Production and Implementation of a Habitat Suitability Model for Breeding Bald Eagles in the Lower Chesapeake Bay

(Model Construction through Habitat Mapping)

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Final Report to: Virginia Department of Game and Inland Fisheries,
(Nongame and Endangered Species Program)

Project sponsored by:

Virginia Environmental Endowment

Virginia Department of Environmental Quality
Virginia Coastal Resources Management Program

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

January 1994

This paper is funded in part by a grant from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

Rec'd. by Dept. of
Environmental Quality

FEB 11 1994

Public & Inter-
governmental Affairs

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QL696.156.V8 1994

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.

The final model was used to classify lands along a 100 mi. reach of the James River and a 75 mi. reach of the Rappahannock River. All lands along these drainages or their

tributaries that fell within 3 km of a channel at least 250 m wide were classified. This land mass included over 2,300 km^2. Classification of the area was accomplished by establishing a network of over 15,000 registration points, parameterizing the model variables for each point independently, and employing the classification model.

A substantial portion of the James and Rappahannock River drainages (458 and 274 km^2 respectively) was classified as unsuitable due to high housing density and/or the lack of adequate nesting substrate. However, a comparable portion of both drainages was also found to contain either good or very good habitat for breeding (344 and 349 km^2 for the James and Rappahannock Rivers respectively). Relationships between habitat quality and the model variables were consistent with those expected based on the univariate results.

ACKNOWLEDGEMENTS

Financial support for this project was provided by the Virginia Environmental Endowment, the Virginia Department of Environmental Quality's Coastal Resources Management Program and the Virginia Department of Game and Inland Fisheries' Nongame and Endangered Species Program. We acknowledge these agencies for supporting new initiatives in Bald Eagle management.

This study would not have been possible without the hard work of many students and associates of the Center for Conservation Biology including: Lanny Bear, Susan Summers, Amanda Allen, Michelle Mabry, Jennifer D'Amico, Brian Dougherty, Megan Davis, Jeff Norgard, and Ellen McLean. Ellen McLean in particular supervised and coordinated the collection of the initial data. Dana Bradshaw collaborated on the initial planning of the project and provided much needed logistical support from the Department of Game and Inland Fisheries.

Production and printing of the final GIS-based classification maps was done by Steve Phillips of the Virginia Department of Game and Inland Fisheries BOVA program under the direction of Becky Wajda. We appreciate their efforts toward the completion of the final maps. This document is publication number 5 of the Virginia Center for Conservation Biology.

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 151 pairs in 1993. 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, 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, and 3) to delineate lands in

selected "demonstration" areas for the purpose of providing local jurisdictions with the information needed to make informed decisions regarding land use and habitat needs of Bald Eagles.

Project objectives were to be accomplished in two distinct phases. Phase I to include data collection and model construction and Phase II to include model implementation and land classification. This report is intended to give a brief overview of the methods, results, and products of these two project phases (project phases presented sequentially).

Phase I

Data Collection/Model Construction

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.

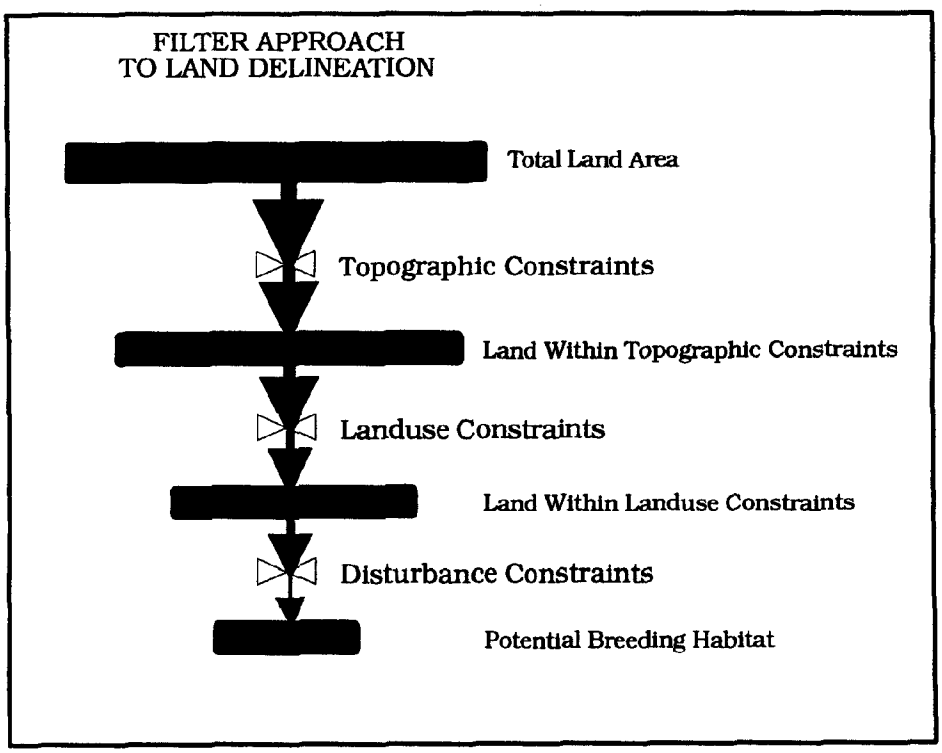

FILTER APPROACH
TO LAND DELINEATION
Total Land Area
Topographic Constraints
Land Within Topographic Constraints
Landuse Constraints
Land Within Landuse Constraints
Disturbance Constraints
Potential Breeding Habitat

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.

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

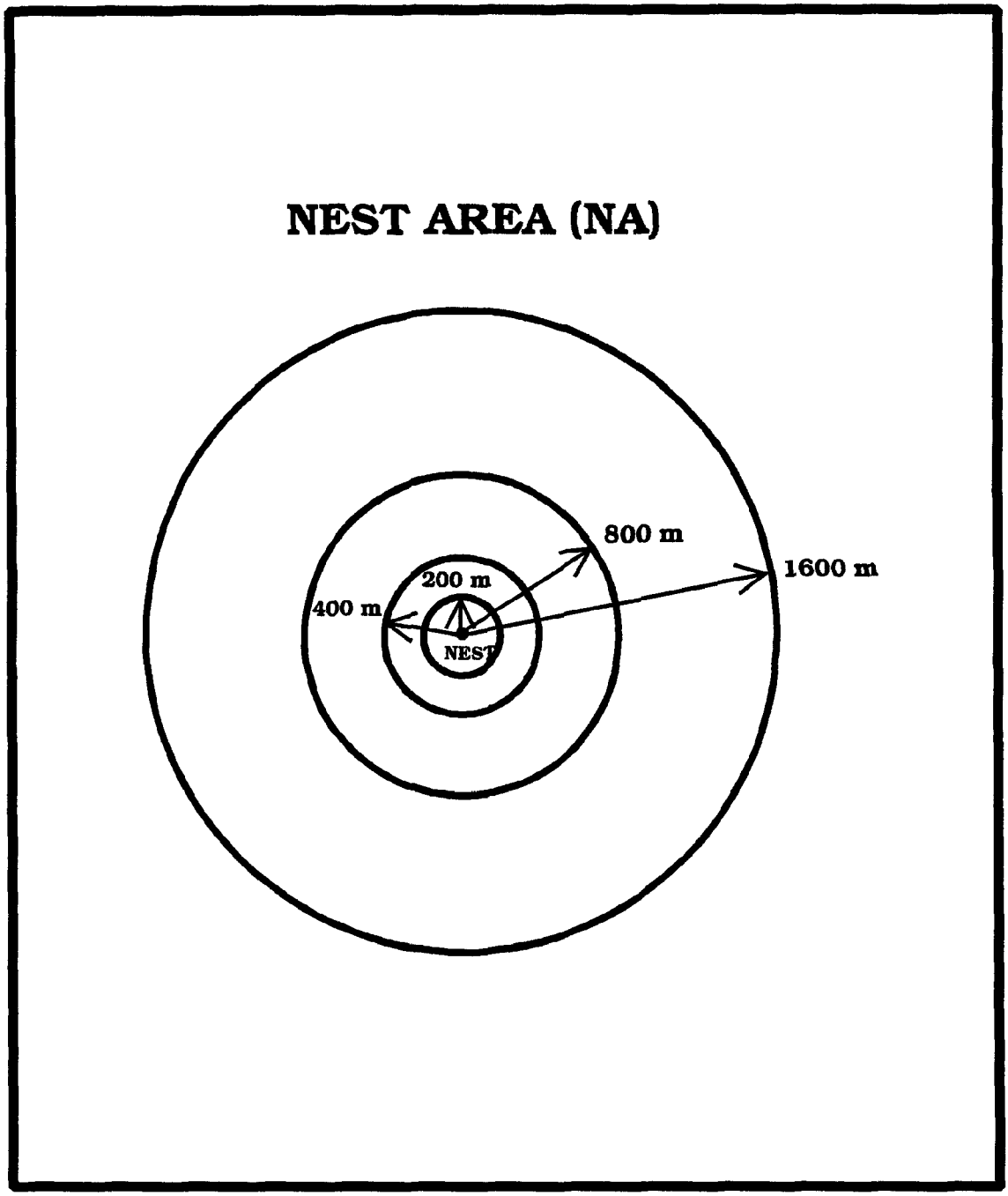


Figure 2

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.

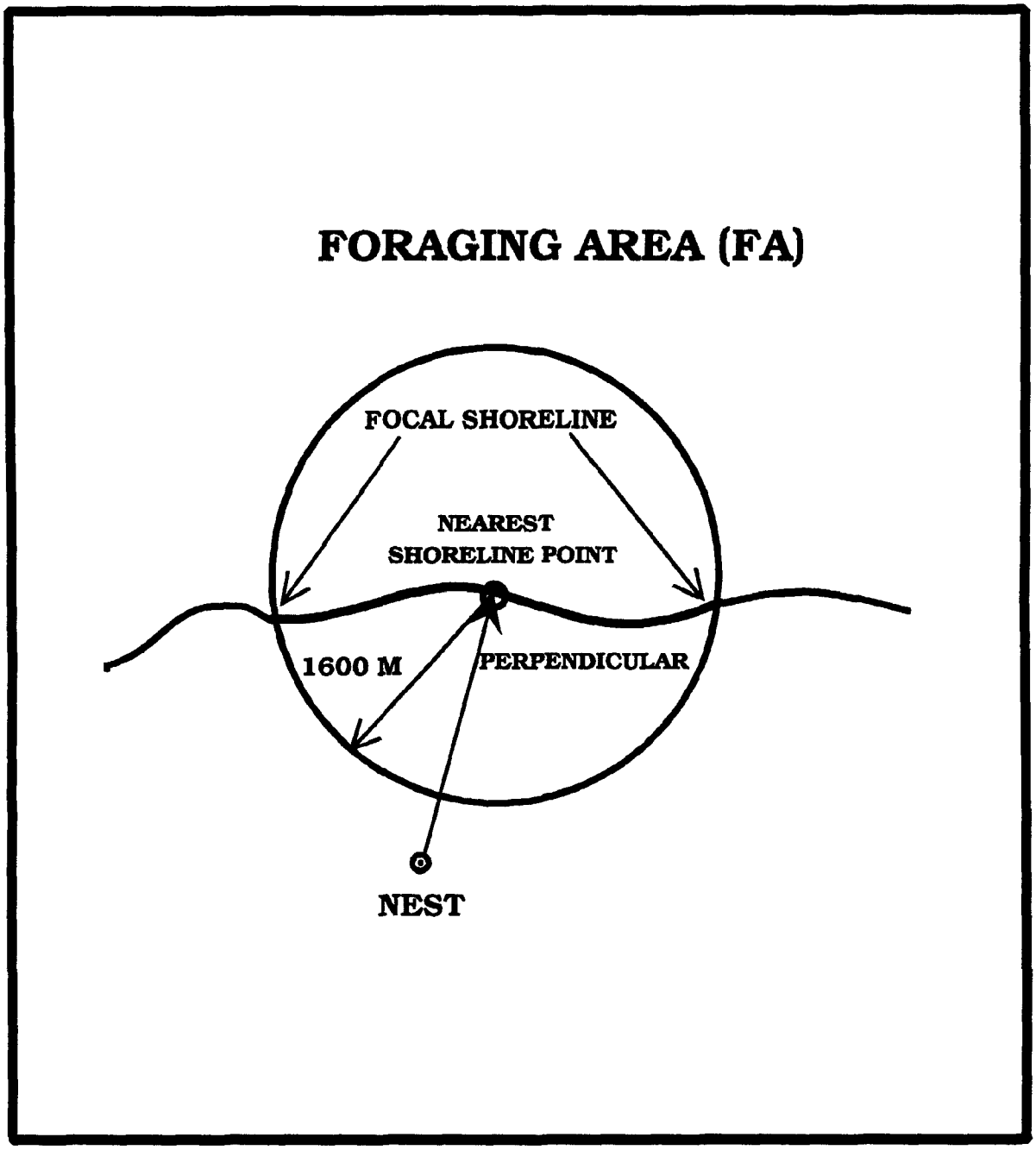

FORAGING AREA (FA)
FOCAL SHORELINE
NEAREST
SHORELINE POINT
1600 M
PERPENDICULAR
NEST

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 (see Appendix I for details on individual measurements).

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 II 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 + or - one standard error.

