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Active land planning for long-term Bald Eagle management within the lower Chesapeake Bay (Phase I: Model construction)

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Virginia Department of Game and Inland Fisheries
Nongame and Endangered Species Program

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INTRODUCTION

One of the primary threats to wildlife, and concomitantly, one of the leading causes of species extinction, is the loss of habitat due to urbanization. As the human population expands and natural areas are developed for residential, commercial and industrial use, critical wildlife habitat is rapidly disappearing. Changes in landuse patterns are widespread and conversion rates are high for many physiographic regions. However, due to their natural appeal, coastal lands are experiencing some of the highest development pressures. Greater than 52 percent of the U.S. human population now lives within 80 km of U.S. coastlines. Between 1950 and 1986, the number of people living along the shores of the Chesapeake Bay increased by 50 percent. This population is projected to increase by at least 2.6 million, or an additional 20 percent, over the next 30 years. Within the greater bay area, pressures on habitats associated with highly desirable waterfront property are immense. In Maryland, a survey in the early 1980's showed that nearly 20 percent of all development activity in the state was occurring within one thousand feet of the edge of the bay and its tidal tributaries. Construction of 53,000 family dwellings within this thin ribbon is expected to occur within the near future.

Historically, the Bald Eagle was a common breeder along major river systems, lakes and coastal areas throughout the Southeast. The widespread use of persistent pesticides for crop management in the region resulted in dramatic declines over a 30-40 year period. By the late 1960's most breeding populations had been decimated by eggshell thinning and associated low productivity. Concern for these populations prompted the elevation of the Bald Eagle to endangered status and led to a national effort to restore historic populations.

Since the nationwide ban on most persistent pesticides in 1972, many populations have experienced gradual recoveries in both productivity and total numbers. In Virginia, the breeding population has steadily increased from an estimated low of approximately 32 pairs in the 1960's to 131 pairs in 1992. Shoreline development poses the most significant threat to the recovery and long-term persistence of Bald Eagles within the Chesapeake Bay. Breeding pairs require open water for foraging and rarely build nests beyond 1-2 km of the shoreline. This suggests that all current and potential breeding habitat lies within the same thin ribbon of land currently experiencing the most rapid development.

Since its elevation to endangered status in 1978, protection of the Bald Eagle and its habitat is governed by the Endangered Species Act of 1973. Under this designation, critical habitat is defined as any area essential to the survival and recovery of the species. Current habitat management practices for nesting Bald Eagles have focused on protecting active nest trees and restricting landuse activities within "recommended" buffer zones. This passive strategy does not address potential nesting habitat. During the course of this recovery phase, much habitat remains unoccupied that is both critical to the continued recovery and maintenance of the population and is under imminent risk of development. Little attention has been given to the delineation of these lands that are critical to the Chesapeake Bay eagle population.

The principal objectives of this study are: 1) to parameterize and screen a series of relevant landuse variables for their ability to predict habitat quality for breeding Bald Eagles, and 2) to construct a quantitative tool capable of delineating lands in Virginia's coastal plain according to their value as habitat for breeding Bald Eagles.

SUMMARY

Since its elevation to endangered status in 1978, protection of the Bald Eagle and its habitat is governed by the Endangered Species Act. Under this designation, critical habitat is defined as any area essential to the survival and recovery of the species. Current habitat management strategies for nesting Bald Eagles are centered around the protection of active nest trees. Although this practice is essential, it does not address potential nesting habitat. Much habitat remains unoccupied that is both critical to the continued recovery and maintenance of the population and is under imminent risk of development.

We quantified 61 topographic, landuse, and disturbance variables within 127 active eagle territories and around 127 randomly chosen points to evaluate their potential as predictors of habitat quality for breeding Bald Eagles. Fifty-four of 61 variables were significantly different between the two samples. Compared to random sites, eagles prefer to nest in areas situated close to large water bodies, away from extensive human disturbance, and having considerable forest cover.

A discriminant function analysis was used to determine the linear combination of variables that best differentiate between active and random sites. Sixteen variables conformed to parametric assumptions and were entered into a step-wise discriminant function procedure. The final 4-variable model constructed produced a classification accuracy of 81.5%. In addition to the model variables, 4 distribution constraints were identified within the data set. A combination of these constraints and the 4-variable model were used in the final land classification model.

APPROACH

During the process of territory selection, Bald Eagles are likely influenced by a complex collage of factors that vary from the structure of a landscape to the size and form of an individual tree. How this suite of factors interact to influence the distribution of breeding pairs is beyond the scope of any single investigation. However, predicting the impacts of alternate landuse decisions on the potential of habitat for breeding does not require an understanding of all possible habitat variables. We have chosen to narrow our focus here from all possible factors to those that are directly relevant to landuse patterns. By doing so we do not dismiss the importance of other factors, but instead highlight those that are most useful for the construction of local landuse policies.

We have chosen to evaluate factors in three broad classes including: 1) topographic variables (parameters that describe long-lived landscape features), 2) landuse variables (parameters that describe landuse features as they exist in 1992), and 3) disturbance/development variables (parameters that describe the extent of human impacts/development as it exists in 1992). Topographic variables (e.g. availability of open water or marsh, distance to nearest waterways) are relatively stable features of the landscape and are used to effectively reduce the land area under consideration. In other words, if eagles are found to nest only within particular topographic constraints then decisions concerning lands that fall outside these constraints will have relatively little impact on potential breeding habitat. Landuse variables (e.g. amount of land in forest or agriculture) are also relatively stable and are used to further refine habitat potential within those areas that meet topographic constraints. Disturbance/development variables (e.g. housing density, miles of roadways) are currently the least stable and are changing at a rapid rate as development continues to expand across the coastal plain. These variables will be used to further refine the distribution of potential habitat that meets both topographic and landuse constraints.

This hierarchical approach to land delineation allows for the systematic exclusion of unusable lands by "filtering" them out based on a series of appropriate constraints (see Figure 1). Using the limited number of factors mentioned above, this approach gives a conservative representation of potential habitat based solely on current landuse patterns. The addition of other classes of factors (e.g. distribution of prey populations, distribution of occupied habitat) would serve to refine usable habitat still further.

STUDY AREA

We confined our investigation to the coastal plain of Virginia from the Atlantic Ocean (including the Delmarva peninsula) west to the fall line and from the Virginia bank of the Potomac south to the southern bank and associated tributaries of the James River. This area includes over 20,000 sqkm of land drained by four major rivers and numerous large tributaries.

Much of the land included in the study area is currently used for agriculture and timber production. Large urban centers are situated around the mouths of larger rivers and their tributaries. Significant metropolitan areas also exist along the fall line near the end of navigable waters. Although much of the landscape remains rural, lands between urban centers are increasingly being converted for residential use, particularly along prominent shorelines.

Figure 1. Conceptual Model illustrating the filter approach to land classification. Shown is the reduction in potential land with the application of successive constraints.

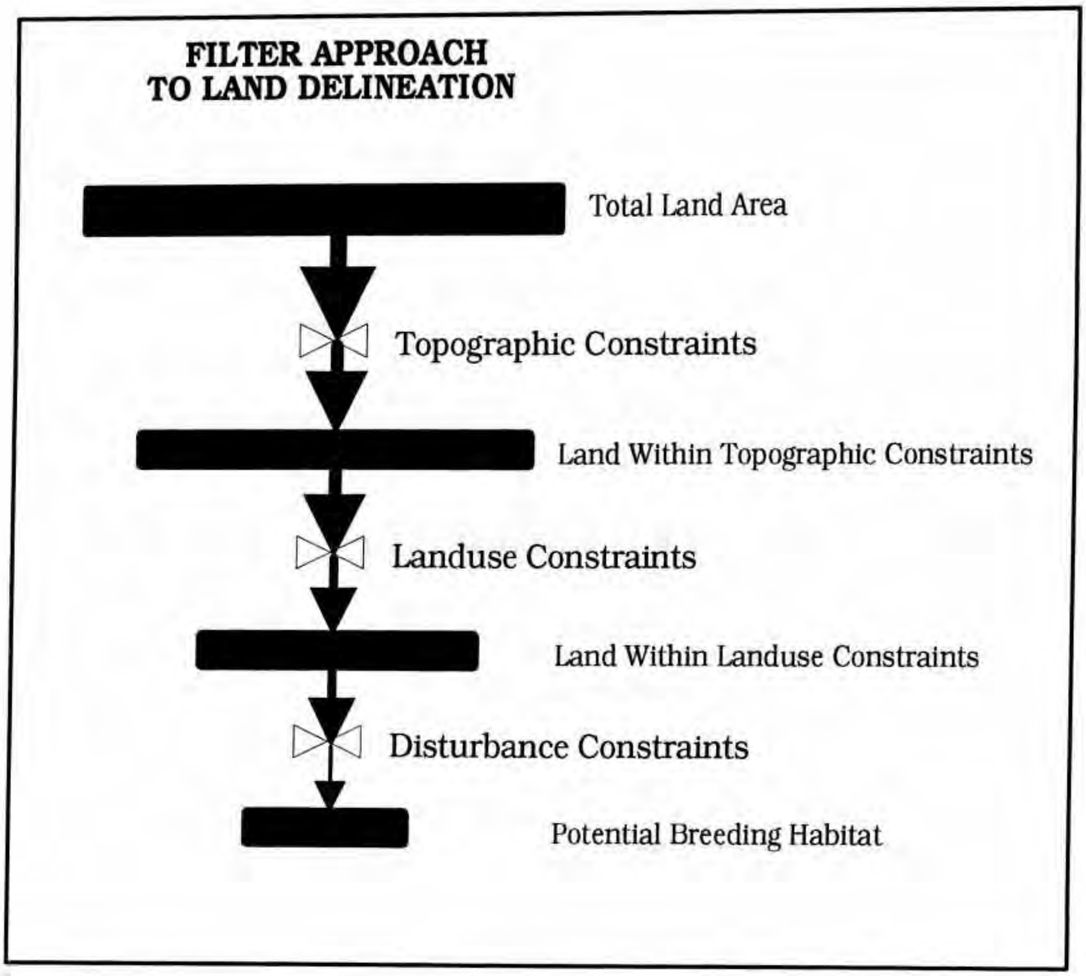

FILTER APPROACH
TO LAND DELINEATION
Total Land Area
Topographic Constraints
Land Within Topographic Constraints
Landuse Constraints
Land Within Landuse Constraints
Disturbance Constraints
Potential Breeding Habitat

Figure 1

METHODS

Active Breeding Areas

We define a "breeding area" as the landscape included within and surrounding the complex of nests that a pair of breeding eagles use over the course of several years. We confined this study to those breeding areas containing a nest known to be active during the 1992 breeding season. The status and location of nests was determined during aerial surveys conducted throughout the early spring of 1992. A nest was considered to be active if an adult eagle was observed on the nest in an incubating posture. Aerial surveys resulted in the location of 127 active nests within the study area during 1992.

Random Points

In order to focus the investigation on relevant variables, all known active and historic nesting sites were examined collectively to uncover any topographic constraints. One distribution constraint emerged. Nearly all known nest sites (N = 367) appear to be within 3 km of a channel that has a minimum width of 250 m. This single constraint was used to redefine the working area for the selection of all random locations.

