
____

Site 3: dir______ dist______ ____

Human dist: ____
Nearby Nest:____________ Shoreline: dist_________ dir___________ descr_______________
Additional Comments:

APPENDIX 4: DATA FORM FOR SECONDARY ZONE EVALUATION

Variable	Number	Category	Within 100m	Category	Within 500m	Category	Within 1000m	Category
Landuse Types	{X}	{X}						
Number of Roads	{X}	{X}						
Number of Houses	{X}	{X}		{X}		{X}		{X}
Distance to Nearest Road			{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest House		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Lake		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest River		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Railroad		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Urban Area (as designated by city roads)		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Cultivated Land *(brownish)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Hay, Pasture, Grassland *(orangish)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Brushland *(greenish)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Forest *(dark blue)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Bog, Marsh, Fen *(purple)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Mining *(white)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Amount of Urban/Rural Devel. *(pale yellow)*	{X}	{X}		{X}		{X}		{X}
Amount of Cultivated Land *(brownish)*	{X}	{X}		{X}		{X}		{X}
Amount of Hay, Pasture, Grassland *(orangish)*	{X}	{X}		{X}		{X}		{X}
Amount of Brushland *(greenish)*	{X}	{X}		{X}		{X}		{X}
Amount of Forest *(dark blue)*	{X}	{X}		{X}		{X}		{X}
Amount of Water *(light blue)*	{X}	{X}		{X}		{X}		{X}
Amount of Bog, Marsh, Fen *(purple)*	{X}	{X}		{X}		{X}		{X}
Amount of Mining *(white)*	{X}	{X}		{X}		{X}		{X}
Amount of Roads	{X}	{X}		{X}		{X}		{X}
Distance to Other		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Other		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Active Nest		{X}	{X}	{X}	{X}	{X}	{X}	{X}

APPENDIX 5: SAS PROGRAM CODE FOR VARIABLE EVALUATION AND MODEL SELECTION

```
PROC UNIVARIATE DATA=Eagle PLOT;
  VAR NestorRandom Dwater lnDwater DBH lnDBH Height lnHeight StandDBH lnStandDBH StandHeight
lnStandHeight Nland1000 lnNland1000 Nroads1000 lnNroads1000 Nhouses1000 lnNhouses1000 droad
lndroad dhouse lndhouse Durban lnDurban Dcultv lnDcultv Dgrass lnDgrass Dactive lnDactive Dforest
lnDforest;
RUN;

PROC CORR DATA=Eagle;
        VAR NestorRandom Dwater lnDwater DBH lnDBH Height lnHeight StandDBH lnStandDBH
StandHeight lnStandHeight Nland1000 lnNland1000 Nroads1000 lnNroads1000 Nhouses1000
lnNhouses1000 droad lndroad dhouse lndhouse Durban lnDurban Dcultv lnDcultv Dgrass lnDgrass
Dactive lnDactive Dforest lnDforest;
RUN;

PROC REG DATA=eagle;
  TITLE 'MODEL ALL POSSIBLE';
  MODEL ProdRank = lnNtoTop lnDWater lnDBH lnStandDBH  Nland1000 NRoads1000 lnDhouse
Durban lnDCultv lnDGrass lnDactive / selection = cp;
RUN;

***** TAKE THE BEST MODELS FROM ABOVE AND RUN THROUGH GENMOD TO GET LOG-
LIKELIHOOD VALUES.**********

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnDiameter lnDistancetoGrassland';
  MODEL ProdRank =  lnDBH lnDGrass / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL DensityofLanduseTypes';
  MODEL ProdRank = Nland1000 / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnDistancetoGrassland';
  MODEL ProdRank = lnDGrass / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnDiameter';
  MODEL ProdRank = lnDBH / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lndiameter DensityoflanduseTypes';
  MODEL ProdRank = lnDBH Nland1000 / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnStandDiameter lnDistancetoGrassland';
  MODEL ProdRank = lnStandDBH lnDGrass / DIST=NORMAL LINK=ID P;

RUN;
```

APPENDIX 6: DATA

The data are enclosed with this report in electronic form (MS Excel).

APPENDIX 7: PHOTOGRAPHS OF DATA COLLECTION

Enclosed with this report is an electronic copy (jpg) of each of the color photographs represented below. These photographs depict various aspects of the data collection process for this project.