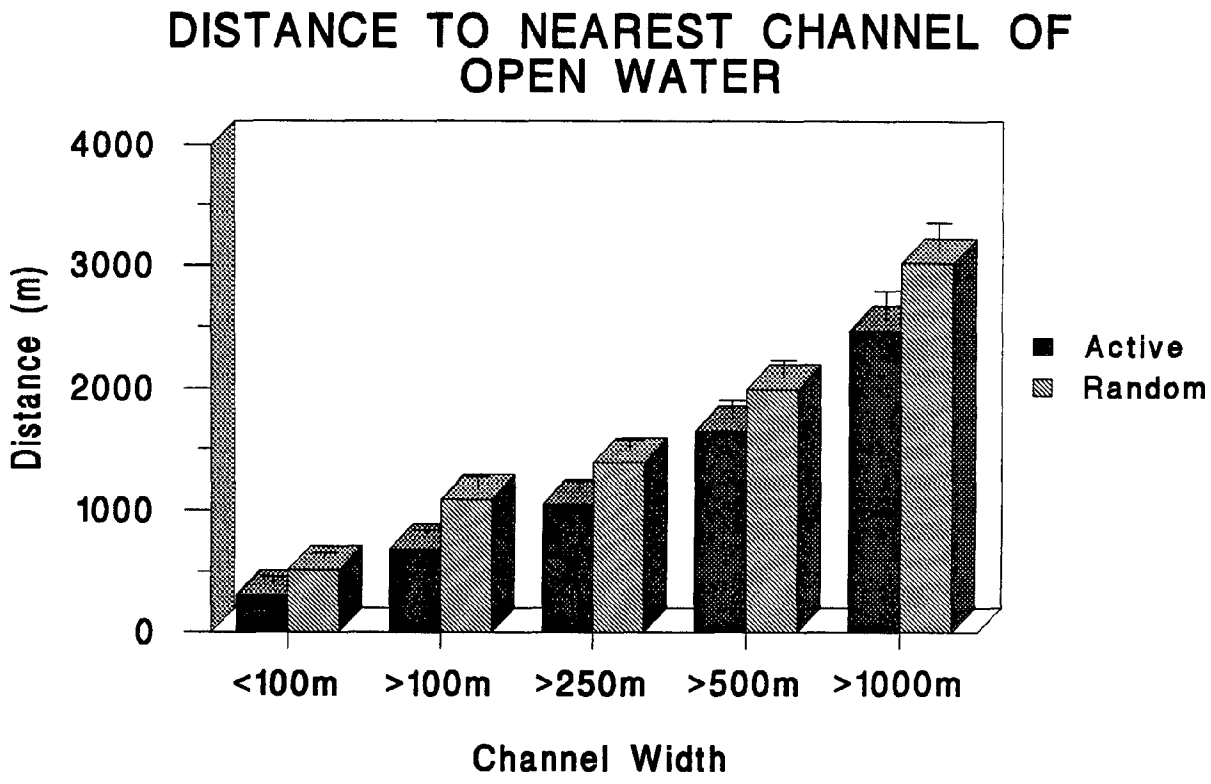
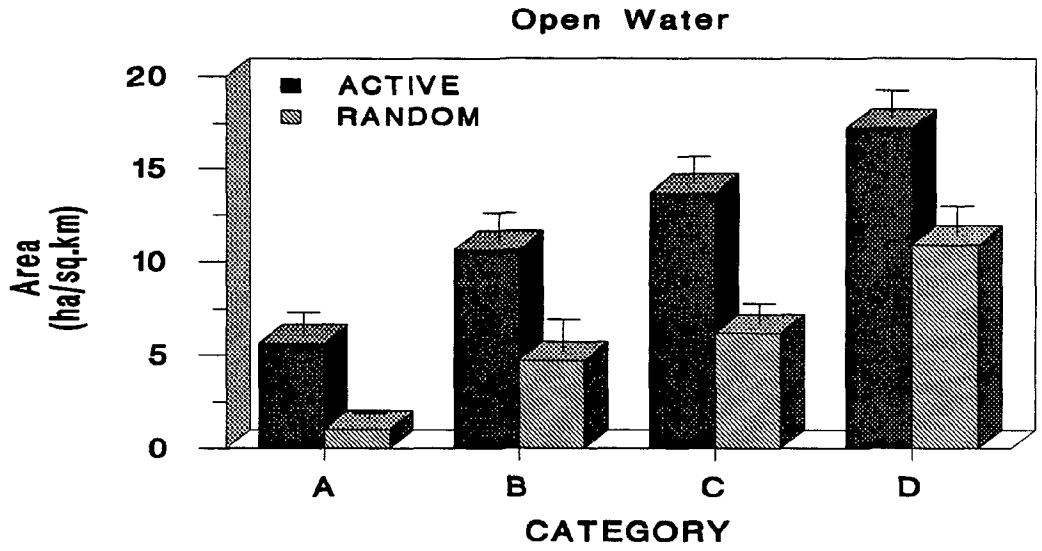

DISTANCE TO NEAREST CHANNEL OF OPEN WATER
4000
3000
2000
1000
0
Distance (m)
<100m
>100m
>250m
>500m
>1000m
Channel Width
Active
Random

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

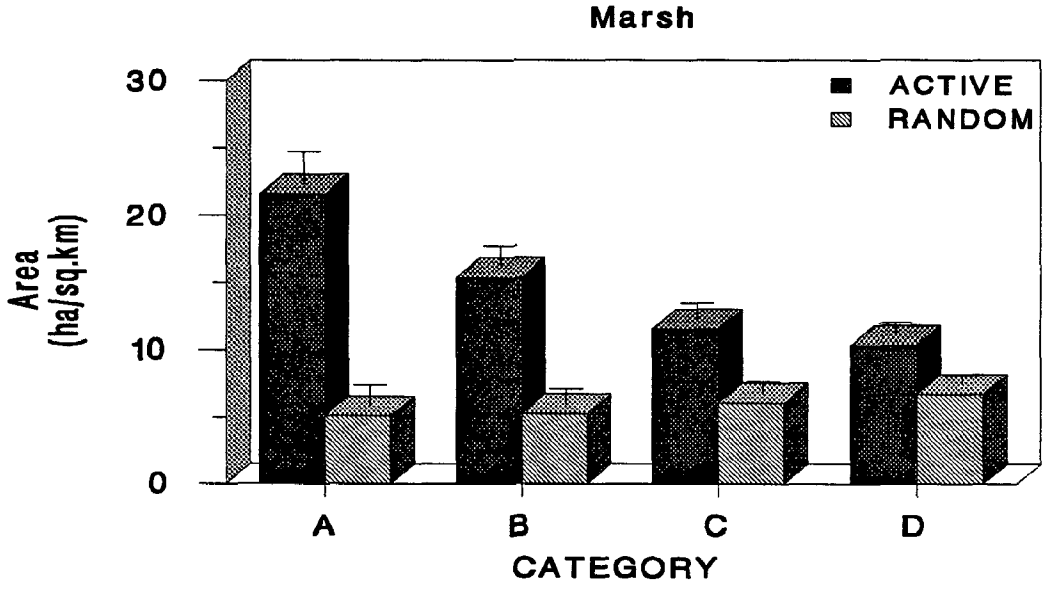

Marsh
ACTIVE
RANDOM
Area (ha/sq.km)
30
20
10
0
A
B
C
D
CATEGORY

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.

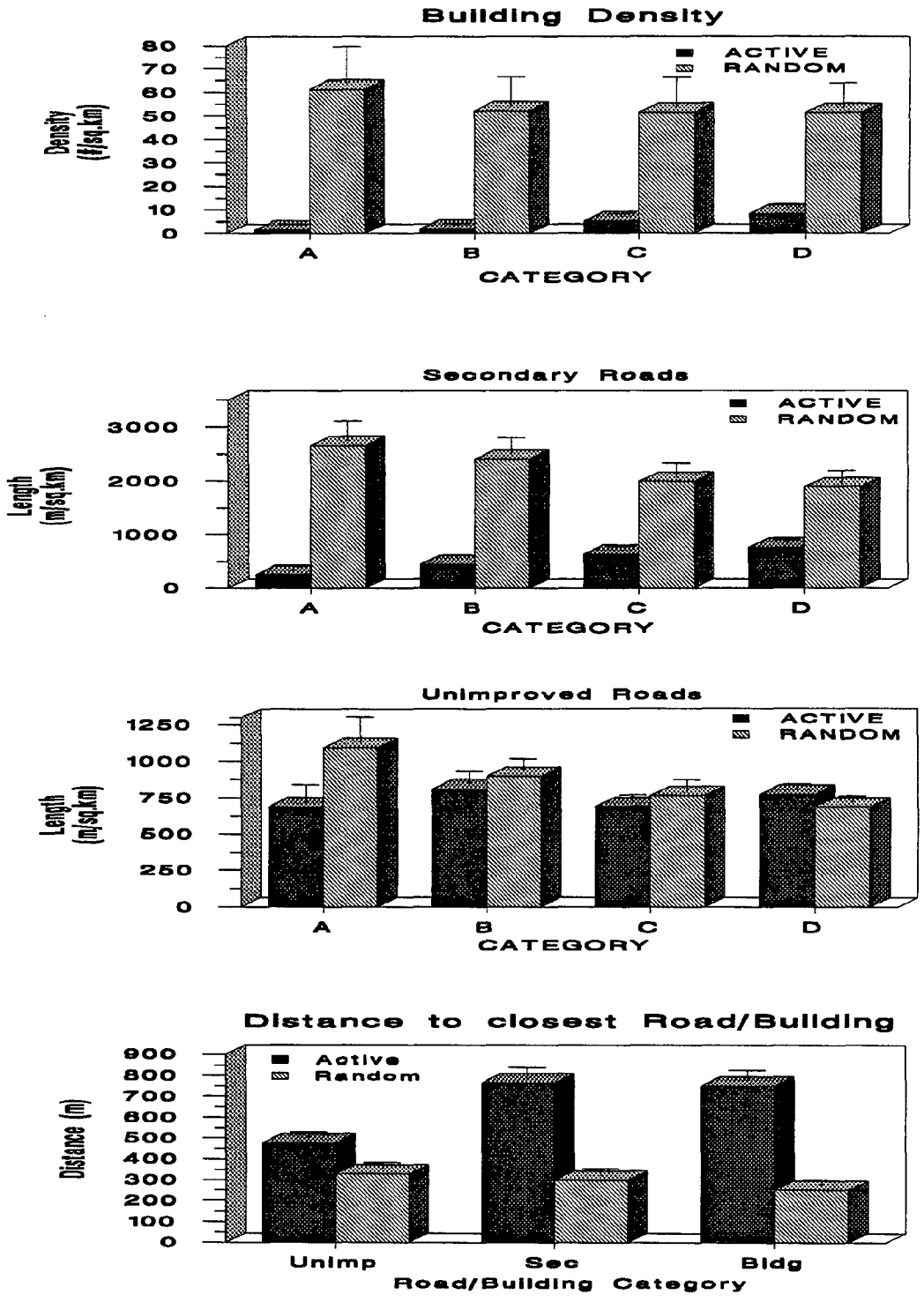

Building Density
Density (#/sq.km)
80
70
60
50
40
30
20
10
0
ACTIVE
RANDOM
A
B
C
D
CATEGORY
Secondary Roads
Length (m/sq.km)
3000
2000
1000
0
ACTIVE
RANDOM
A
B
C
D
CATEGORY
Unimproved Roads
Length (m/sq.km)
1250
1000
750
500
250
0
ACTIVE
RANDOM
A
B
C
D
CATEGORY
Distance to closest Road/Building
Distance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

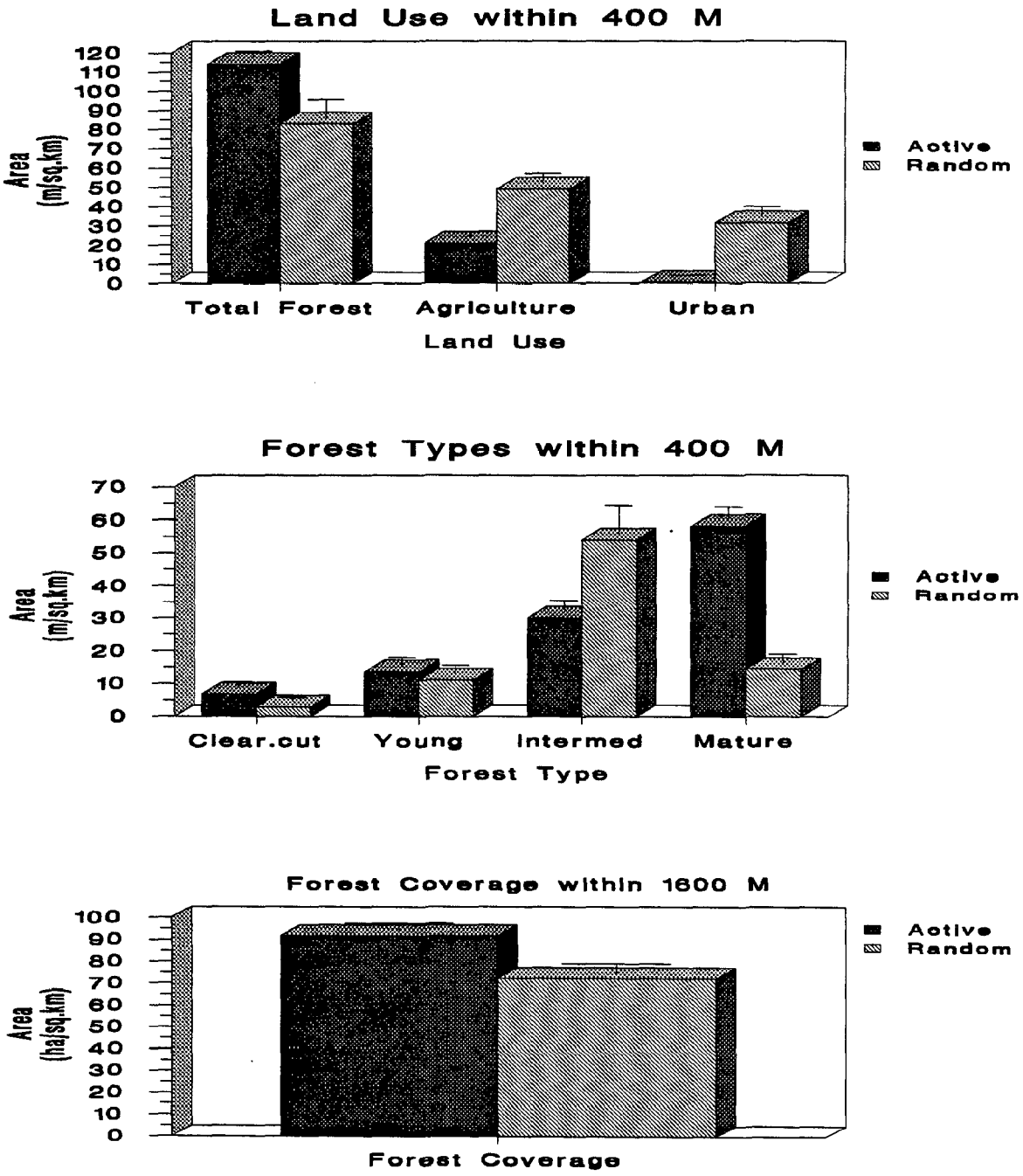

Land Use within 400 M
Area (m/sq.km)
120
110
100
90
80
70
60
50
40
30
20
10
0
Total Forest
Agriculture
Urban
Land Use
Active
Random
Forest Types within 400 M
Area (m/sq.km)
70
60
50
40
30
20
10
0
Clear.cut
Young
Intermed
Mature
Forest Type
Active
Random
Forest Coverage within 1600 M
Area (ha/sq.km)
100
90
80
70
60
50
40
30
20
10
0
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.