Random locations were used to represent the general availability of habitat variables for comparison to active sites. Random sites were initially chosen on a 1:250,000 scale topographic map of the study area by overlaying a transparent, 10,000 cell grid and choosing random coordinates without replacement. Only coordinates falling within the defined working area were retained for analysis. Random coordinates were chosen until 127 points were accumulated. Plotted points were then transferred, as accurately as possible, onto 7.5 min topographic maps.

Upon closer examination of random point locations, 22 were found to be situated within active, old or new (1993) territories. In order to achieve a clearer separation between active and random sites, these points were reclassified as active before analysis.

Habitat Variables and Data Collection

Active nest sites were the focal points for data collection and were used to establish a nesting area (NA), (see Figure 2) and a foraging area (FA) for each territory. These study plots were used to investigate habitat variables that might directly influence nest placement and primary foraging areas respectively and ultimately the location of breeding territories. The NA included all of the area within a 1600 m radius of the nest site. Because many of the nests were located well beyond 1 - 2 km from major drainages, the same approach could not be used in delineating the FA (i.e. if a fixed radius from the nest was used, the FA variables would be highly influenced by the distance to water). This problem was avoided by drawing a line from the nest to the nearest shoreline point on a channel $\geq$ 100 m wide. This point was considered the "nearest shoreline point" (see Figure 3). The FA included all of the area associated with the shoreline within a 1600 m radius of this designated point. We assumed that this area included the shoreline most used by the resident pair. The same procedure outlined above was used to determine both the NA and FA for each randomly chosen location.

Habitat variables measured within each NA and FA were divided into three general categories. Categories included: 1) topographic variables, 2) disturbance variables, and 3) landuse variables. Tables 1 and 2 give a brief description of all variables measured.

Figu re 2. Illustration of nest area plot where all NA variables were quantified. Note that many of the variables were stratified according to the various concentric rings shown.

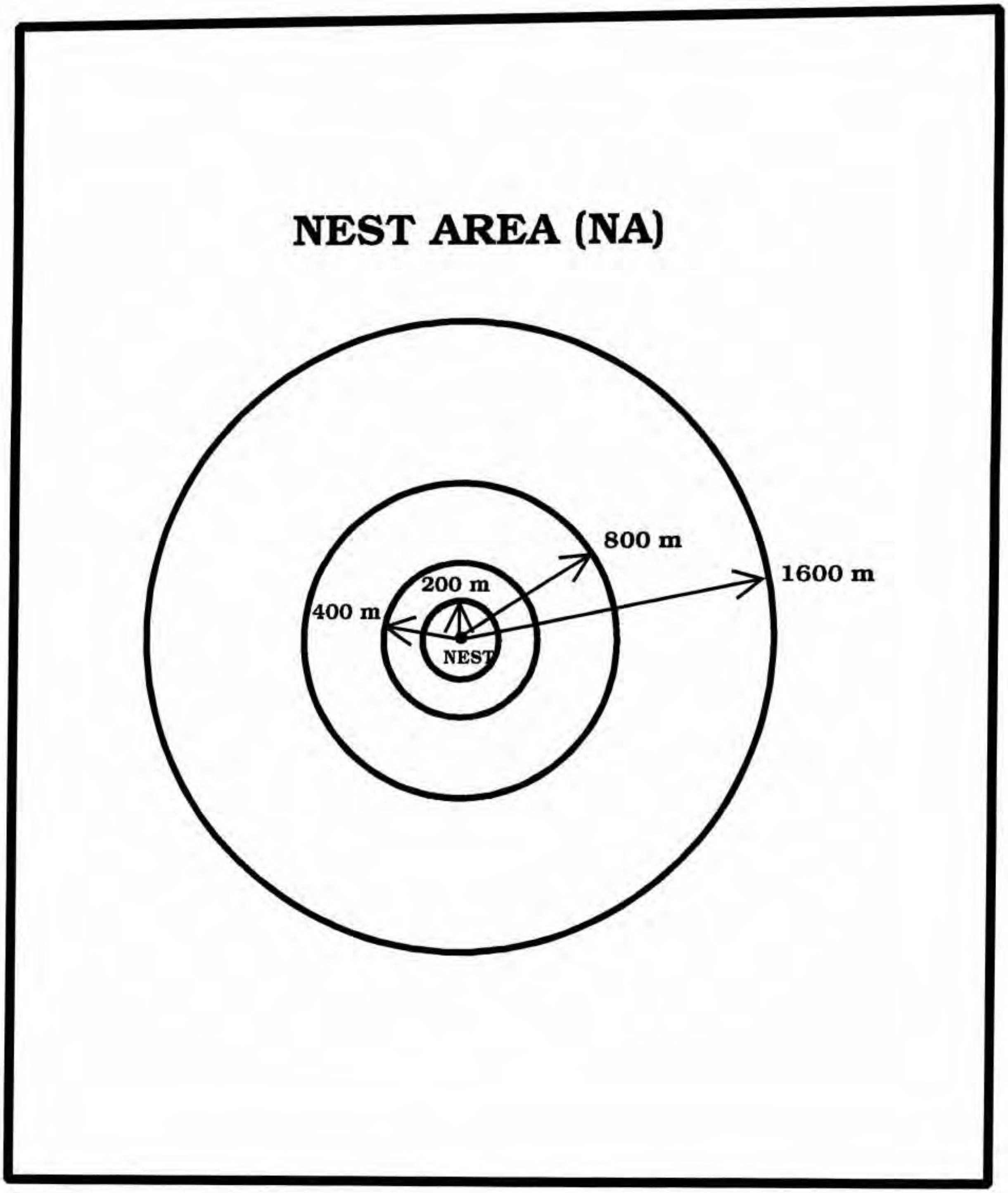


Figure 2

Figure 3. Illustration of the foraging area plot where all FA variables were quantified. Plot was located by extending a perpendicular to the "nearest shoreline point" associated with a channel greater than 100 m wide. All shoreline enclosed within a 1600 m radius of the nearest point was considered the focal shoreline.

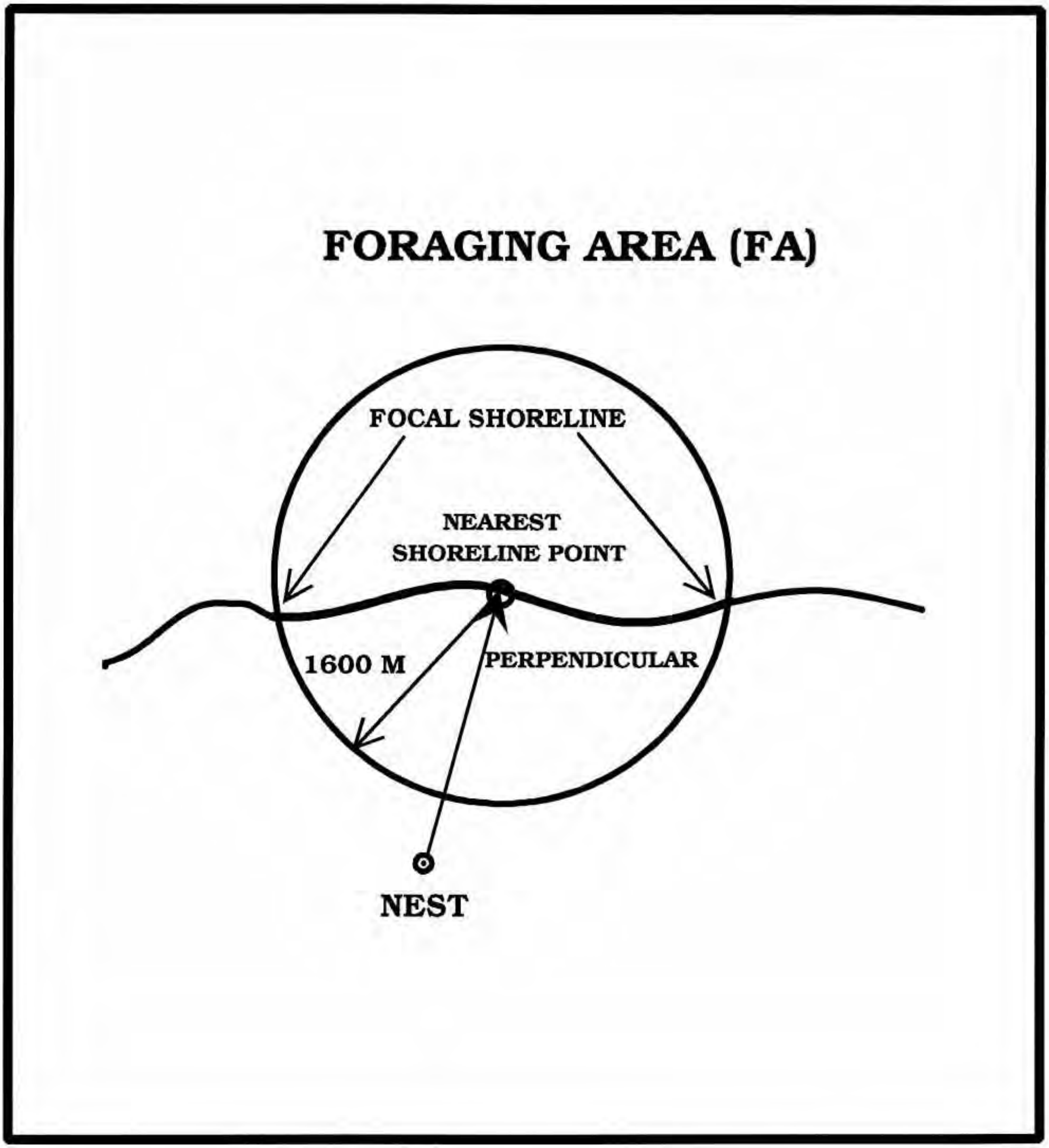

FORAGING AREA (FA)
FOCAL SHORELINE
NEAREST
SHORELINE POINT
1600 M
PERPENDICULAR
NEST

Figure 3

TABLE 1. Variables measured within 1600 m of active nest sites and random sites.