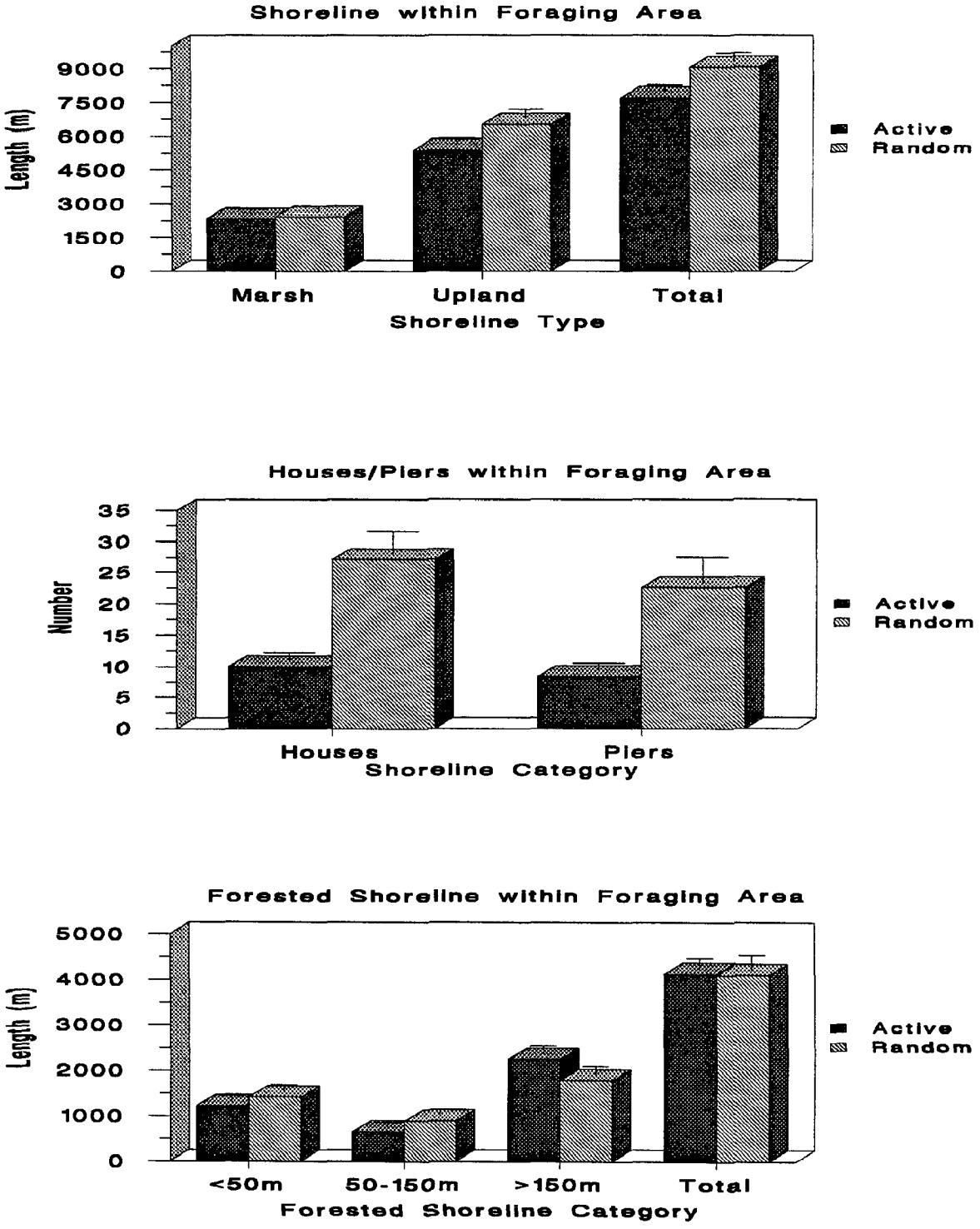

Shoreline within Foraging Area
Length (m)
9000
7500
6000
4500
3000
1500
0
Marsh
Upland
Total
Shoreline Type
Active
Random
Houses/Piers within Foraging Area
Number
35
30
25
20
15
10
5
0
Houses
Piers
Shoreline Category
Active
Random
Forested Shoreline within Foraging Area
Length (m)
5000
4000
3000
2000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

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

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			Classification Rate (%)
	Random	Active	Total	
-------	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 X 10^{-1}
DISBLD	$(X)^{1/2}$	.7842094 X 10^{-1}
DISCH1	$(X)^{1/2}$	-.2893781 X 10^{-1}
DISCH2	$(X)^{1/2}$	-.2205771 X 10^{-1}

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

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

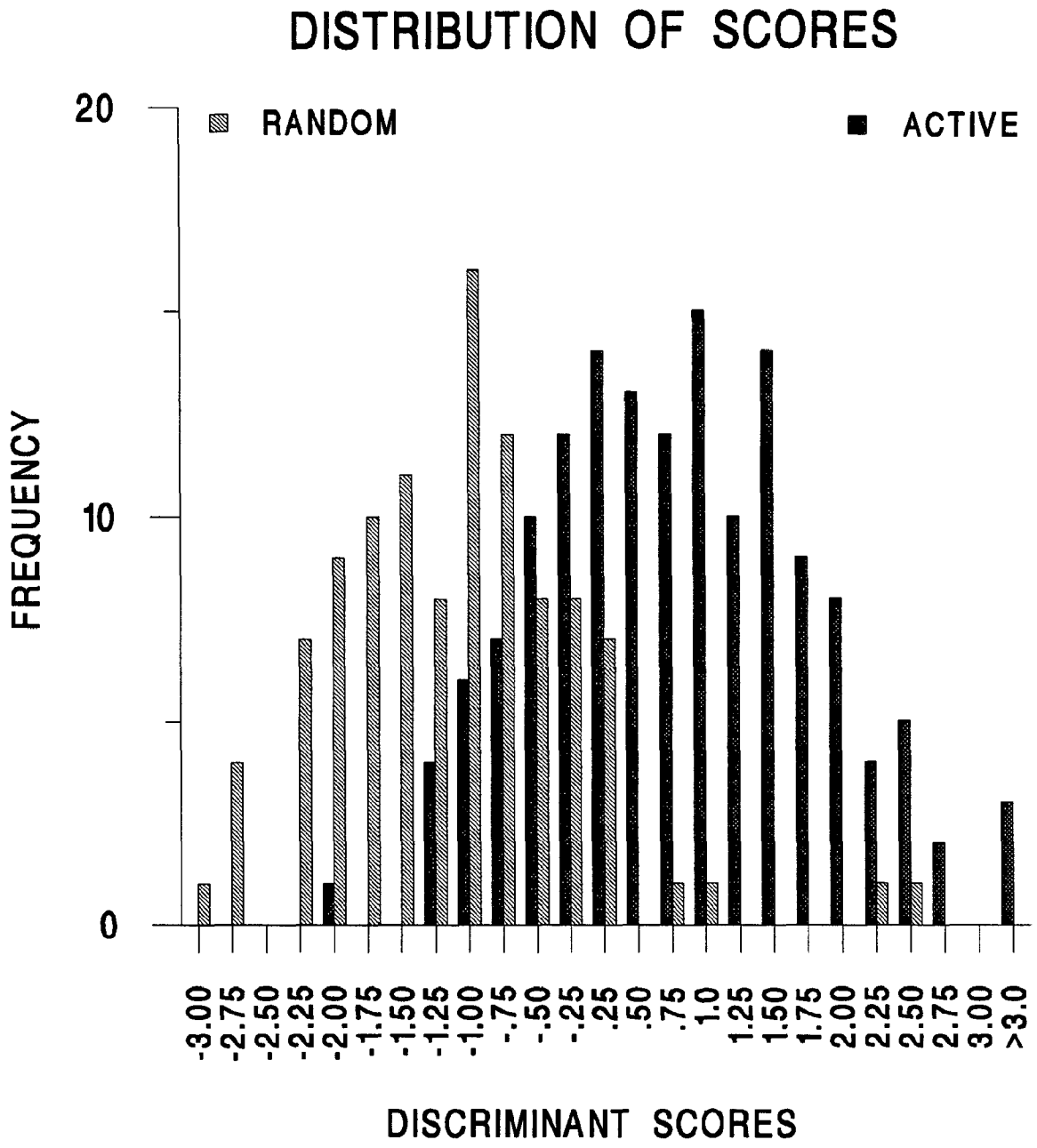

DISTRIBUTION OF SCORES
RANDOM
ACTIVE
20
10
0
FREQUENCY
-3.00
-2.75
-2.50
-2.25
-2.00
-1.75
-1.50
-1.25
-1.00
-.75
-.50
-.25
.25
.50
.75
1.0
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
>3.0
DISCRIMINANT SCORES

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	

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

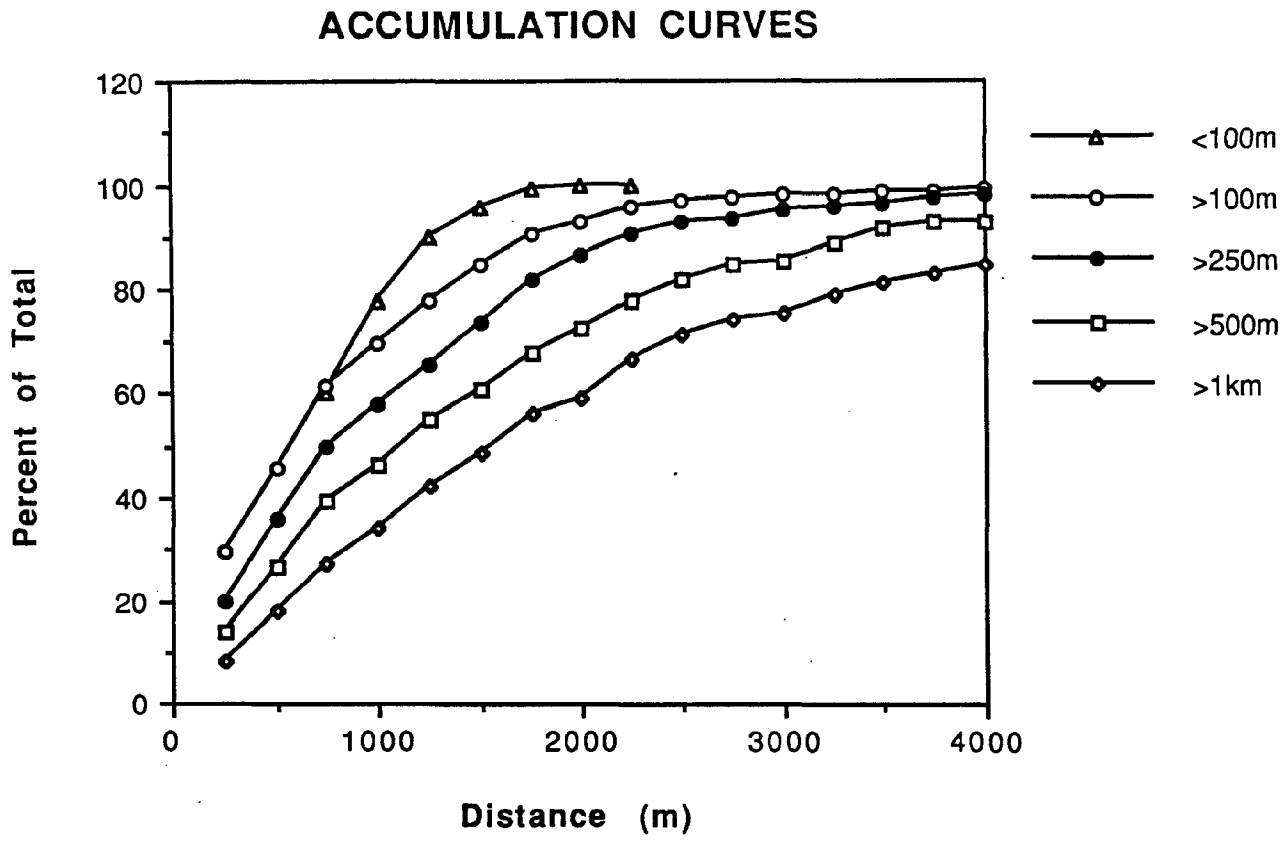

ACCUMULATION CURVES
Percent of Total
120
100
80
60
40
20
0
0
1000
2000
3000
4000
Distance (m)
<100m
>100m
>250m
>500m
>1km

Figure 10

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.

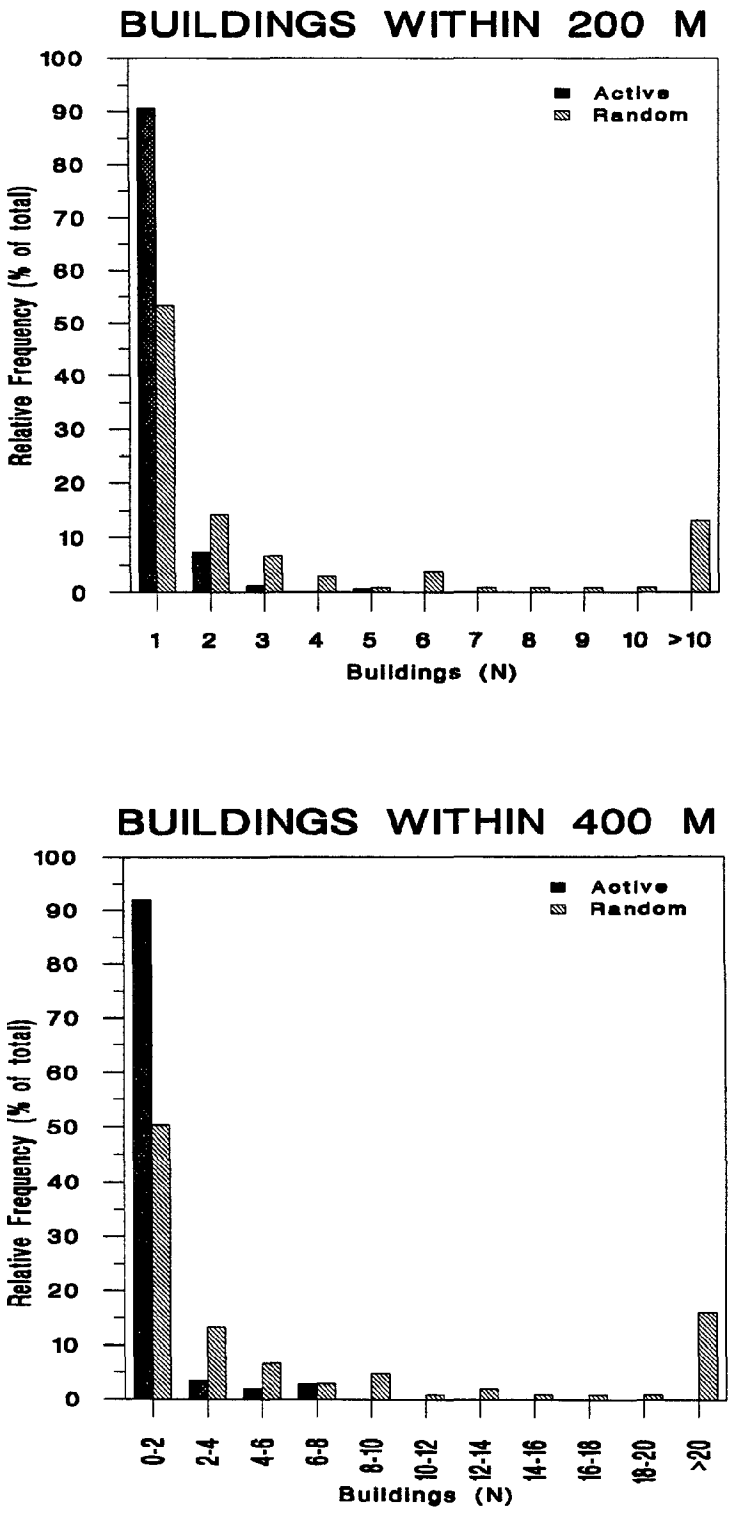

BUILDINGS WITHIN 200 M
Active
Random
Relative Frequency (% of total)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
>10
Buildings (N)
BUILDINGS WITHIN 400 M
Active
Random
Relative Frequency (% of total)
100
90
80
70
60
50
40
30
20
10
0
0-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
>20
Buildings (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.

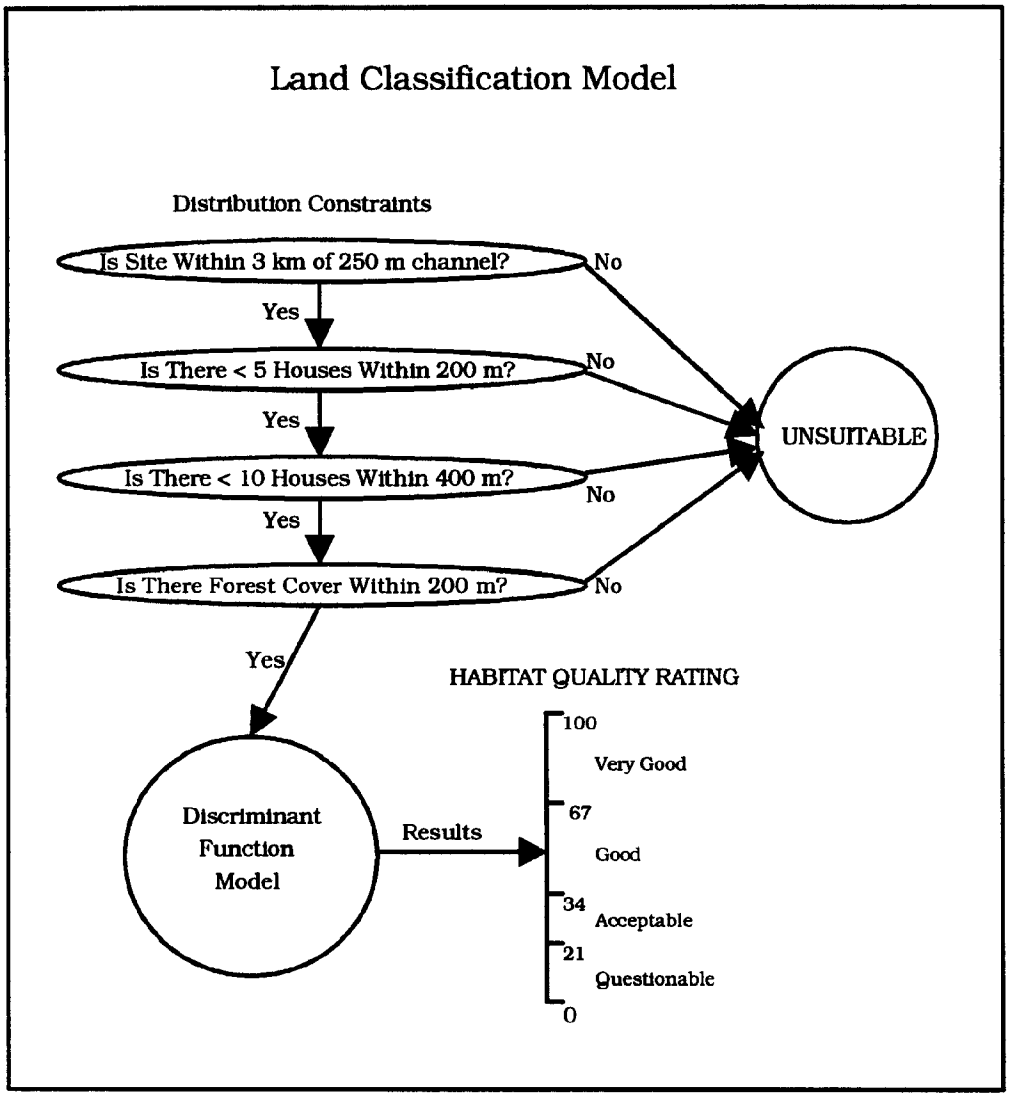

Land Classification Model
Distribution Constraints
Is Site Within 3 km of 250 m channel?
No
Yes
Is There < 5 Houses Within 200 m?
No
Yes
Is There < 10 Houses Within 400 m?
No
Yes
Is There Forest Cover Within 200 m?
No
Yes
UNSUITABLE
HABITAT QUALITY RATING
Discriminant Function Model
Results
100
Very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

Figure 12

APPENDIX I: Measurements: USGS topographic maps (1:24,000) and aerial photographs dated from 1988-89 (USDA) and 1986-1989 (VDOT) were used to gather raw data. All active nest locations and random points were fixed onto both topographic maps and aerial photographs. Concentric circles of 200, 400, 800 and 1600 m radii were drawn around all points on the topographic maps. Similarly, 400 and 1600 m concentric circles drawn on acetate were overlaid on aerial locations to outline different landuse areas. An electromagnetic digitizer was used for measuring lengths and areas, a millimeter ruler was used for measuring straight line distances, and a visual count was employed to obtain numbers of structures.

Lengths:	UNRDN1	digitized length of unimproved roads within 200 m radius directly off topo
	UNRDN2	added UNRDN1+UNRDN5
	UNRDN3	added UNRDN1+UNRDN5+UNRDN6
	UNRDN4	added UNRDN1+UNRDN5+UNRDN6+UNRDN7
	UNRDN5	digitized length of unimproved roads between 200 and 400 m radius directly off topo
	UNRDN6	""between 400 and 800 m""
	UNRDN7	""between 800 and 1600 m""
	SCRDN1	digitized length of secondary roads within 200 m radius directly off topo
	SCRDN2	added SCRDN1+SCRDN5
	SCRDN3	added SCRDN1+SCRDN5+SCRDN6
	SCRDN4	added SCRDN1+SCRDN5+SCRDN6+SCRDN7
	SCRDN5	digitized length of secondary roads between 200 and 400 m radius directly off topo
	SCRDN6	""between 400 and 800 m""
	SCRDN7	""between 800 and 1600 m ""
	MASHLE	digitized along marsh shoreline (200 m on either side of closest point perp. to nest)
	UPSHLE	"" along upland shoreline""
	TOSHLE	added MASHLE+UPSHLE
	FORSH1	digitized length of forested shoreline (< 50 m wide) within a 1200 m radius from nest or point off photos only
	FORSH2	""(50-150 m wide)""
	FORSH3	""(>150 m wide)""
	TFORSH	added FORSH1+FORSH2+FORSH3
Areas:	MSHAR1	digitized area of marsh within 200 m radius directly off topo
	MSHAR2	added MSHAR1+MSHAR5

Appendix I: Measurements (con't)

	MSHAR3	added MSHAR1+MSHAR5+MSHAR6
	MSHAR4	added MSHAR1+MSHAR5+MSHAR6+MSHAR7
	MSHAR5	digitized area of marsh between 200 and 400 m radius directly off topo
	MSHAR6	"" between 400 and 800 m""
	MSHAR7	"" between 800 and 1600 m""
	WATAR1	digitized area of open water within 200 m radius directly off topo
	WATAR2	added WATAR1+WATAR5
	WATAR3	added WATAR1+WATAR5+WATAR6
	WATAR4	added WATAR1+WATAR5+WATAR6+WATAR7
	WATAR5	digitized area of open water between 200 and 400 m radius directly off topo
	WATAR6	"" between 400 and 800 m""
	WATAR7	"" between 800 and 1600 m""
	CLCTAR	digitized area of clearcut land within a 400 m radius from aerial photographs
	YGFRAR	""of young forest coverage""
	IMFRAR	""of intermediate age forest coverage""
	MATFAR	""of mature age forest coverage""
	FRWTAR	""of forested wetland coverage""
	FORAR1	added CLCTAR+YGFRAR+IMFRAR+MATFAR+FRWTAR
	FORAR2	added FORAR1+ digitized area of any type of forest cover between 400 and 1600 m
	ALGAAR	digitized area of agricultural use within a 400 m radius from aerial photographs
	URLAAR	"" area of urban land""
Density:	BLDDN1	visual count of the number of buildings within 200 m radius off topos or aerial photographs
	BLDDN2	added BLDDN1+BLDDN5
	BLDDN3	added BLDDN1+BLDDN5+BLDDN6
	BLDDN4	added BLDDN1+BLDDN5+BLDDN6+BLDDN7
	BLDDN5	visual count of the number of buildings between 200 and 400 m radius off topos or aerial photographs
	BLDDN6	"" between 400 and 800 m""
	BLDDN7	"" between 800 and 1600 m""
	BLDDEN	visual count of the number of buildings along a 200 m wide strip just inside the 1200 m radius off topos
	PIRDEN	visual count of the number of piers along shoreline just inside the 1200 m radius off aerial photos only

Appendix I: Measurements (con't)

Distances:	DISCH1	measured distance from nest or point to nearest open channel < 100 m wide using a millimeter ruler off topo
	DISCH2	"" open channel > 100 m wide""
	DISCH3	"" open channel > 250 m wide""
	DISCH4	"" open channel > 500 m wide""
	DICSH5	"" open channel > 1000 m wide""
	DISUNR	measured distance from nest or point to nearest unimproved road using a millimeter ruler off topo
	DISSCR	"" to nearest secondary road""
	DISBLD	"" to nearest building""

APPENDIX II. 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 II: --- 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 II: --- 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 II: --- 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

Phase II

Model Implementation/Land Classification

APPROACH

The land classification model developed during phase I of this project is a point-based model. That is to say that all of the parameters that were used in its development (even though some were area parameters) were focused on or determined by an individual point (either a nest location or randomly chosen point). Because of this, classification results apply to discrete points in space rather than, for example, to some area included in a polygon. However, the area within a polygon of interest could be classified by establishing a network of points across its surface and classifying each individually. The set of classification values obtained would give a collective representation of not only the average habitat quality within the polygon as a whole but also the spatial arrangement of habitat categories across its surface. Assuming that the model used gives a reasonable representation of habitat quality, how well the set of points reveals the true habitat value within the polygon depends on the resolution of the point network. A progressive increase in the number of points within the network (i.e. reducing the space between points) would theoretically lead to a nearly continuous view of habitat quality. This was the approach used to implement the model in phase II.