Code	(units)	Variable Description
TOPOGRAPHIC		
DISCH1	(m)	Distance to nearest open channel <100 m wide.
DISCH2	(m)	Distance to nearest open channel >100 m wide.
DISCH3	(m)	Distance to nearest open channel >250 m wide.
DISCH4	(m)	Distance to nearest open channel >500 m wide.
DISCH5	(m)	Distance to nearest open channel >1 km wide.
MSHAR1	(ha)	Area of marsh within a 200 m radius.
MSHAR2	(ha)	Area of marsh within a 400 m radius.
MSHAR3	(ha)	Area of marsh within an 800 m radius.
MSHAR4	(ha)	Area of marsh within a 1600 m radius.
MSHAR5	(ha)	Area of marsh between 200 and 400 m from point.
MSHAR6	(ha)	Area of marsh between 400 and 800 m from point.
MSHAR7	(ha)	Area of marsh between 800 and 1600 m from point.
WATAR1	(ha)	Area of water within a 200 m radius.
WATAR2	(ha)	Area of water within a 400 m radius.
WATAR3	(ha)	Area of water within a 800 m radius.
WATAR4	(ha)	Area of water within a 1600 m radius.
WATAR5	(ha)	Area of water between 200 and 400 m from point.
WATAR6	(ha)	Area of water between 400 and 800 m from point.
WATAR7	(ha)	Area of water between 800 and 1600 m from point.
DISTURBANCE		
DISUNR	(m)	Distance to nearest unimproved road.
DISSCR	(m)	Distance to nearest secondary road.
DISBLD	(m)	Distance to nearest building.
UNRDN1	(m/km)	Length of unimproved roads within 200 m radius.
UNRDN2	(m/km)	Length of unimproved roads within 400 m radius.
UNRDN3	(m/km)	Length of unimproved roads within 800 m radius.
UNRDN4	(m/km)	Length of unimproved roads within 1600 m radius.
UNRDN5	(m/km)	Length of unimproved roads between 200 and 400 m.
UNRDN6	(m/km)	Length of unimproved roads between 400 and 800 m.
UNRDN7	(m/km)	Length of unimproved roads between 800 and 1600 m.
SCRDN1	(m/km)	Length of secondary roads within 200 m radius.
SCRDN2	(m/km)	Length of secondary roads within 400 m radius.
SCRDN3	(m/km)	Length of secondary roads within 800 m radius.
SCRDN4	(m/km)	Length of secondary roads within 1600 m radius.
SCRDN5	(m/km)	Length of secondary roads between 200 and 400 m.
SCRDN6	(m/km)	Length of secondary roads between 400 and 800 m.
SCRDN7	(m/km)	Length of secondary roads between 800 and 1600 m.
BLDDN1	(N/km)	Number of buildings within 200 m radius.
BLDDN2	(N/km)	Number of buildings within 400 m radius.
BLDDN3	(N/km)	Number of buildings within 800 m radius.
BLDDN4	(N/km)	Number of buildings within 1600 m radius.
BLDDN5	(N/km)	Number of buildings between 200 and 400 m.
BLDDN6	(N/km)	Number of buildings between 400 and 800 m.
BLDDN7	(N/km)	Number of buildings between 800 and 1600 m.

TABLE 1. -- Continued --

Code	(Units)	Variable Description
LANDUSE		
CLCTAR	(ha)	Area of clearcut land within 400 m radius.
YGFRAR	(ha)	Area of young forest coverage within 400 m radius.
IMFRAR	(ha)	Area of intermediate age forest coverage within 400 m radius.
MATFAR	(ha)	Area of mature forest coverage within 400 m radius.
FRWTAR	(ha)	Area of forested wetland coverage within 400 m radius.
FORAR1	(ha)	Total area of forest coverage within 400 m radius.
FORAR2	(ha)	Total area of forest coverage within 1600 m radius.
AGLAAR	(ha)	Area of agricultural land within 400 m radius.
URLAAR	(ha)	Area of urban land within 400 m radius.

TABLE 2. Habitat variables measured within foraging area (1600 m radius around shoreline point nearest to nest or random point).

Code	(Units)	Variable Description
TOPOGRAPHIC		
MASHLE	(m)	Length of shoreline composed of marsh within foraging area.
UPSHLE	(m)	Length of shoreline composed of upland within foraging area.
TOSHLE	(m)	Total shoreline length within foraging area.
DISTURBANCE		
BLDDEN	(N)	Number of buildings within 200 m of foraging area.
PIRDEN	(N)	Number of piers or docks within foraging area.
LANDUSE		
FORSH1	(m)	Length of shoreline, within foraging area, with forest buffer <50 m wide.
FORSH2	(m)	Length of shoreline, within foraging area, with forest buffer >50 m wide but <150 m wide.
FORSH3	(m)	Length of shoreline, within foraging area, with forest buffer >150 m wide.
TFORSH	(m)	Total length of forested shoreline within foraging area.

Variable Measurement and Analysis

Measurements of habitat variables were taken from 7.5 minute USGS topographic maps or on recent aerial photographs. The vast majority of photographs used were obtained from the U.S. Department of Agriculture's (USDA) office of Agricultural Soils Conservation Service and were 1:16000 scale, black and white. A few photographs were obtained from the Virginia Department of Transportation (VDOT) to fill gaps in coverage and were 1:12000 scale, black and white. Date of aerial photography was 1988-89 for USDA and 1986-89 for VDOT. The season of photographs ranged from October - April. Distance measurements were made using a millimeter ruler, lengths and areas were measured using an electromagnetic digitizing tablet.

Lilliefor's test was used to assess distribution patterns for each variable. All non-normal variables were transformed using three standard functions (including: 1) $\log(X + 1)$, 2) $(X)^{1/2}$, and 3) arcsine(X)) and retested. Significance between active and random points was evaluated using an F-test for all parametric variables and Mann-Whitney U test for all nonparametric variables. Significance levels of 0.15 were used to control the Type II error. When the null hypothesis was accepted (i.e., the means were equal) it was assumed that the eagles were using the variable according to its availability and it, therefore, was excluded from further analysis. A correlation matrix was generated for all significant, parametric variables to investigate variable independence. When two or more variables were highly correlated, the variable that was most easily interpreted or measured was retained.

All variables surviving the above criteria were processed in a discriminant function procedure using active vs random as the grouping parameter. A procedure to maximize Wilk's Lambda was employed using equal prior probabilities.

OVERVIEW OF UNIVARIATE RESULTS

Nest site selection for Bald Eagles within the study area appears to be influenced by several habitat dimensions. Univariate test results (see Appendix I for a full accounting of the results) revealed that active nest sites were significantly different from random sites with respect to 54 of 61 habitat variables measured. In general, eagles prefer to nest in areas that are situated close to large water bodies, away from extensive human disturbance, and having considerable forest cover.

Nest Area

Topography

Despite the fact that the selection of random points was constrained to within 3 km of a large water body, active sites were still significantly closer to the entire range of channel widths measured (see Figure 4). However, the average distance to water was positively related to channel width for both active and random sites. This seems to suggest that although nests tend to be closer to all channels than expected eagles are not selecting any particular channel width. In essence nest sites tend to be close to narrow channels because narrow channels are comparatively more abundant and widespread than wider channels.

In addition to being near water, "nest areas" associated with active sites contained significantly more marsh and open water when compared to random sites (see Figure 5).

Figure 4. Comparison between active and random sites in distance to channels of various widths. Histograms indicate means + or - one standard error.

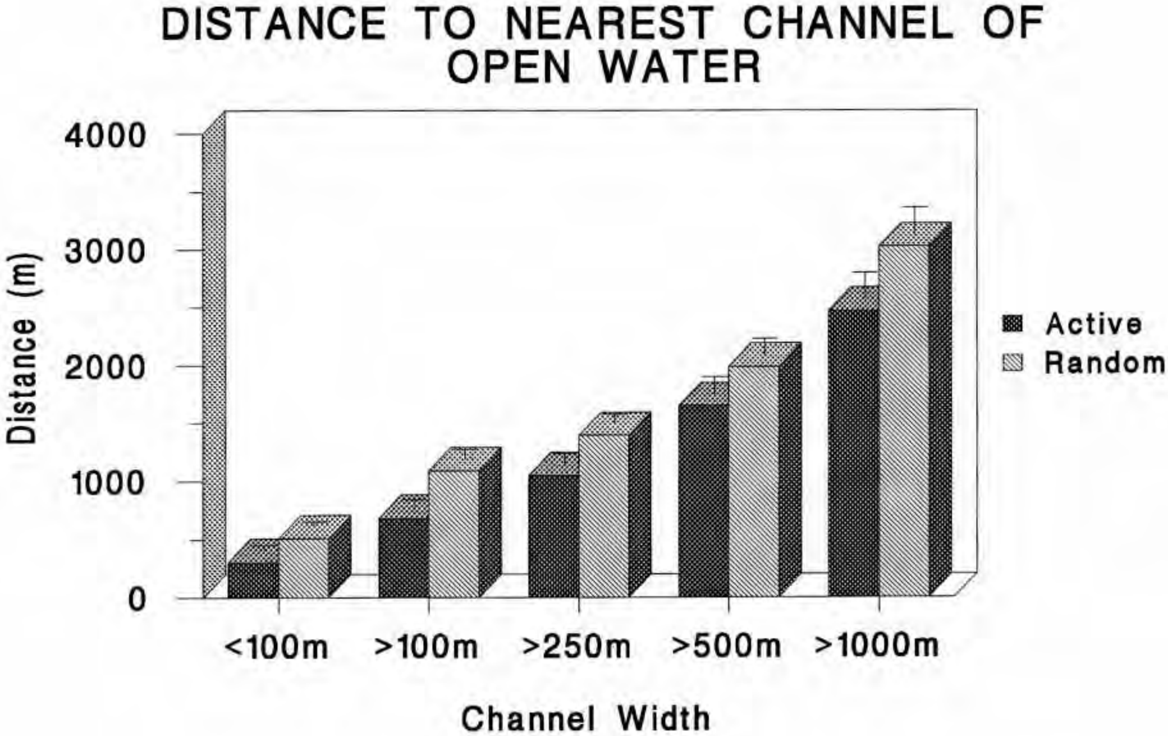
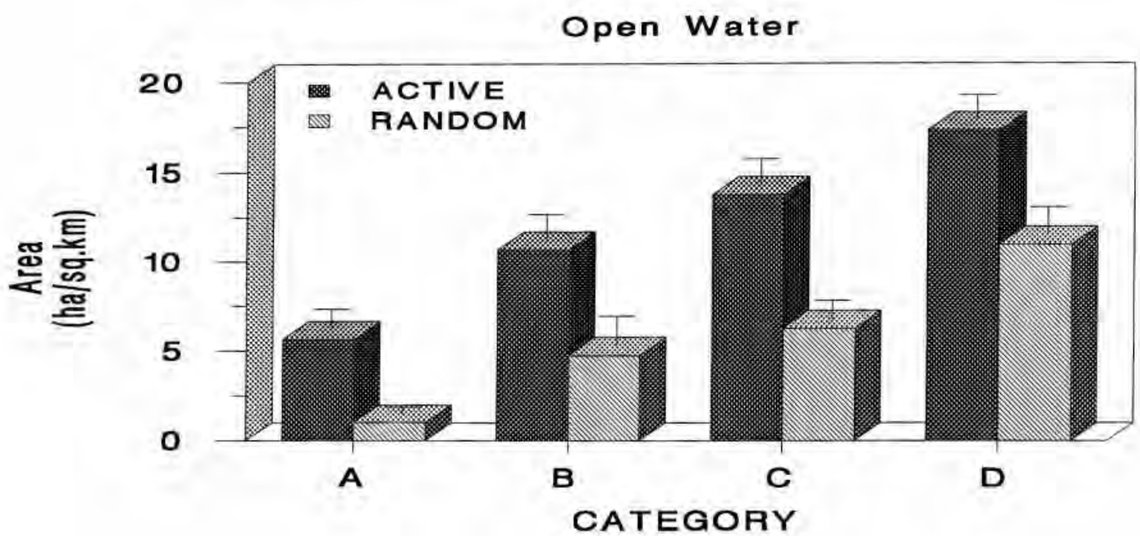

DISTANCE TO NEAREST CHANNEL OF OPEN WATER
4000
3000
2000
1000
0
Distance (m)
Active
Random
<100m
>100m
>250m
>500m
>1000m
Channel Width

Figure 4

Figure 5. Comparison between active and random sites in area of open water and marsh. Categories A, B, C, and D indicate concentric rings moving outward from the nest (0 - 200 m, 200 - 400 m, 400 - 800 m, and 800 - 1600 m respectively). Histograms indicate means + or - one standard error.