The model was implemented within two demonstration areas including: 1) a 100 mi. reach of the James River, 2) a 75 mi. reach of the Rappahannock River. The working area surrounding these two drainages and their tributaries was considered to be all lands that were within 3 km of a channel that was at least 250 m wide (this is taken from the first constraint of the final model, see Figure 12 of phase I above). Once the working area was delineated, a network of coded, registration points was established across its surface. The network was

constructed with 400 m spacing between points. This level of resolution was used because it 1) provided considerable overlap in area measurements (thus providing a good level of redundancy across the working area), 2) resulted in a manageable number of points to be parameterized, and 3) provided low enough resolution such that classification results could be presented on an entire drainage map of reasonable size.

METHODS

Just as in the delineation of the working area for the selection of random points in phase I above, the first model constraint (see Figure 12 above) was used to determine the working area within the demonstration areas. All lands surrounding the two major drainages and their tributaries that were within 3 km of a channel measuring at least 250 wide were considered to be within the working area. This land mass was delineated on topographic maps by beginning at the respective river mouths and measuring outward from the shorelines to 3 km. By moving along appropriate shorelines, the outer boundary of the working area was penciled in. The buffer zones created in this way silhouetted the drainages to a point at which channel widths were approximately 250 m wide where they were rounded and closed off. Major tributaries off the rivers were treated in a similar fashion. This procedure resulted in the delineation of a working area on the James that extended up from the mouth to Drewry's Bluff and included three major tributaries (the Nansemond, the Pagan, and the Chickahominy Rivers). The Rappahannock River was followed to Spotsylvania and included just one major tributary (the Corrotoman River). In total 51, 7.5 minute topographic maps were used to cover the two river systems (Appendix I).

After working areas on both drainages had been delineated, a network of registration points was established. The network was established over the entire surface using a large acetate template. The template was composed of 30 rows of 50 small holes in a grid pattern such that holes were separated by 400 m on a 1:24000 scale topographic map. Beginning at the mouth, topographic maps were aligned and taped together at the seems before registration points were marked. The template was large enough that three topographic maps could be marked before having to realign. After the entire working area had been marked, each point received an individualized alpha-numeric code. A total of 8091 registration points were fixed within the James River working area and 7293 within the Rappahannock area.

Registration points were classified by first testing them for compliance with model constraints 2 - 4 (see Figure 12 above). Compliance with constraints was assessed quickly using a transparency with a central point surrounded by two circles (with 200 and 400 m radii respectively). Points that violated any one of the following criteria: 1) $<$ 5 houses within 200 m, 2) $<$ 10 houses within 400 m, 3) any mature forest cover within 200 m were considered to be unsuitable and no further measurements were made.

Registration points that fell within the model constraints were retained for further measurements. Model variables were parameterized for each of these points and measurements were manipulated according to the model specifications to compute scores. Scores were then re-scaled using the Habitat Quality Equation and grouped into the following categories: questionable, useable, good, and very good. Descriptive statistics were computed for model variables and land classification results for each river system separately.

After land classification procedures were completed, a digital database was constructed for both the working area and the network of registration points using arcinfo. After a common coding system was developed, the land classification database was merged with the GIS database to display classification results on drainage maps.

RESULTS

Land Area

The working area or buffer zone along the James River enclosed approximately 1,233 km^2 of land of which 458 km^2 (37.1%) did not meet the model constraints and so was considered unsuitable. The majority (85%) of this land was classified as unsuitable because building density was beyond the tolerance range (Figure 1). The buffer zone along the Rappahannock River encompassed approximately 1,111 km^2 of land of which only 274 km^2 (24.7%) were considered unsuitable. Not only does the Rappahannock appear to have relatively more suitable land compared to the James, a greater portion of the unsuitable land is due to the lack of nest trees when compared to the James. This is a clear indication of the agricultural character of the landscape along the shores of the Rappahannock.

Model Variables

Descriptive statistics for the four model variables by classification category and river system are presented in Table 1. Relationships between the land classification categories and the model variables reflect the patterns in habitat quality detected during phase I analyses. The habitat quality rating for a given location is negatively influenced by distance from water and positively related to distance from sources of disturbance.

Figure 1. Summary of Unsuitable Categories.

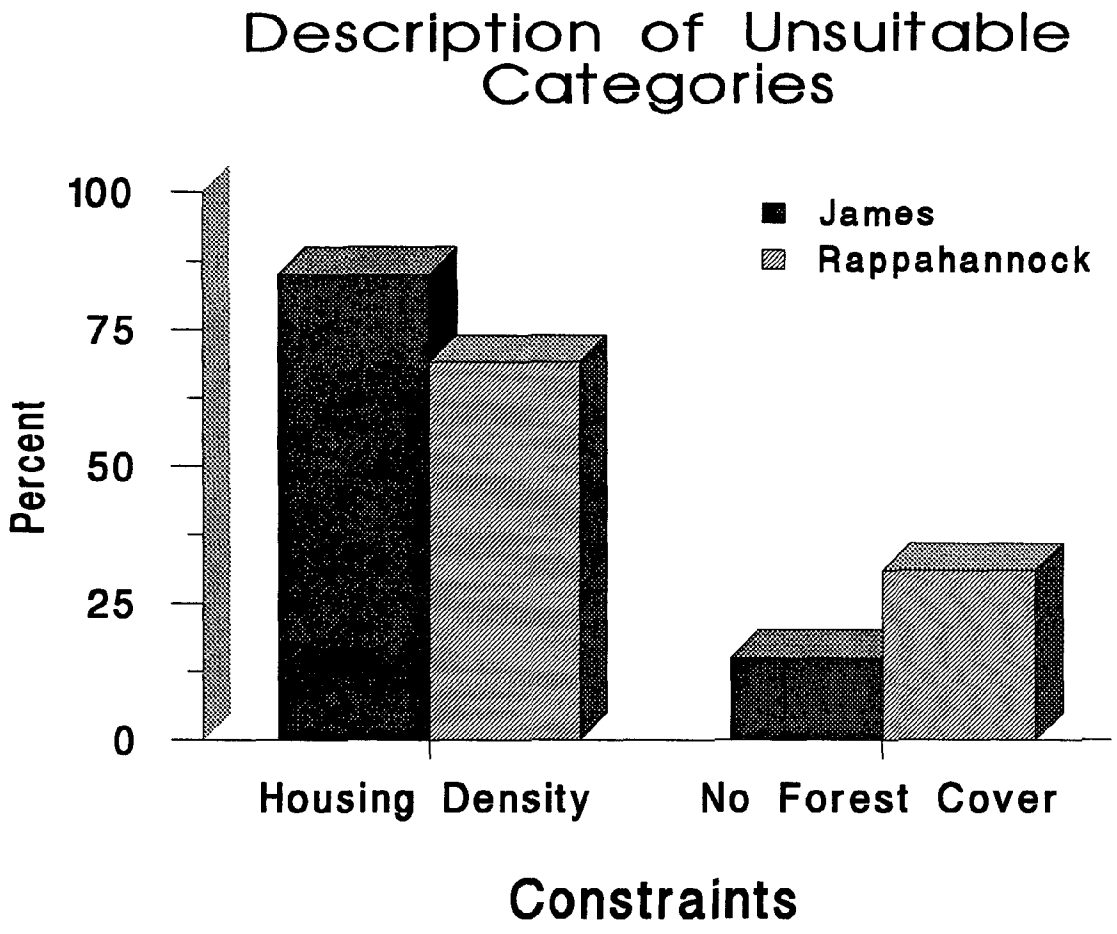

Description of Unsuitable Categories
100
75
50
25
0
Percent
James
Rappahannock
Housing Density
No Forest Cover
Constraints

Figure 1

Table 1. Mean closest distances, minimum and maximum distances for each variable by range for James and Rappahannock Rivers.

RANGE CATEGORIES	CODE	JAMES	RAPPAHANNOCK
Questionable	1	991	1222
Useable	2	1836	1980
Good	3	2154	2246
Very Good	4	103	44

VARIABLE DISTANCES IN METERS

		James				Rappahannock			
VAR	RANGE	MEAN	STDERR	MIN	MAX	MEAN	STDERR	MIN	MAX
DISCH1	1	789.6	15.6	0.0	2506.4	710.5	10.8	0.0	2144.9
	2	516.5	9.7	0.0	2337.7	445.5	7.1	0.0	2169.0
	3	295.5	6.8	0.0	2313.6	245.7	4.8	0.0	1711.1
	4	106.5	12.7	0.0	530.2	87.6	14.1	0.0	361.5
DISCH2	1	1816.4	25.1	0.0	3590.9	1796.2	22.0	24.1	3398.1
	2	1366.2	18.8	0.0	3639.1	1376.1	18.8	0.0	3542.7
	3	935.9	16.7	0.0	3446.3	1022.2	17.5	0.0	3374.0
	4	326.4	26.9	0.0	1638.8	237.2	29.8	0.0	747.1
DISSCR	1	149.9	4.7	0.0	1253.2	151.8	4.0	0.0	964.0
	2	320.8	5.3	0.0	1638.8	348.1	5.0	0.0	1903.9
	3	741.4	9.3	0.0	2626.9	800.9	8.7	0.0	2626.9
	4	1736.4	55.3	265.1	2892.0	1804.8	66.0	674.8	2795.6
DISBLD	1	200.8	4.3	0.0	1012.2	167.7	3.0	0.0	698.9
	2	379.2	4.8	24.1	1494.2	337.5	3.8	24.1	1132.7
	3	741.7	7.9	24.1	2385.9	625.6	5.9	24.1	2024.4
	4	1679.5	46.5	795.3	2771.5	1434.5	48.8	723.0	2144.9

Patterns and actual values were very consistent for both drainages.

Habitat Quality

Habitat quality ratings from registration points that met the model constraints showed similar patterns for both river systems. The majority of points fell within the good range, followed by the useable, and questionable ranges (Table 2). For both rivers, a small number of points also fell into the very good range. A rough estimate of potential breeding habitat may be achieved by summing the area within the useable categories (i.e. useable, good, very good). The estimated total potential habitat remaining on the James River is 623 km^2 or 51% of the total area. This may be compared to 650 km^2 or 59% for the Rappahannock River (see Figure 2 for summary of categories).

In order to display the spatial distribution of habitat categories, the working areas of both drainages were broken into sections. The resulting map plates are presented in Appendix II of this section.

Table 2. Summary of Habitat Quality Ratings for James and Rappahannock River Systems.

Range	James			Rappahannock		
Habitat Suitability (range)	N	Mean HQ Rating	STDERR	N	Mean HQ Rating	STDERR
Questionable (0 < 22)	991	15.81	.16	1222	15.16	.15
Useable (>=22 < 35)	1836	28.76	.09	1980	28.67	.08
Good (>=35 < 68)	2154	46.21	.18	2246	44.78	.15
Very Good (>=68 <=100)	103	74.74	.58	44	73.37	.66
Constr. 1a	1682	n/a	n/a	676	n/a	n/a
Constr. 1b	865	n/a	n/a	559	n/a	n/a
Constr. 2	460	n/a	n/a	566	n/a	n/a

Figure 2. Land Classification results of areas within buffer zones of James and Rappahannock Rivers.

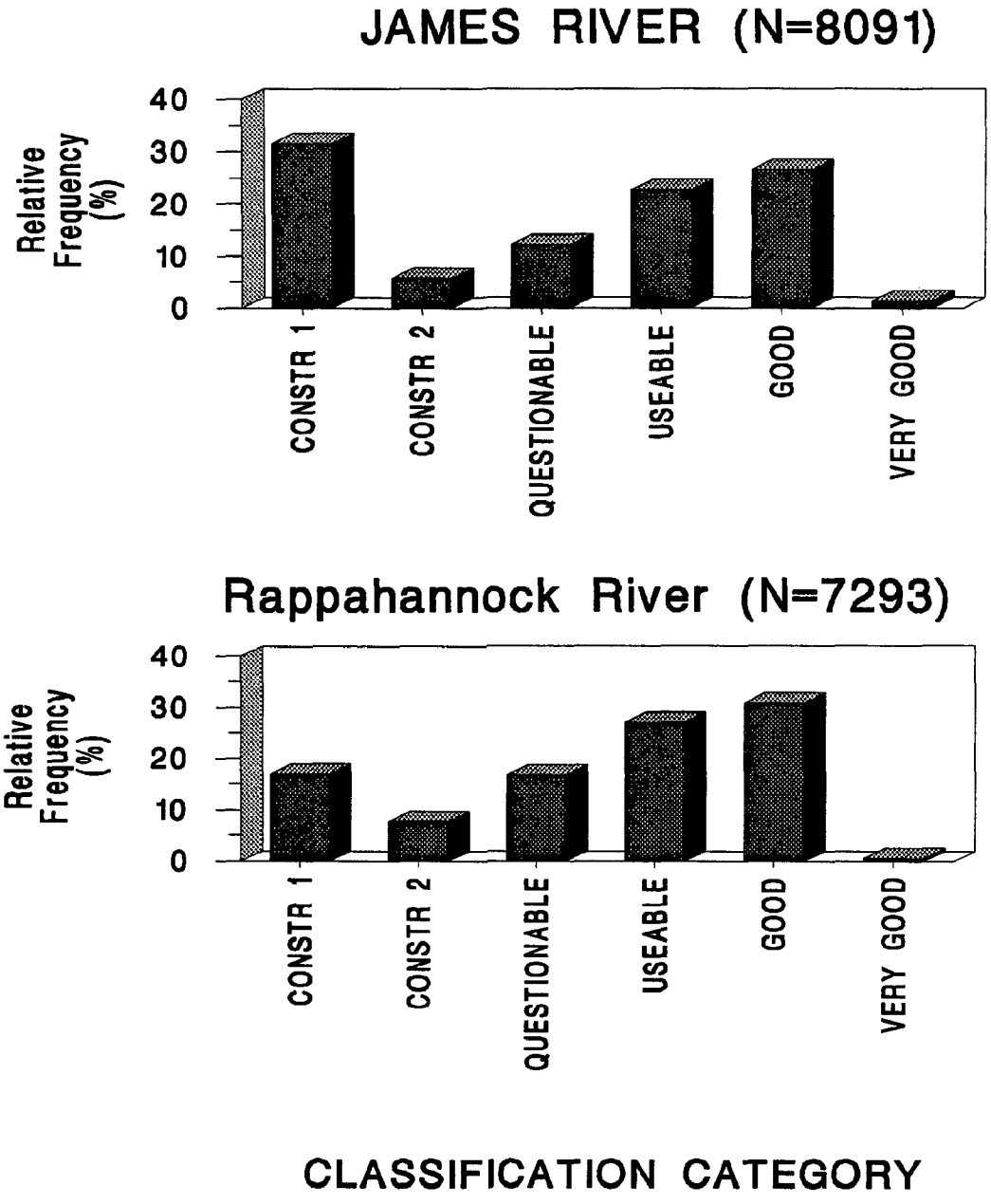

JAMES RIVER (N=8091)
Relative Frequency (%)
40
30
20
10
0
CONSTR 1
CONSTR 2
QUESTIONABLE
USEABLE
GOOD
VERY GOOD
Rappahannock River (N=7293)
Relative Frequency (%)
40
30
20
10
0
CONSTR 1
CONSTR 2
QUESTIONABLE
USEABLE
GOOD
VERY GOOD
CLASSIFICATION CATEGORY

Figure 2

Appendix 1. List of topographic maps used to collect data for model implementation.

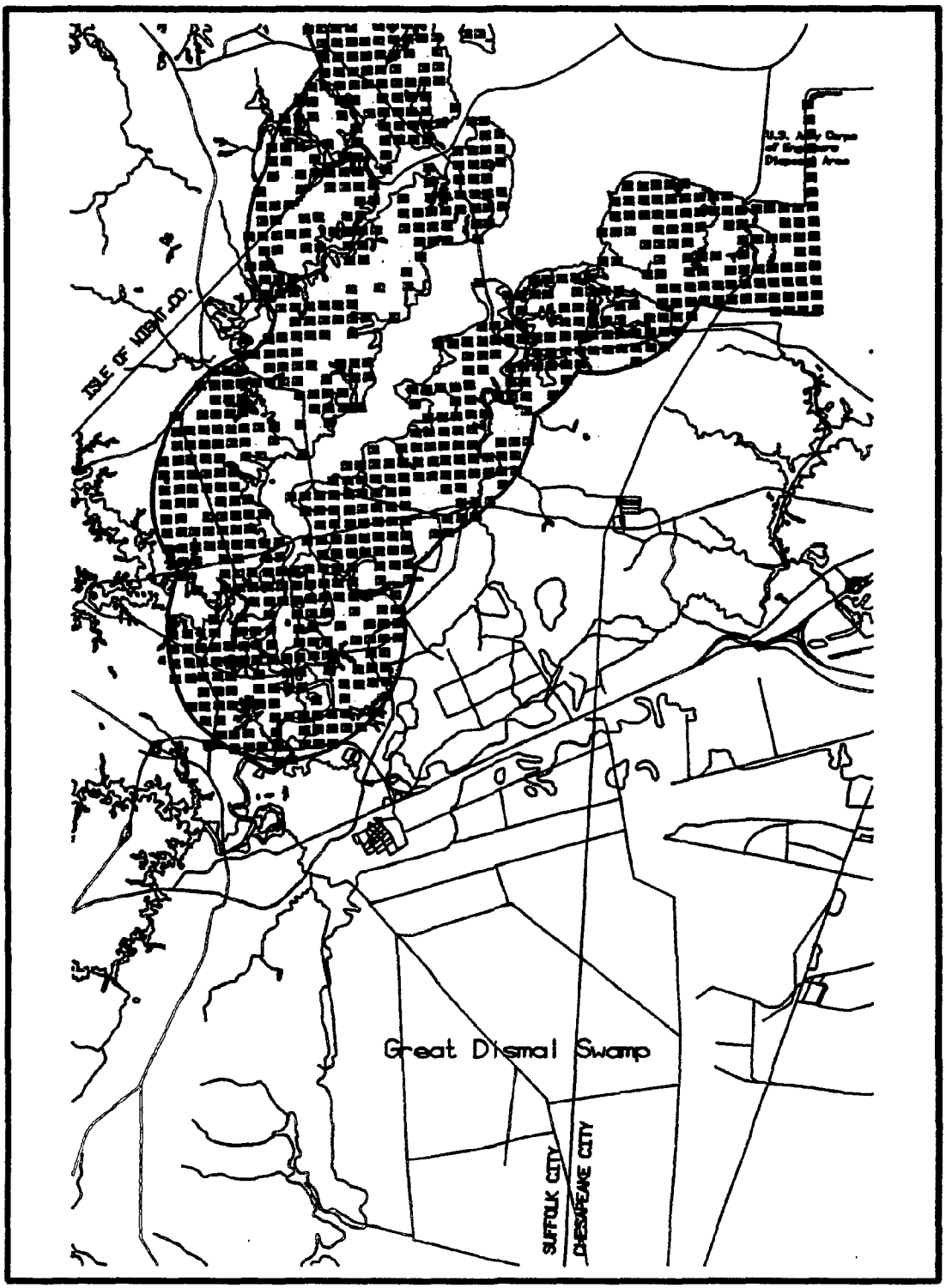
James	Rappahannock
Newport News North	Deltaville
Newport News South	Fleets Bay
Bowers Hill	Irvington
Chuckatuck	Lancaster
Benns Church	Wilton
Smithfield	Saluda
Mulberry Island	Urbanna
Yorktown	Lively
Bacons Castle	Church View
Hog Island	Morattico
Surry	Dunnsville
Claremont	Haynesville
Brandon	Tappahannock
Norge	Montross
Toano	Mount Landing
Walkers	Champlain
Providence Forge	Loretto
Charles City	Supply
Savedge	Colonial Beach South
Westover	Rollins Fork
Hopewell	Port Royal
Roxbury	Rappahannock Academy
Dutch Gap	King George
Chester	Passapatanzy
Drewry's Bluff	Guinea
	Fredericksburg

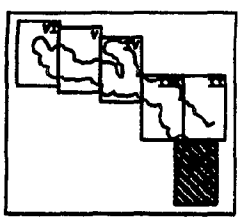
Appendix II: Map plates representing habitat suitability for breeding Bald Eagles for the James River.
Plates I - VI.