Open Water
ACTIVE
RANDOM
Area (ha/sq.km)
20
15
10
5
0
A
B
C
D
CATEGORY

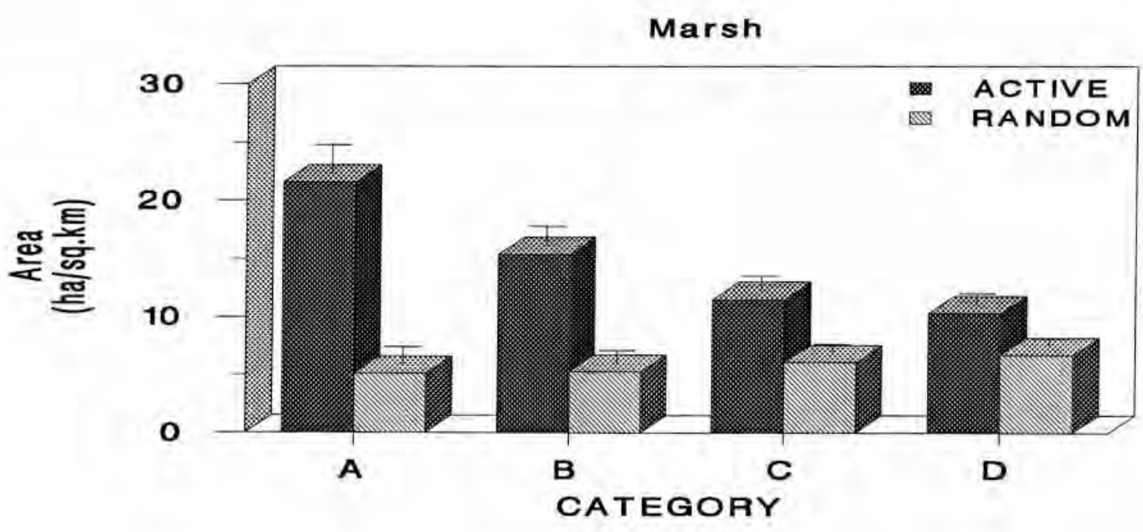

Marsh
ACTIVE
RANDOM
Area (ha/sq.km)
30
20
10
0
A
B
C
D
CATEGORY

Figure 5

This result does not appear to be an artifact of proximity to water (as might be expected with the fixed radius measurements employed). Area of water or marsh was not negatively correlated with distance to water ($P > 0.05$). This seems to suggest that eagle pairs are selecting areas along the shoreline that have concentrations of marsh and open water.

Disturbance

Active nest sites and random points were significantly different with respect to their location relative to all human-related structures examined (see Appendix I for summary of test results). Nest sites were generally distributed further from all disturbance types. The occurrence of disturbance structures within NA sample plots was also different between random and active sites with active sites having significantly lower densities. This suggests that eagles are selectively breeding in locations away from human-related structures.

In addition to the lower overall density of structures, active and random sites differed in the spatial arrangement of disturbance structures within NA plots (see Figure 6). For active sites, density increased significantly with distance for all three structure types (Kruskal-Wallace statistic > 100.0 and $P < 0.001$ for all types). The same pattern was not detected within random plots (Kruskal-Wallace statistic < 7000 and $P > 0.05$ for all types). The disparity in these spatial patterns (between active and random plots) is illustrated by the significance patterns for distance/disturbance categories and suggests that eagle sensitivity to all of these structures declines with distance.

Land-use

Land-use patterns differed significantly between active and random locations. Active nest sites were surrounded by comparatively more forest cover (within both 400 and 1600

Figure 6. Comparison between active and random sites in disturbance variables. Categories A, B, C, and D indicate concentric rings moving outward from the nest (0 - 200 m, 200 - 400 m, 400 - 800 m, and 800 - 1600 m respectively). Histograms indicate means + or - one standard error.

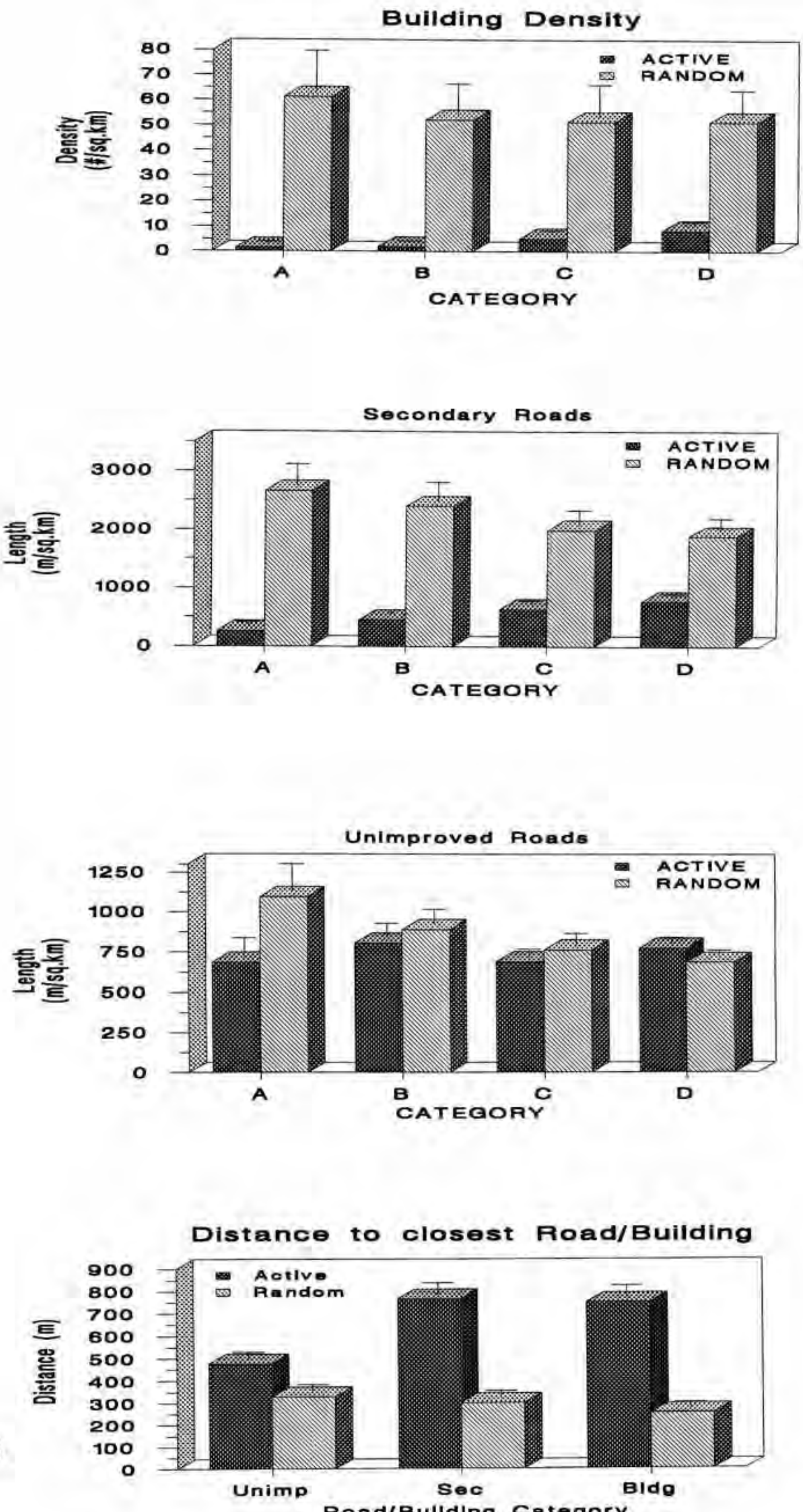

Building Density
80
70
60
50
40
30
20
10
0
Density (#/sq.km)
ACTIVE
RANDOM
A
B
C
D
CATEGORY
Secondary Roads
3000
2000
1000
0
Length (m/sq.km)
ACTIVE
RANDOM
A
B
C
D
CATEGORY
Unimproved Roads
1250
1000
750
500
250
0
Length (m/sq.km)
ACTIVE
RANDOM
A
B
C
D
CATEGORY
Distance to closest Road/Building
900
800
700
600
500
400
300
200
100
0
Distance (m)
Active
Random
Unimp
Sec
Bldg
Road/Building Category

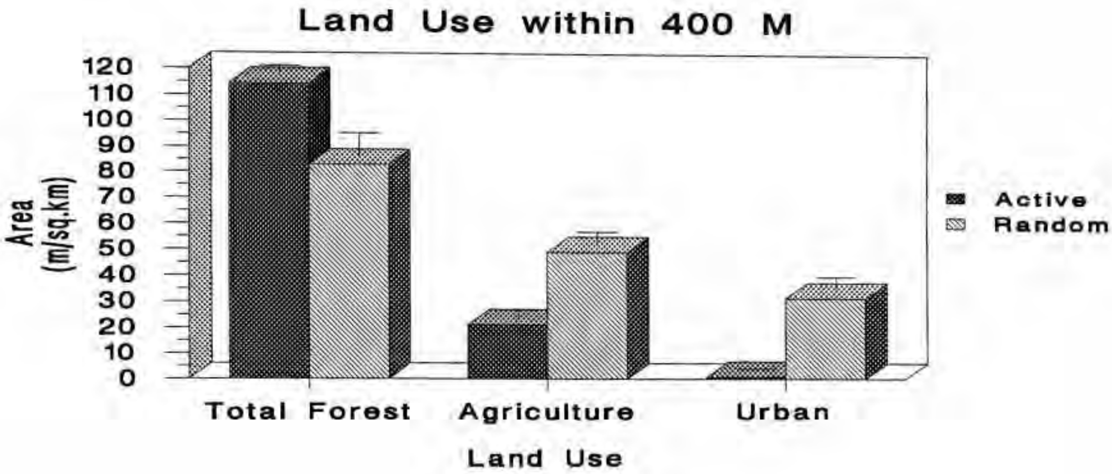
Figure 6

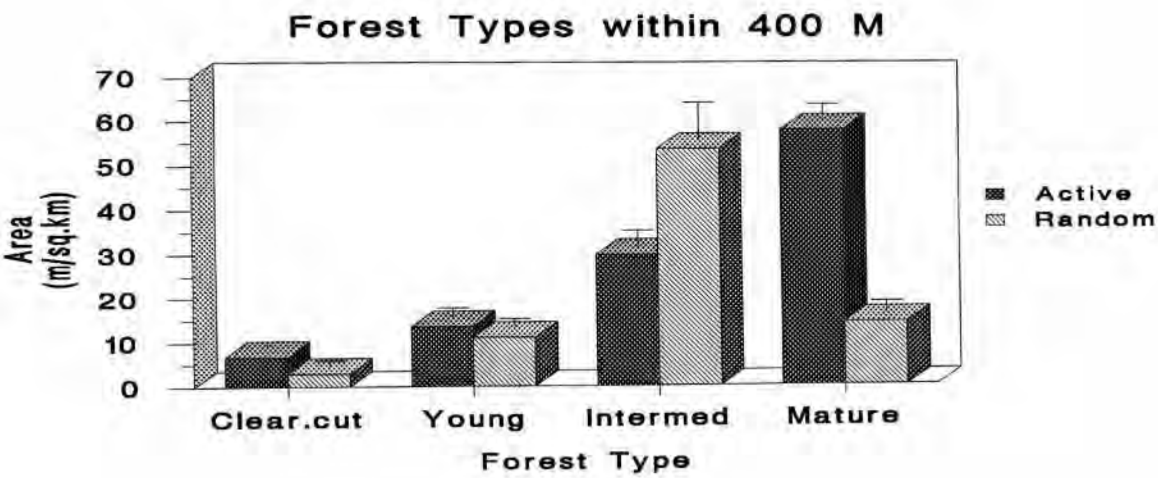
m), less agricultural land, and less urban development (see Figure 7). Forest coverage for active sites was not only more extensive but also exhibited a different age distribution. While random sites had comparatively more area in intermediate age forest, active sites contained significantly more mature forest. Active and random sites were not significantly different with respect to land area in clearcut and young forests.