JAMES RIVER

I

HABITAT SUITABILITY FOR BREEDING EAGLES





0.8 0 0.8 1.5 2.3 3 Miles

N

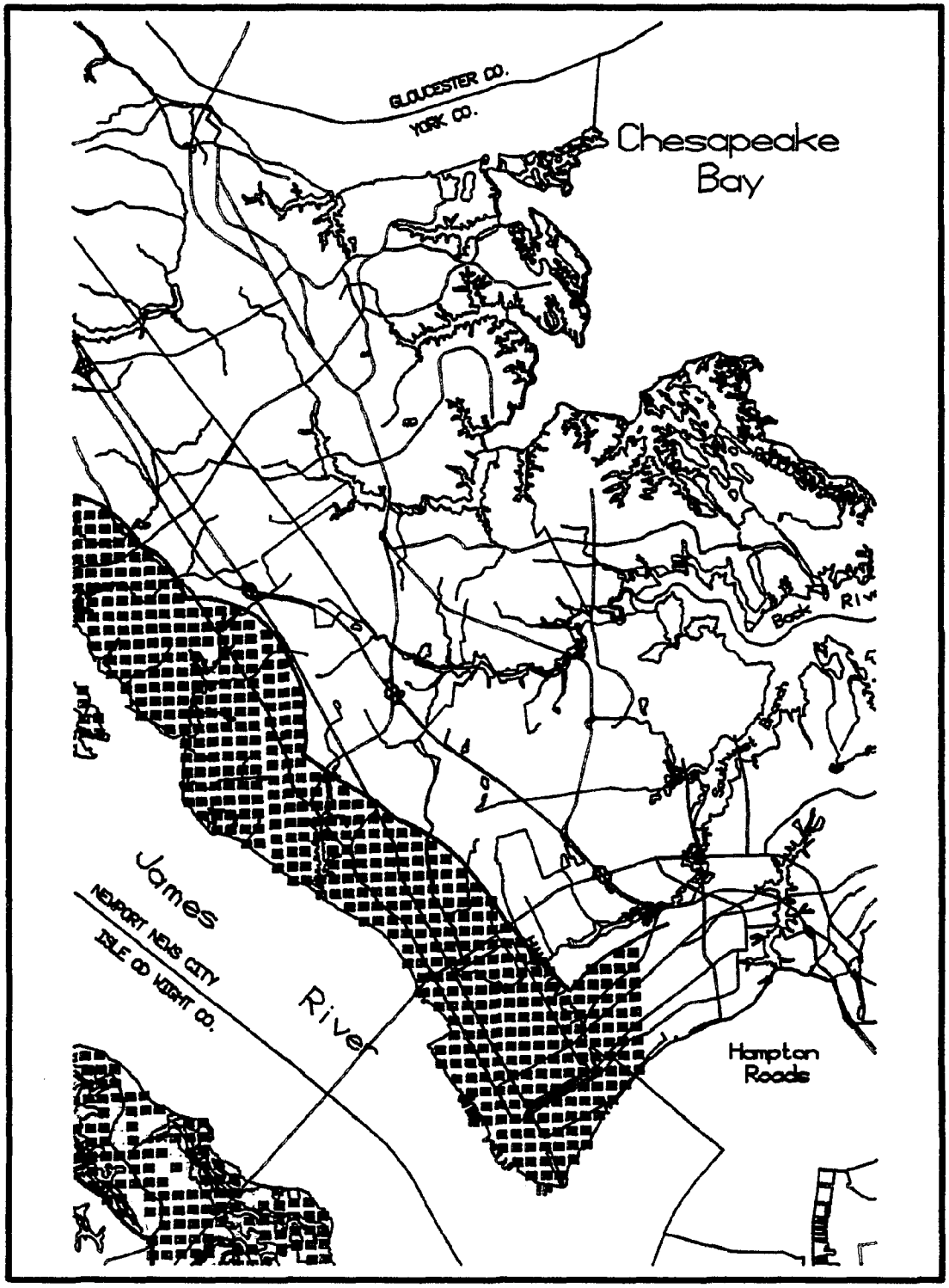
LEGEND

- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

JAMES RIVER

II

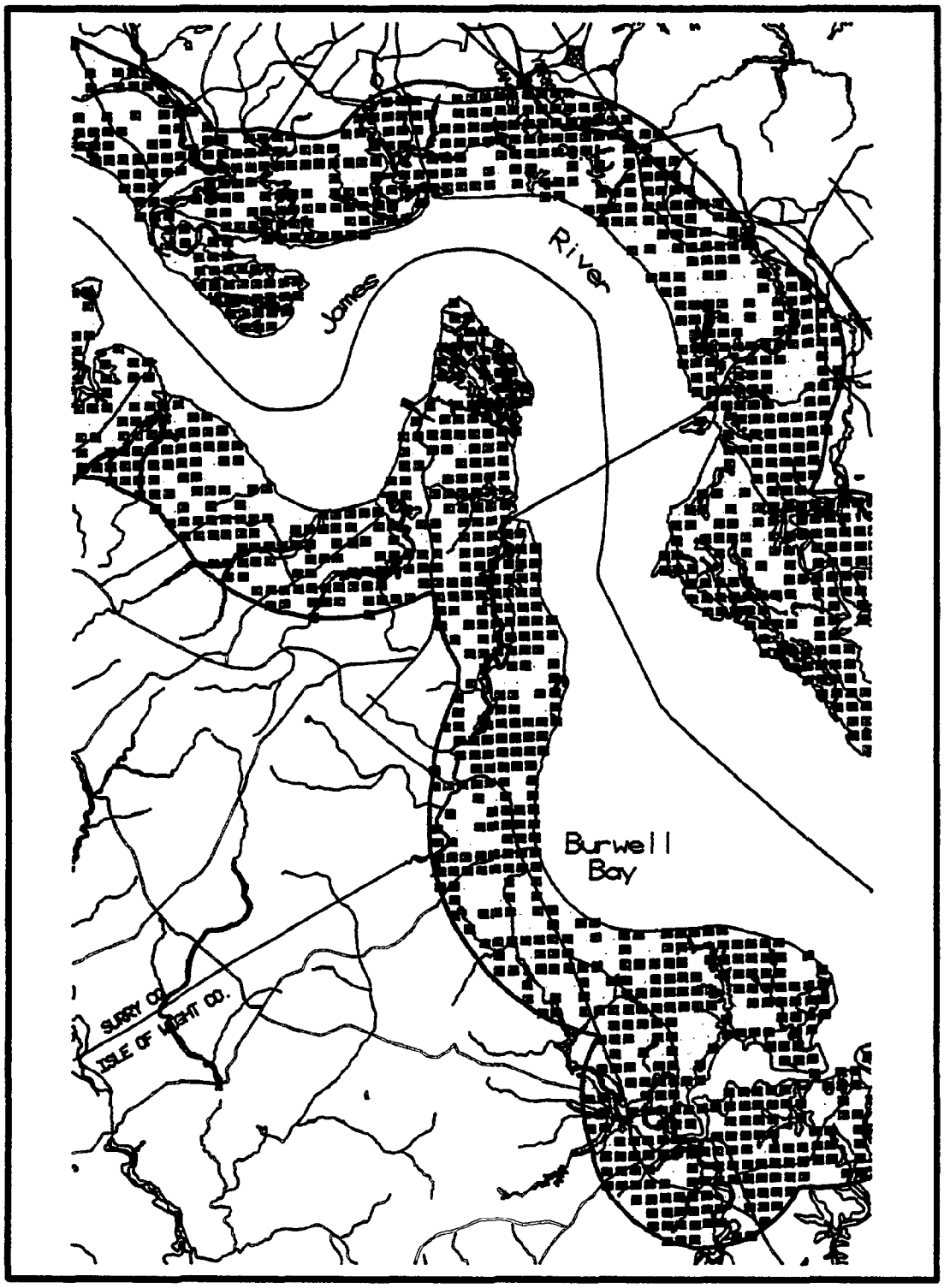
HABITAT SUITABILITY FOR BREEDING EAGLES

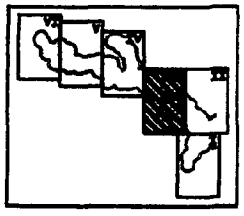


JAMES RIVER

III

HABITAT SUITABILITY FOR BREEDING EAGLES





0.8 0 0.8 1.5 2.3 3 Miles

N

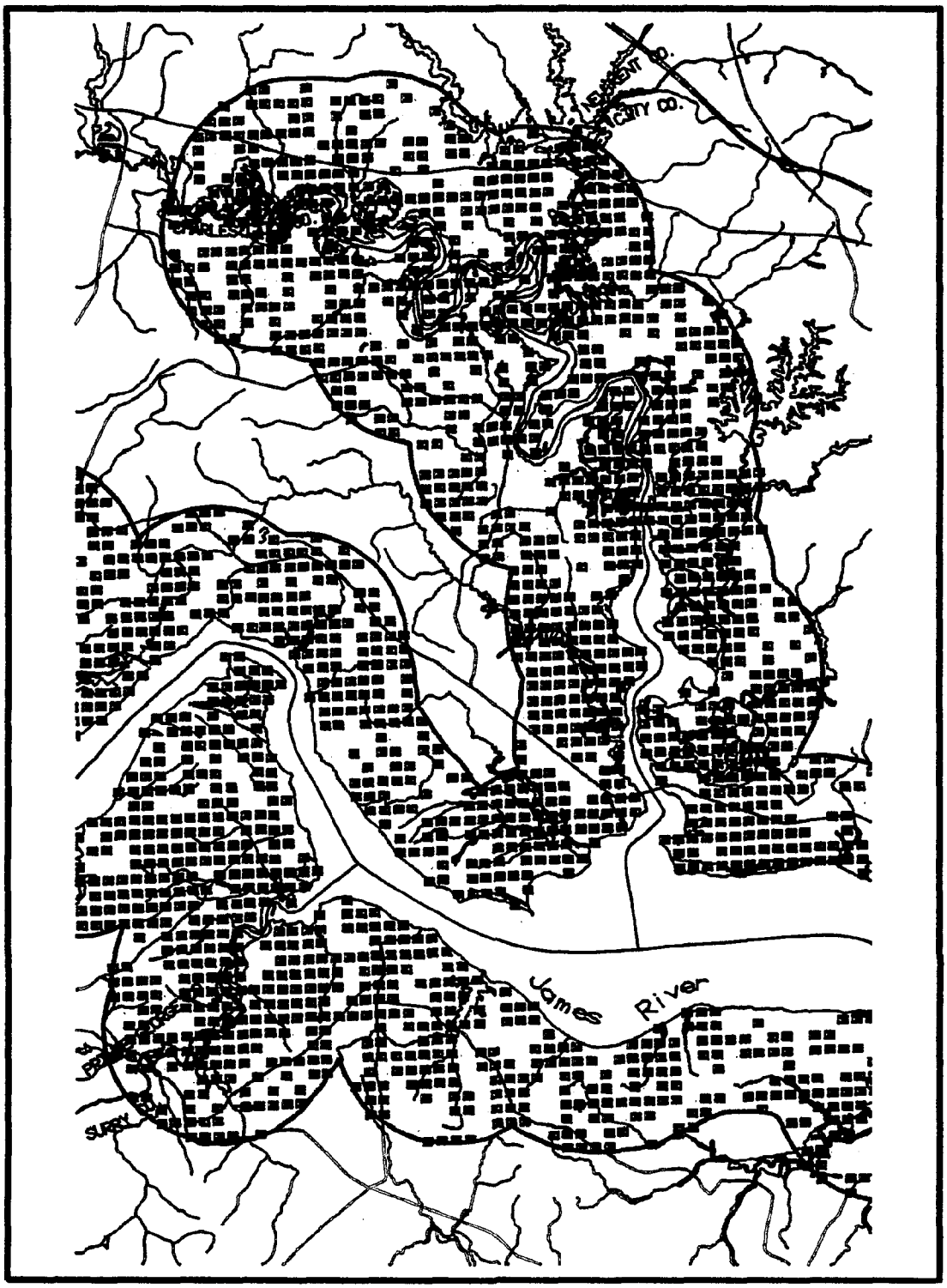
LEGEND

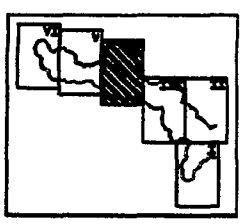
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

JAMES RIVER

IV

HABITAT SUITABILITY FOR BREEDING EAGLES





0.8 0 0.8 1.5 2.3 3 Miles

N

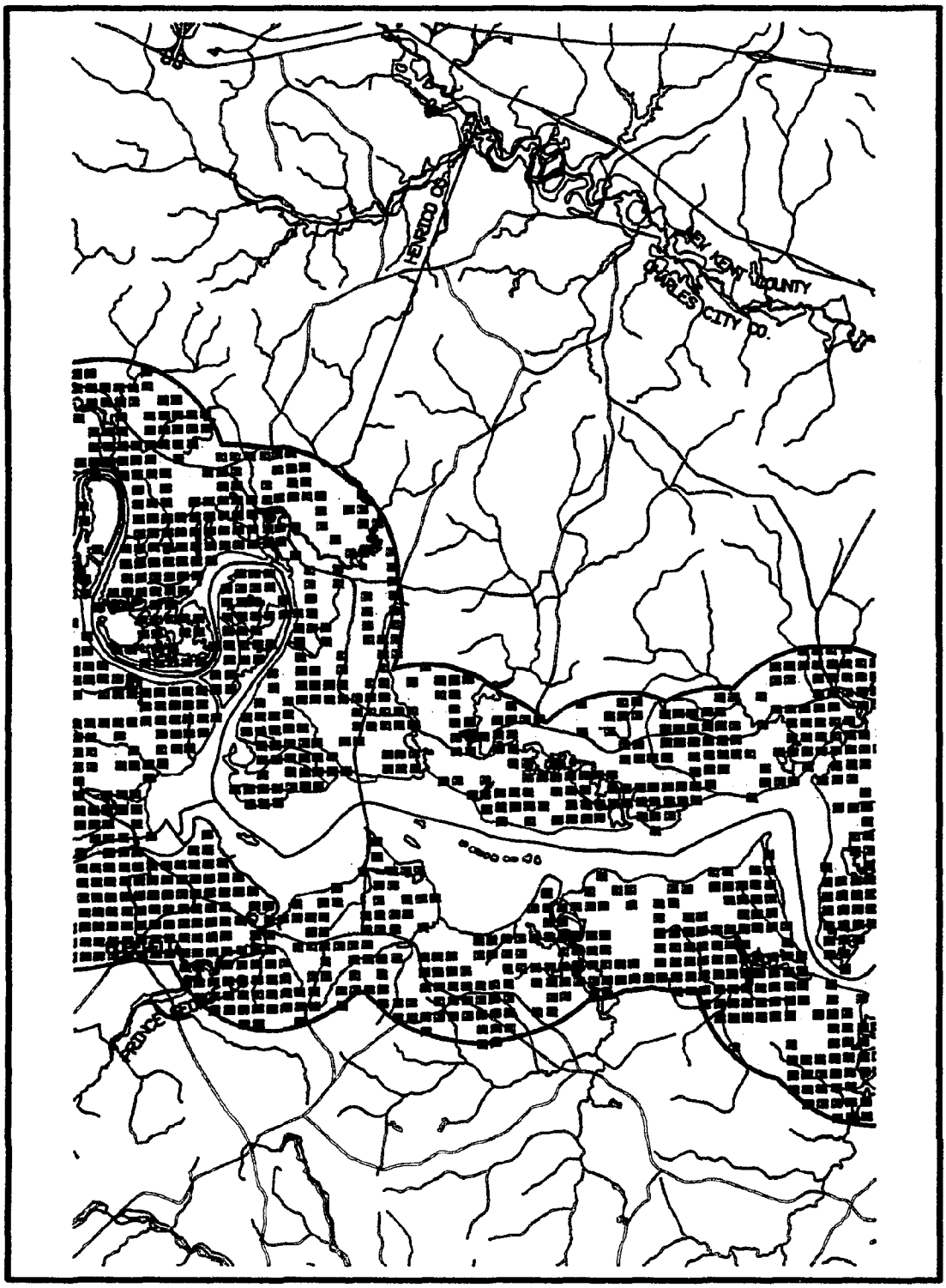
LEGEND

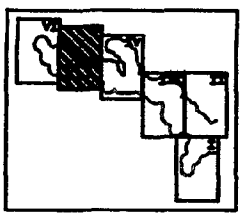
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

JAMES RIVER

V

HABITAT SUITABILITY FOR BREEDING EAGLES





0.8 0 0.8 1.5 2.3 3 Miles

N

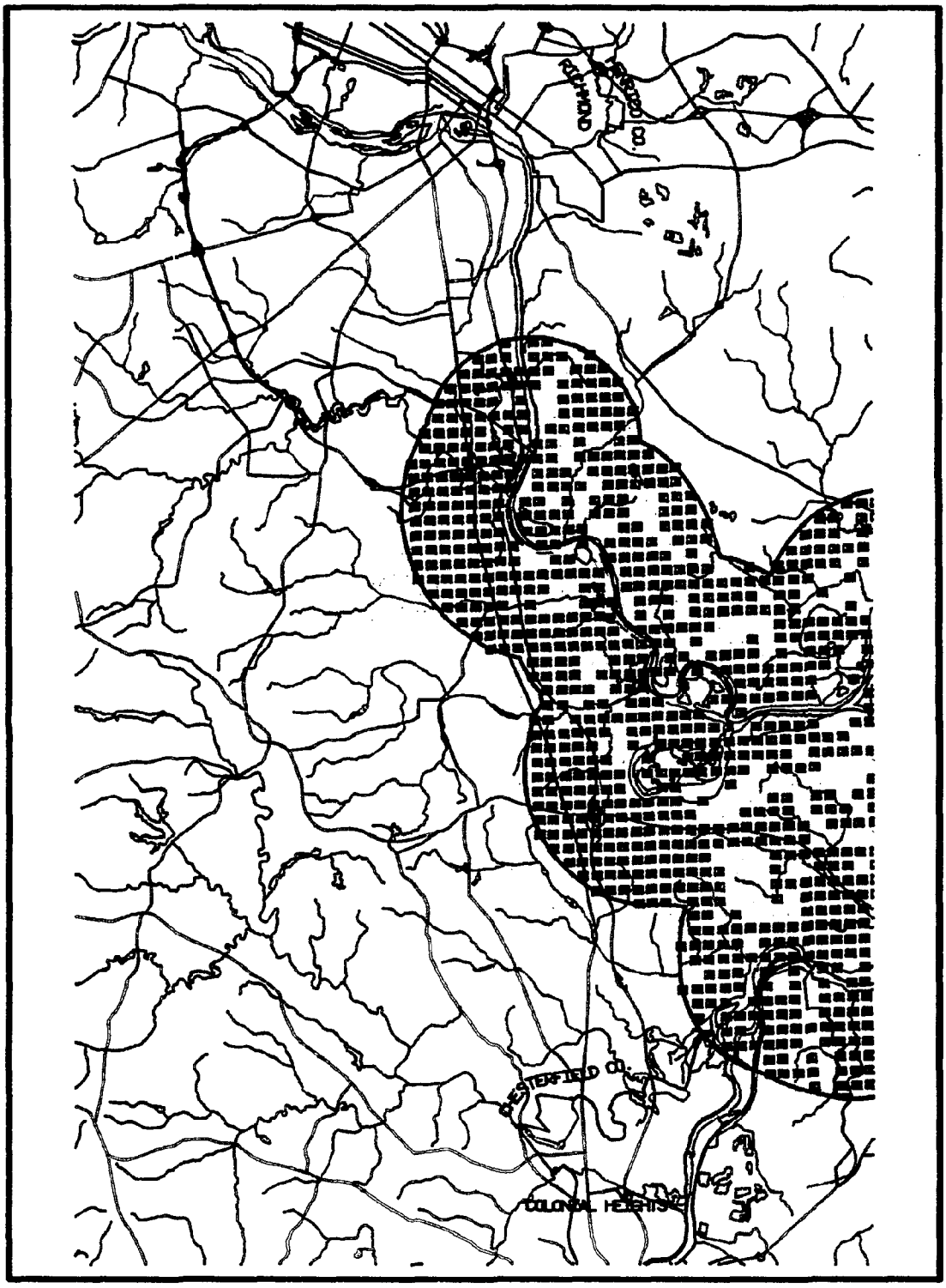
LEGEND

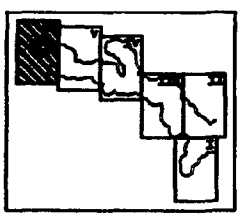
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