Foraging Area

Results were mixed in terms of comparisons between random and active sites for shoreline characteristics (see Figure 8). Total shoreline length within the defined foraging area was significantly higher for shorelines associated with random sites, suggesting that active shorelines were less convoluted. The length of shorelines designated as marsh or unclassified uplands did not differ between the two samples. Shorelines associated with random points had greater numbers of houses and associated piers along their lengths when compared to active shorelines. No difference was detected between the two samples regarding any of the measurements for length or width of forested shorelines.

Figure 7. Comparison between active and random sites in the area of surrounding lands in various landuse categories. Histograms indicate means + or - one standard error.


Land Use within 400 M
Area (m/sq.km)
0
10
20
30
40
50
60
70
80
90
100
110
120
Total Forest
Agriculture
Urban
Land Use
Active
Random


Forest Types within 400 M
Area (m/sq.km)
0
10
20
30
40
50
60
70
Clear.cut
Young
Intermed
Mature
Forest Type
Active
Random

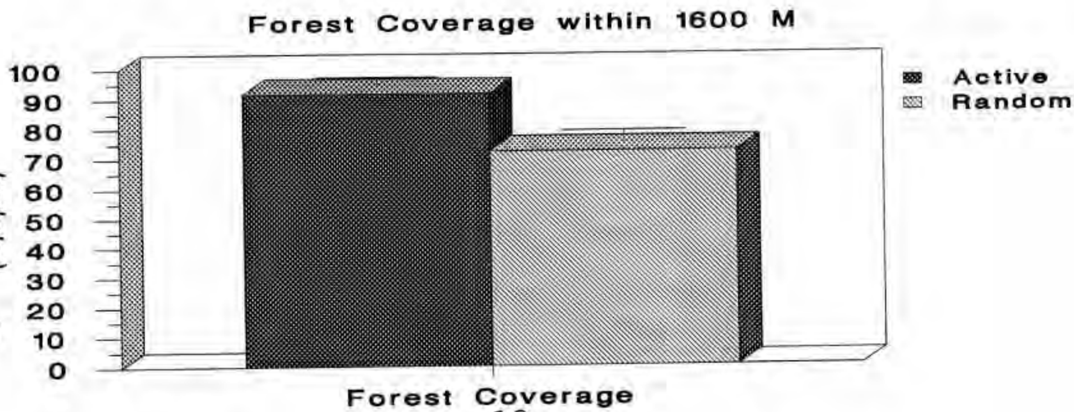

Forest Coverage within 1600 M
Area (ha/sq.km)
0
10
20
30
40
50
60
70
80
90
100
Forest Coverage
Active
Random

Figure 7

Figure 8. Comparison between active and random sites in the density of buildings within 200 m and 400 m. Histograms indicate the relative frequency of sites with respective building densities.

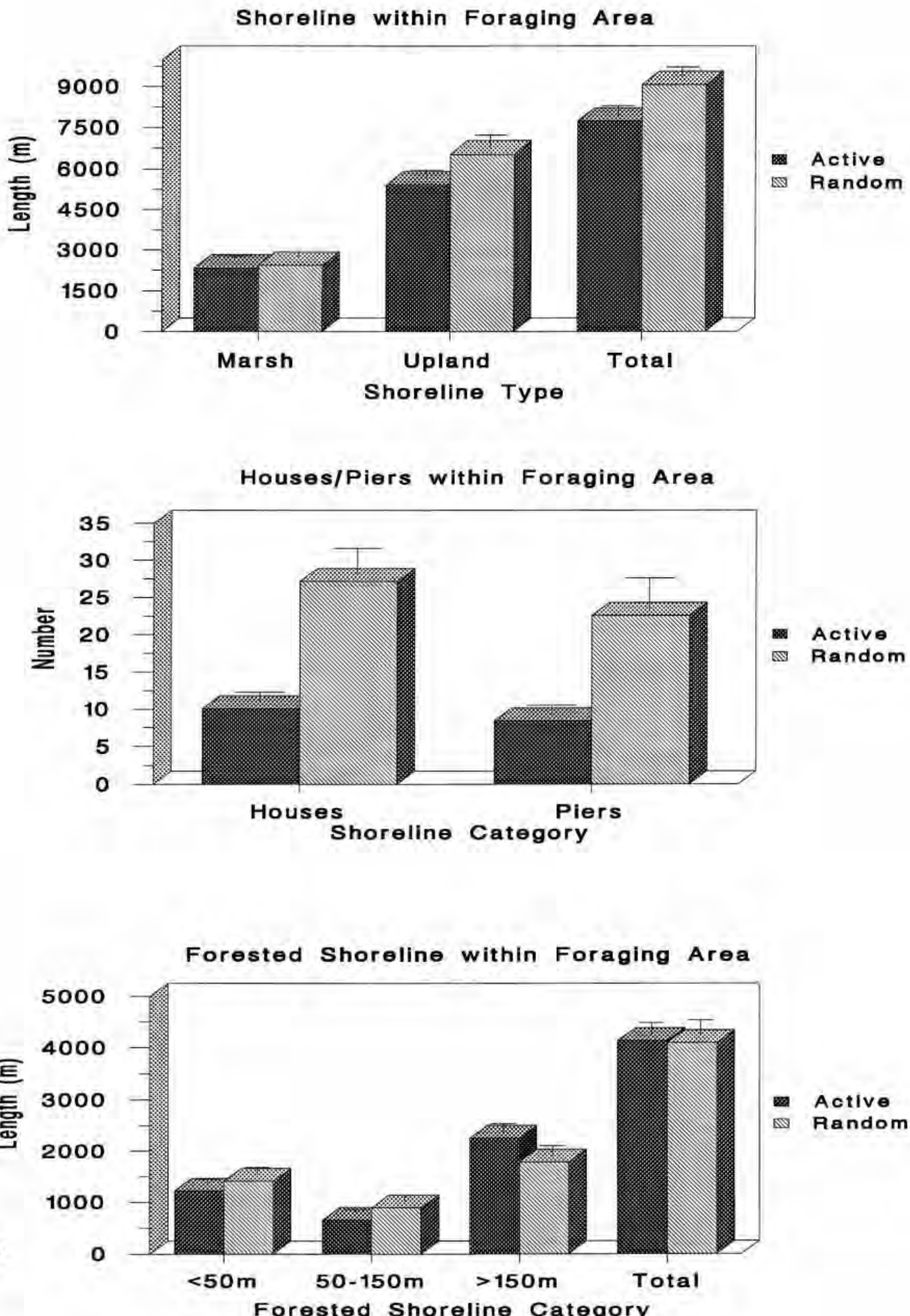

Shoreline within Foraging Area
Length (m)
9000
7500
6000
4500
3000
1500
0
Marsh
Upland
Total
Shoreline Type
Active
Random
Houses/Piers within Foraging Area
Number
35
30
25
20
15
10
5
0
Houses
Piers
Shoreline Category
Active
Random
Forested Shoreline within Foraging Area
Length (m)
5000
4000
3000
2000
1000
0
<50m
50-150m
>150m
Total
Forested Shoreline Category
Active
Random

Figure 8

THE MODEL

Sixteen variables survived the selection criteria and were evaluated using a direct discriminant function procedure. This procedure resulted in the following linear combination of variables:

-.02971984 X DISCH1
-.02264714 X DISCH2
-.01185676 X DISCH3
-.00060520 X DISCH4
-.00521514 X DISCH5
-.00042232 X MSHAR4
+.03209294 X DISUNR
+.02622746 X DISSCR
+.04761829 X DISBLD
+.00321745 X UNRDN4
+.00093799 X FORAR2
+.00399596 X FORAR1
-.16315130 X SCRDN2
+.00135922 X SCRDN4
-.04559869 X BLDDN4
+.03957766 X BLDDEN
-1.126655 (constant)

To further evaluate these variables and help assess their relative predictive value across the full range of conditions, 50 randomly selected subsets, each comprising 75% of the observations, were chosen and run through a 15-step DFA. On average, eight variables entered into the functions before variable selection stopped due to the low F-values for remaining variables. Two variables (DISBLD and DISUNR) entered into the functions on every run, one variable (DISUNR) entered 49 times, and three variables (DISSCR, DISCH2, and FORAR2) entered 43 times. The high loading frequency and high mean rank of these six variables suggest that they have superior discriminating power (Table 3).

Table 3. Loading frequency and mean rank of variables entered into discriminant analysis of 50 randomly selected subsets.

Variable	Transformation	N (freq)	Mean Rank	S.E.
DISBLD	$X^{1/2}$	50	1.000	0.000
DISCH1	$X^{1/2}$	50	4.140	0.200
DISUNR	$X^{1/2}$	49	5.735	0.130
DISSCR	$X^{1/2}$	43	2.674	0.239
DISCH2	$X^{1/2}$	43	3.349	0.199
FORAR2	----	43	5.000	0.160
SCRDN2	Log(1+X)	39	6.282	0.348
DISCH5	$X^{1/2}$	22	7.000	0.147
DISCH3	$X^{1/2}$	19	6.316	0.459
FORAR1	----	16	5.688	0.561
UNRDN4	$X^{1/2}$	11	8.364	0.279
DISCH4	$X^{1/2}$	9	6.778	0.641
MSHAR4	----	4	8.500	0.289
SCRDN4	Log(1+X)	3	7.667	0.882
BLDDEN	Log(1+X)	3	8.333	0.882
BLDDN4	Log(1+X)	1	10.000	-----

To evaluate the sensitivity of the discriminant model to the six-variable set, classification rates were examined from runs with each variable excluded in sequence (Table 4). Results from this sensitivity analysis suggest that DISUNR and FORAR2 do not contribute a great deal to the classification accuracy of the model. This result is consistent with their average loading positions (see Table 3). For ease of implementation, these variables were omitted from the final model.

The final 4-variable model is presented in Table 5 and produced a classification accuracy of 81.5%. Figure 9 shows the distribution of discriminant scores for both active and random points. Scores ranged from a low of -2.8396 for random sites to a high of 4.7340 for active nest sites. The range of highest overlap between the two groups was between -1.25 and 0.25. Discriminant scores were rescaled from 0 to 100 for ease of interpretation using the following equation:

$$\text{Habitat Quality (HQ)} = (DS + 2.8396)/0.075736$$

Four categories of habitat quality were derived from the distribution of habitat values. These categories included: 1) 0 - 21 corresponding to exclusively random sites (except for one nest outlier), and 2) 22 - 34 corresponding to the range of greatest overlap. These two categories were labelled questionable and acceptable. Beyond the range of greatest overlap, the remaining range was split fairly evenly to form two additional categories including: 3) 35 - 67 and 4) 68 - 100 labelled good and very good respectively.

To assess the classification accuracy of the final model across the full range of conditions, 20 hold-out runs were conducted. A model was first generated using a random portion (75%) of the total cases. The model equation was then used to compute scores and

Table 4. Classification rates of truncated six-step model with one variable withheld.

Variable withheld	Misclassified Random	Active	Total	Classification Rate (%)
-------	15	32	47	81.50
DISSCR	17	33	50	80.31
DISCH2	16	32	48	81.10
DISBLD	17	30	47	81.50
DISCH1	18	28	46	81.89
DISUNR	13	32	45	82.28
FORAR2	13	32	45	82.28

TABLE 5. Coefficients for variables entered into the final four-variable model.

Variable[a]	Transformation	Model Coefficient
Constant	------	-1.456741
DISSCR	$(X)^{1/2}$	$.4155321 \times 10^{-1}$
DISBLD	$(X)^{1/2}$	$.7842094 \times 10^{-1}$
DISCH1	$(X)^{1/2}$	$-.2893781 \times 10^{-1}$
DISCH2	$(X)^{1/2}$	$-.2205771 \times 10^{-1}$

[a] - See Tables 1 and 2 for variable descriptions.

Figure 9. Frequency distribution of discriminant scores for active and random sites.

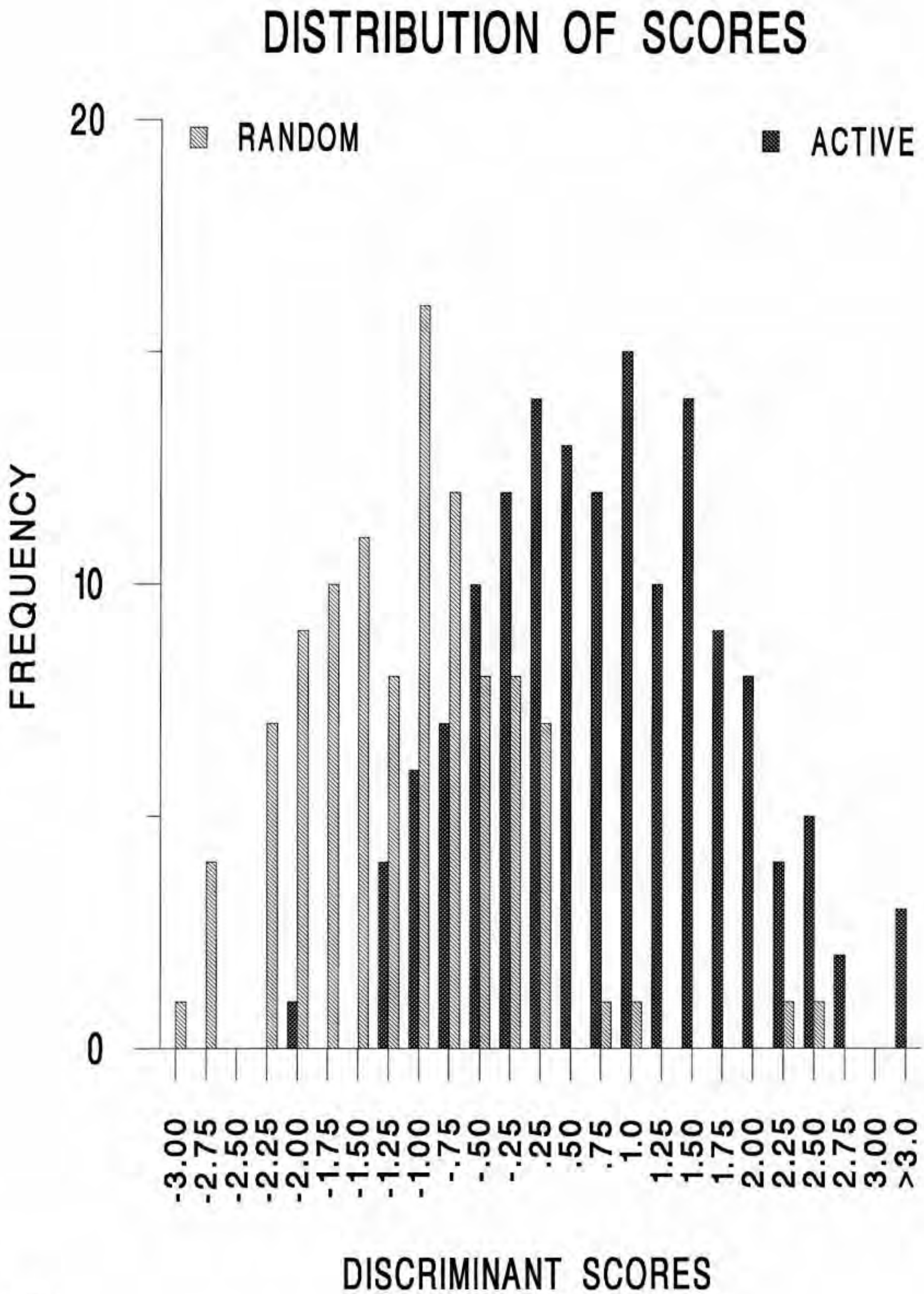

DISTRIBUTION OF SCORES
RANDOM
ACTIVE
FREQUENCY
20
10
0
-3.00
-2.75
-2.50
-2.25
-2.00
-1.75
-1.50
-1.25
-1.00
-.75
-.50
-.25
.25
.50
.75
1.0
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
>3.0
DISCRIMINANT SCORES

Figure 9

classify the remaining hold-out cases (25%). Classification rates ranged from 65.6% to 85.9% (see Table 6). Of the 1280 cases withheld during the 20 runs, 79.5% were classified correctly. This result suggests that the 4-variable model is reasonably robust over the range of conditions within the data set.

ADDITIONAL CONSTRAINTS

Because of the parametric constraints imposed on variables used in this sort of multivariate analysis, several variables that clearly bear on the distribution of eagles were excluded from the model. These variables were examined for their value in reducing the time and energy needed for model implementation. For this purpose some of these variables were incorporated into the final model in the form of constraints. These constraints were used as a "quick and dirty" method of determining whether or not the full array of parameters were needed to classify a given location as unsuitable. Four such constraints were identified including: 1) distance to water, 2) building density within 200 m, 3) building density within 400 m, and 4) presence or absence of forest cover within 200 m.

The first constraint used was distance to water. As mentioned in the methods, the distribution of 367 historic nest sites were examined relative to channels of varying widths. Five channel widths were addressed including: 1) < 100 m in width, 2) > 100 m in width, 3) > 250 m in width, 4) > 500 m in width, and 5) > 1 km in width. By examining accumulation curves arranged by distance (see Figure 10) it was possible to determine what proportion of the nest sites would be enclosed by a given distance from a particular channel. The distance needed to enclose all nest sites increased with channel width. All of the nests were within 2 km of small streams. However, the utility of this information in predicting the

Table 6. Accuracy of the model: classification results for the 20 hold out runs of discriminant analysis with maximum four variables.

RUN	WITHHELD		MISCLASSIFIED		TOTAL MISCLASSIFIED	CLASSIFICATION RATE (%)
	RANDOM	ACTIVE	RANDOM	ACTIVE		
1	26	38	5	12	17	73.44
2	27	37	6	7	13	79.69
3	28	36	2	10	12	81.25
4	27	37	1	10	11	82.81
5	25	39	3	11	14	78.13
6	30	34	4	6	10	84.38
7	25	39	5	10	15	76.56
8	30	34	2	10	12	81.25
9	26	38	3	7	10	84.38
10	28	36	5	8	13	79.69
11	26	38	2	7	9	85.94
12	26	38	4	10	14	78.13
13	26	38	3	9	12	81.25
14	25	39	7	15	22	65.63
15	27	37	6	10	16	75.00
16	27	37	5	5	10	84.38
17	23	41	4	8	12	81.25
18	26	38	6	8	14	78.13
19	26	38	4	9	13	79.69
20	27	37	3	10	13	79.69
TOTAL	531	749	80	182	262	

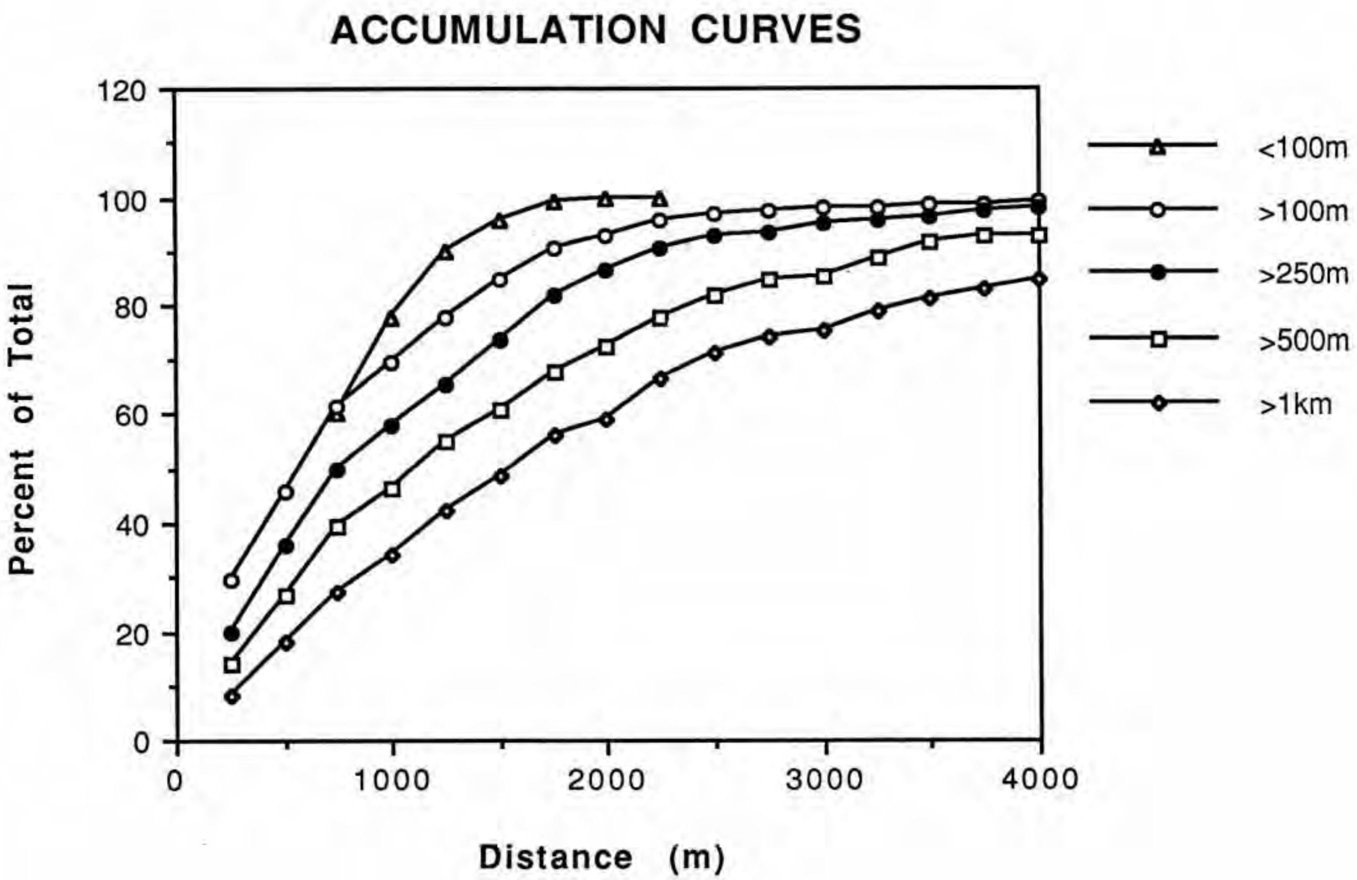

ACCUMULATION CURVES
Percent of Total
Distance (m)
0
20
40
60
80
100
120
0
1000
2000
3000
4000
<100m
>100m
>250m
>500m
>1km

Figure 10

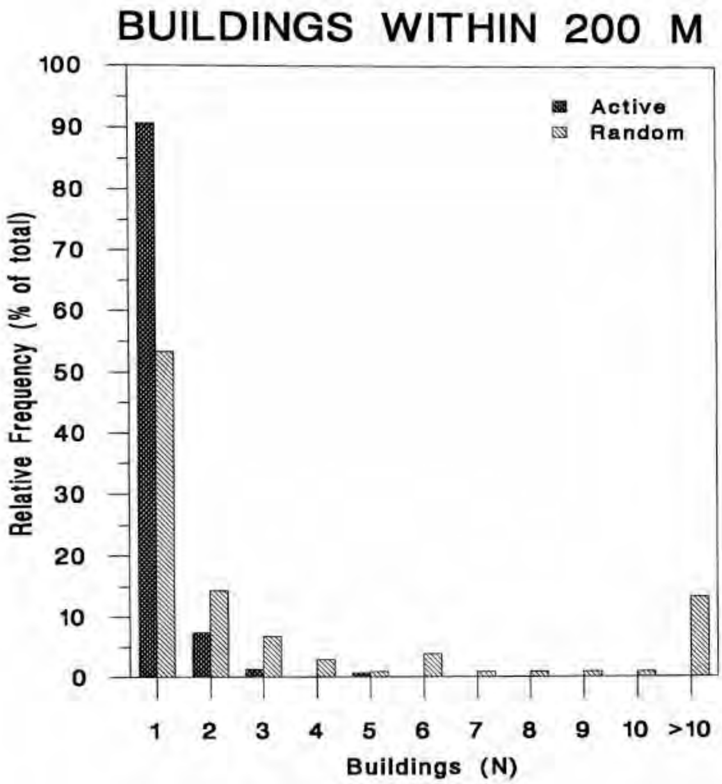
Figure 10. Accumulation curves for the proportion of nests within given distances to water bodies with various channel widths.

distribution of eagles is very low because small streams are distributed widely across the entire coastal plain (in essence most points within the coastal plain are within this distance of small streams). The channel width that seemed to have the most value in reducing the working area was 250 m. This is suggested not only by the accumulation curves but also by the fact that when moving up major drainages that contain nesting eagles, pairs tend to disappear when the channel narrows to below this width. For a channel width of 250 m, virtually all nests are enclosed within a 3 km buffer zone. This value was used for the distance to water constraint and defines the focal area for model implementation.

The second set of constraints used was associated with the density of houses. As observed in Figure x, Bald Eagles exhibit a strong aversion to buildings and densities in close proximity to nests were low in comparison to background levels. Upon closer examination, it was determined that although housing densities were high in many areas, eagles did not nest in locations having greater that 5 houses within 200 m or having greater than 10 houses within 400 m (see Figure 11). These apparent tolerance limits were used as building density constraints.

The final constraint used was associated with forest cover. On average, Bald Eagle nest sites were associated with more extensive forest cover than was generally available on the coastal plain. Because eagles require large, mature trees for nesting it then follows that areas devoid of trees would not be potential nesting sites. For this reason, the presence of some forest cover was a prerequisite for employing the classification model.

Figure 11. Comparison between active and random sites in the density of buildings within 200 and 400 m. Histograms indicate the relative frequency of sites with respective building densities.


BUILDINGS WITHIN 200 M
Active
Random
Relative Frequency (% of total)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
>10
Buildings (N)

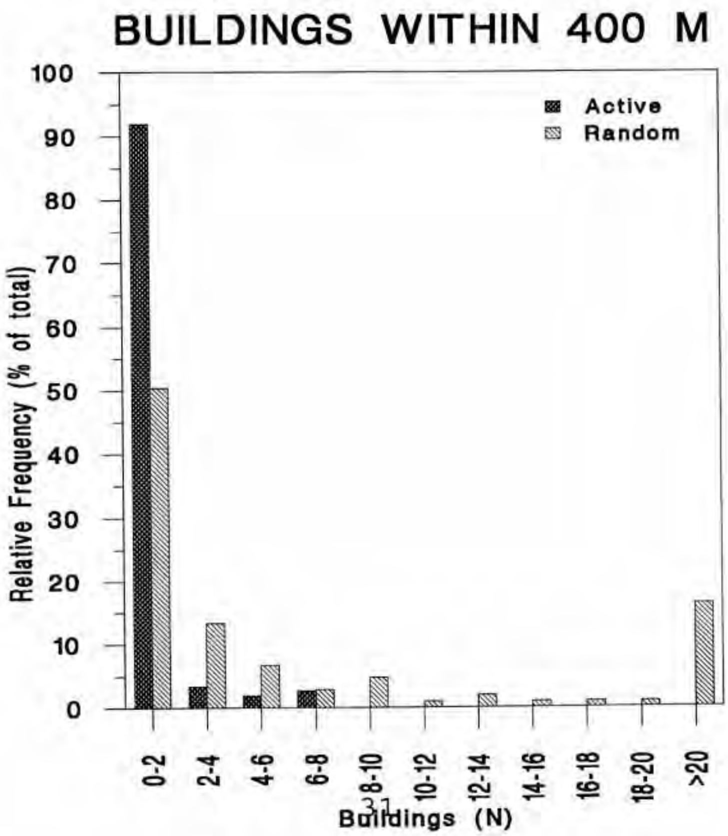

BUILDINGS WITHIN 400 M
Active
Random
Relative Frequency (% of total)
100
90
80
70
60
50
40
30
20
10
0
0-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
>20
Buildings (N)

Figure 11

THE FINAL MODEL

The final land classification model is a combination of the constraints and the final 4-variable discriminant function model (see Figure 12). A given site may be classified by first employing the sequence of constraints to determine whether or not the site is suitable for nesting, and then evaluating the quality of the site by quantifying the 4 model variables. The resulting score may then be rescaled and compared to the ordinal scale to determine relative nesting potential.

Figure 12. Conceptual illustration of final land classification model. Schematic indicates the process of implementation from the series of constraints to the application of discriminant model. Habitat quality values are rescaled between 0 and 100.

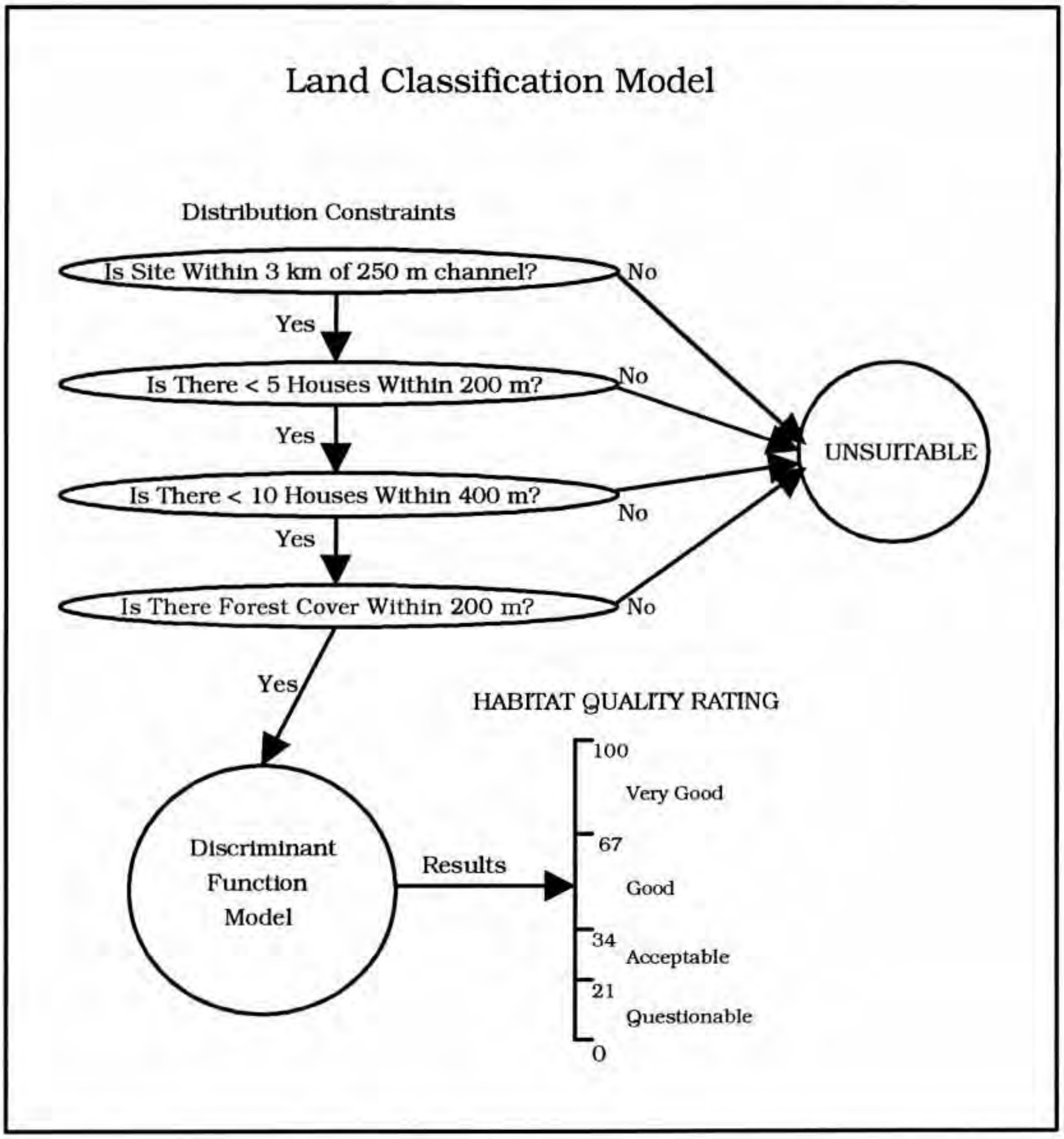

Land Classification Model
Distribution Constraints
Is Site Within 3 km of 250 m channel?
No
Yes
Is There < 5 Houses Within 200 m?
No
Yes
Is There < 10 Houses Within 400 m?
No
Yes
Is There Forest Cover Within 200 m?
No
UNSUITABLE
Yes
HABITAT QUALITY RATING
100
Very Good
67
Good
34
Acceptable
21
Questionable
0
Discriminant
Function
Model
Results

Figure 12

APPENDIX I. Descriptive statistics on untransformed variables and univariate test results. All statistics presented are F-statistics, unless otherwise indicated.

Variable	Nest (N = 149) X ± SE (Range)	Random (N = 105) X ± SE (Range)	Stat[a]	P
DISCH1	309 ± 42.7 (0.0 - 5520)	511 ± 40.9 (24 - 2230)	23.9	<0.001
DISCH2	686 ± 54.1 (0.0 - 4214)	1090 ± 80.4 (72 - 3000)	21.1	<0.001
DISCH3	1051 ± 83.0 (0.0 - 7501)	1392 ± 83.3 (73 - 3000)	12.6	<0.001
DISCH4	1655 ± 147.1 (0.0 - 10857)	1991 ± 139.0 (84 - 7272)	6.9	<0.01
DISCH5	2471 ± 228.9 (0.0 - 13320)	3026 ± 235.2 (84 - 12000)	6.2	<0.05
MSHAR1	2.7 ± 0.31 (0.0 - 15.8)	0.6 ± 0.20 (0.0 - 15.0)	10242.0[a]	<0.001
MSHAR2	8.5 ± 0.87 (0.0 - 50.3)	2.6 ± 0.60 (0.0 - 44.1)	10533.0[a]	<0.001
MSHAR3	25.9 ± 2.53 (0.0 - 169.9)	11.8 ± 1.71 (0.0 - 99.0)	10855.5[a]	<0.001
MSHAR4	88.5 ± 7.70 (0.0 - 496.1)	52.5 ± 5.50 (0.0 - 243.1)	12.3	<0.01
MSHAR5	5.8 ± 0.62 (0.0 - 34.6)	2.0 ± 0.44 (0.0 - 29.1)	10722.5[a]	<0.001
MSHAR6	17.4 ± 1.83 (0.0 - 135.4)	9.2 ± 1.26 (0.0 - 54.9)	11302.5[a]	<0.001
MSHAR7	62.6 ± 5.67 (0.0 - 393.6)	40.7 ± 4.19 (0.0 - 171.3)	11828.5[a]	<0.01
WATAR1	0.7 ± 0.15 (0.0 - 11.0)	0.1 ± 0.05 (0.0 - 2.5)	12263.0[a]	<0.01
WATAR2	4.7 ± 0.66 (0.0 - 45.3)	1.9 ± 0.65 (0.0 - 58.2)	11776.5[a]	<0.001

Appendix I. --- continued ---

WATAR3	25.4 ± 2.73 (0.0 - 161.6)	11.3 ± 2.08 (0.0 - 108.1)	11400.0[a]	<0.001
WATAR4	129.5 ± 11.08 (0.0 - 574.4)	77.2 ± 10.91 (0.0 - 427.6)	11221.0[a]	<0.001
WATAR5	4.0 ± 0.55 (0.0 - 34.3)	1.8 ± 0.64 (0.0 - 58.2)	11825.5[a]	<0.01
WATAR6	20.7 ± 2.19 (0.0 - 116.3)	9.3 ± 1.66 (0.0 - 72.3)	11482.0[a]	<0.001
WATAR7	104.1 ± 8.95 (0.0 - 463.0)	66.0 ± 9.39 (0.0 - 416.6)	11334.5[a]	<0.001
DISUNR	475.5 ± 30.61 (24.1 - 2361.8)	328.7 ± 32.14 (24.1 - 1879.8)	13.5	<0.001
DISSCR	765.0 ± 50.97 (48.2 - 4265.7)	299.5 ± 31.69 (24.1 - 1373.7)	82.2	<0.001
DISBLD	749.0 ± 54.72 (24.1 - 5470.7)	252.5 ± 24.88 (24.1 - 1373.7)	59.8	<0.001
UNRDN1	86.4 ± 15.17 (0.0 - 863.8)	137.7 ± 22.03 (0.0 - 908.5)	14560.5[a]	<0.05
UNRDN2	391.2 ± 44.19 (0.0 - 2333.5)	474.0 ± 51.73 (0.0 - 2013.3)	14451.5[a]	<0.10
UNRDN3	1430.3 ± 105.08 (0.0 - 5157.1)	1624.5 ± 137.27 (0.0 - 9126.9)	14118.0[a]	NS
UNRDN4	6091.4 ± 292.08 (0.0 - 19903.0)	5755.5 ± 354.40 (0.0 - 20235.1)	1.0	NS
UNRDN5	304.8 ± 33.30 (0.0 - 1591.0)	336.3 ± 35.29 (0.0 - 1490.9)	14185.0[a]	<0.15
UNRDN6	1039.1 ± 72.19 (0.0 - 3277.0)	1150.5 ± 112.90 (0.0 - 8303.0)	13679.0[a]	NS
UNRDN7	4661.1 ± 236.38 (0.0 - 16688.9)	4131.0 ± 264.09 (0.0 - 14551.7)	12502.0[a]	<0.15
SCRDN1	32.2 ± 9.07 (0.0 - 610.7)	334.2 ± 46.22 (0.0 - 2173.2)	16823.5[a]	<0.001
SCRDN2	199.0 ± 38.53 (0.0 - 3817.0)	1239.4 ± 159.58 (0.0 - 8507.7)	74.5	<0.001

Appendix I. --- continued ---

SCRDN3	1157.0 ± 112.79 (0.0 - 6317.0)	4238.8 ± 531.23 (0.0 - 30911.7)	41.5	<0.001
SCRDN4	5747.0 ± 364.16 (0.0 - 21526.6)	15618.4 ± 1846.37 (306.8 - 102914.2)	28.4	<0.001
SCRDN5	166.8 ± 34.09 (0.0 - 3817.0)	905.2 ± 120.28 (0.0 - 6792.7)	17437.5[a]	<0.001
SCRDN6	958.0 ± 93.61 (0.0 - 5820.0)	2999.4 ± 386.50 (0.0 - 22404.0)	36.8	<0.001
SCRDN7	4589.9 ± 291.88 (0.0 - 19344.6)	11379.5 ± 1341.67 (217.0 - 72002.5)	16431.5[a]	<0.001
BLDDN1	0.2 ± 0.06 (0 - 8)	7.7 ± 2.07 (0 - 147)	16487.5[a]	<0.001
BLDDN2	0.9 ± 0.17 (0 - 12)	27.3 ± 6.58 (0 - 354)	18342.5[a]	<0.001
BLDDN3	8.6 ± 1.72 (0 - 170)	104.8 ± 25.92 (0 - 1528)	17971.0[a]	<0.001
BLDDN4	59.2 ± 11.19 (0 - 1346)	414.2 ± 87.82 (0 - 4247)	48.2	<0.001
BLDDN5	0.7 ± 0.15 (0 - 12)	19.6 ± 4.63 (0 - 226)	18041.0[a]	<0.001
BLDDN6	7.7 ± 1.65 (0 - 170)	77.5 ± 19.52 (0 - 1174)	17615.5[a]	<0.001
BLDDN7	50.7 ± 10.15 (0 - 1293)	309.3 ± 63.67 (0 - 3016)	16815.0[a]	<0.001
CLCTAR	3.4 ± 0.95 (0.0 - 73.4)	1.5 ± 0.58 (0.0 - 35.2)	12873.0[a]	<0.15
YGFRAR	6.8 ± 1.28 (0.0 - 80.9)	5.5 ± 1.33 (0.0 - 80.5)	13374.0[a]	NS
IMFRAR	15.1 ± 1.77 (0.0 - 87.6)	27.1 ± 4.40 (0.0 - 421.6)	15476.5[a]	<0.001
MATFAR	29.2 ± 2.09 (0.0 - 93.9)	7.2 ± 1.45 (0.0 - 81.6)	62.9	<0.001
FRWTAR	3.0 ± 0.66 (0.0 - 51.1)	0.5 ± 0.23 (0.0 - 19.5)	12071.5[a]	<0.001

Appendix I. --- continued ---

FORAR1	57.4 ± 1.89 (0.0 - 109.1)	41.7 ± 4.70 (0.0 - 440.8)	10195.0[a]	<0.001
FORAR2	738.1 ± 24.37 (65.2 - 1497.3)	581.0 ± 34.58 (0.0 - 1630.6)	14.6	<0.001
AGLAAR	10.6 ± 1.35 (0.0 - 77.8)	24.6 ± 2.57 (0.0 - 107.7)	15883.5[a]	<0.001
URLAAR	0.4 ± 0.14 (0.0 - 13.8)	15.8 ± 2.66 (0.0 - 86.3)	15771.0[a]	<0.001
MASHLE	2331.7 ± 188.01 (0.0 - 9544.1)	2420.5 ± 255.72 (0.0 - 12158.9)	13383.0[a]	NS
UPSHLE	5397.7 ± 307.80 (0.0 - 18266.4)	6515.8 ± 438.46 (0.0 - 20742.3)	14537.5[a]	<0.05
TOSHLE	7718.7 ± 319.05 (0.0 - 21963.8)	9064.8 ± 404.16 (3319.3 - 21555.0)	15049.5[a]	<0.01
BLDDEN	10.0 ± 1.40 (0 - 120)	27.1 ± 3.60 (0 - 210)	22.3	<0.001
PIRDEN	8.4 ± 1.27 (0 - 85)	22.6 ± 4.15 (0 - 353)	16021.5[a]	<0.001
FORSH1	1221.4 ± 109.16 (0.0 - 5943.5)	1417.6 ± 140.39 (0.0 - 5913.5)	14028.0[a]	NS
FORSH2	655.8 ± 83.76 (0.0 - 9416.6)	892.7 ± 123.36 (0.0 - 7680.3)	2.7	<0.15
FORSH3	2251.7 ± 163.34 (0.0 - 9254.0)	1782.6 ± 191.35 (0.0 - 10519.9)	3.5	<0.10
TFORSH	4128.8 ± 226.83 (0.0 - 12571.4)	4092.8 ± 312.29 (0.0 - 14600.0)	0.01	NS

[a] - Mann-Whitney U test statistic