JAMES RIVER

VI

HABITAT SUITABILITY FOR BREEDING EAGLES





0.8 0 0.8 1.5 2.3 3 Miles

N

LEGEND

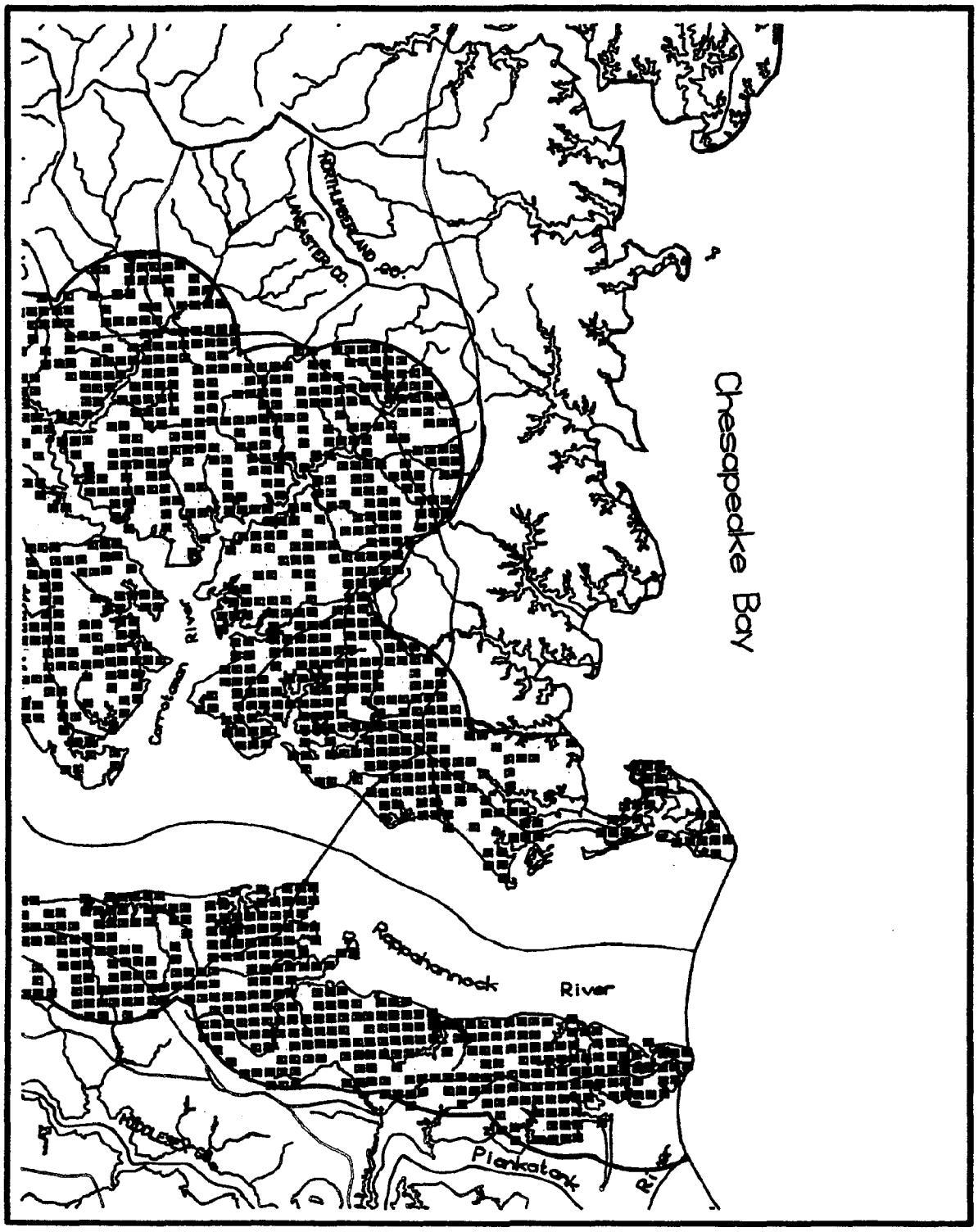
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

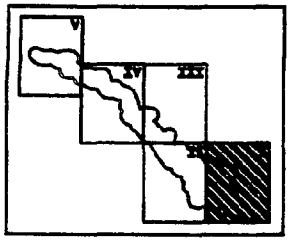
Appendix II: --- continued---
Map plates representing habitat suitability for breeding Bald Eagles for the Rappahannock River.
Plates I - V.

RAPPAHANNOCK RIVER

I

HABITAT SUITABILITY FOR BREEDING EAGLES





1 0 1 2 3 4 Miles

N

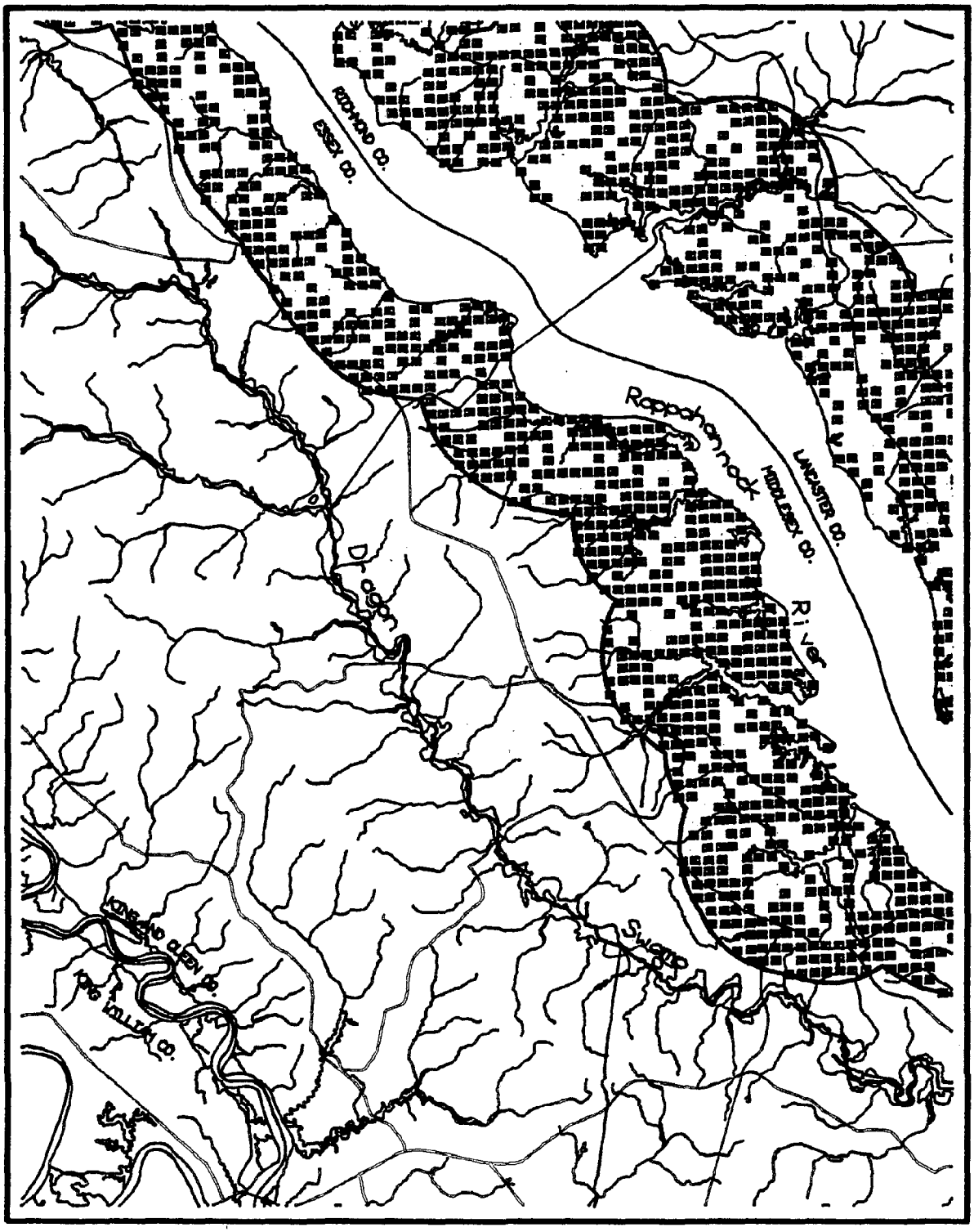
LEGEND

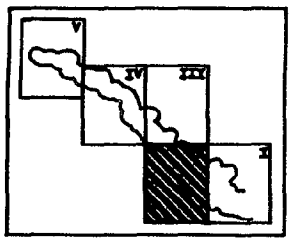
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

RAPPAHANNOCK RIVER

II

HABITAT SUITABILITY FOR BREEDING EAGLES





1 0 1 2 3 4 Miles

N

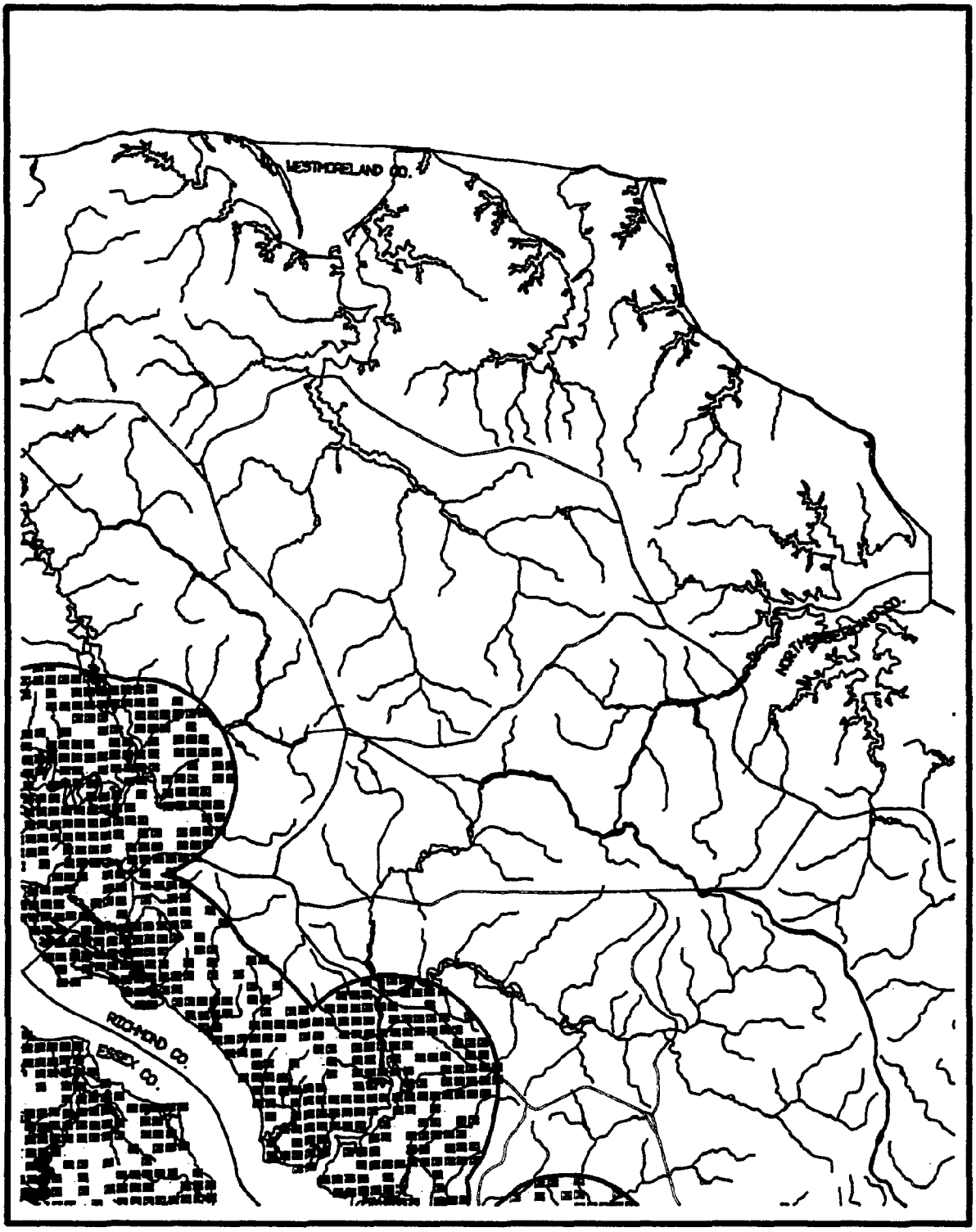
LEGEND

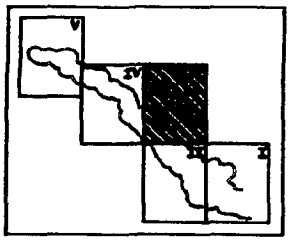
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

RAPPAHANNOCK RIVER

III

HABITAT SUITABILITY FOR BREEDING EAGLES





1 0 1 2 3 4 Miles

N

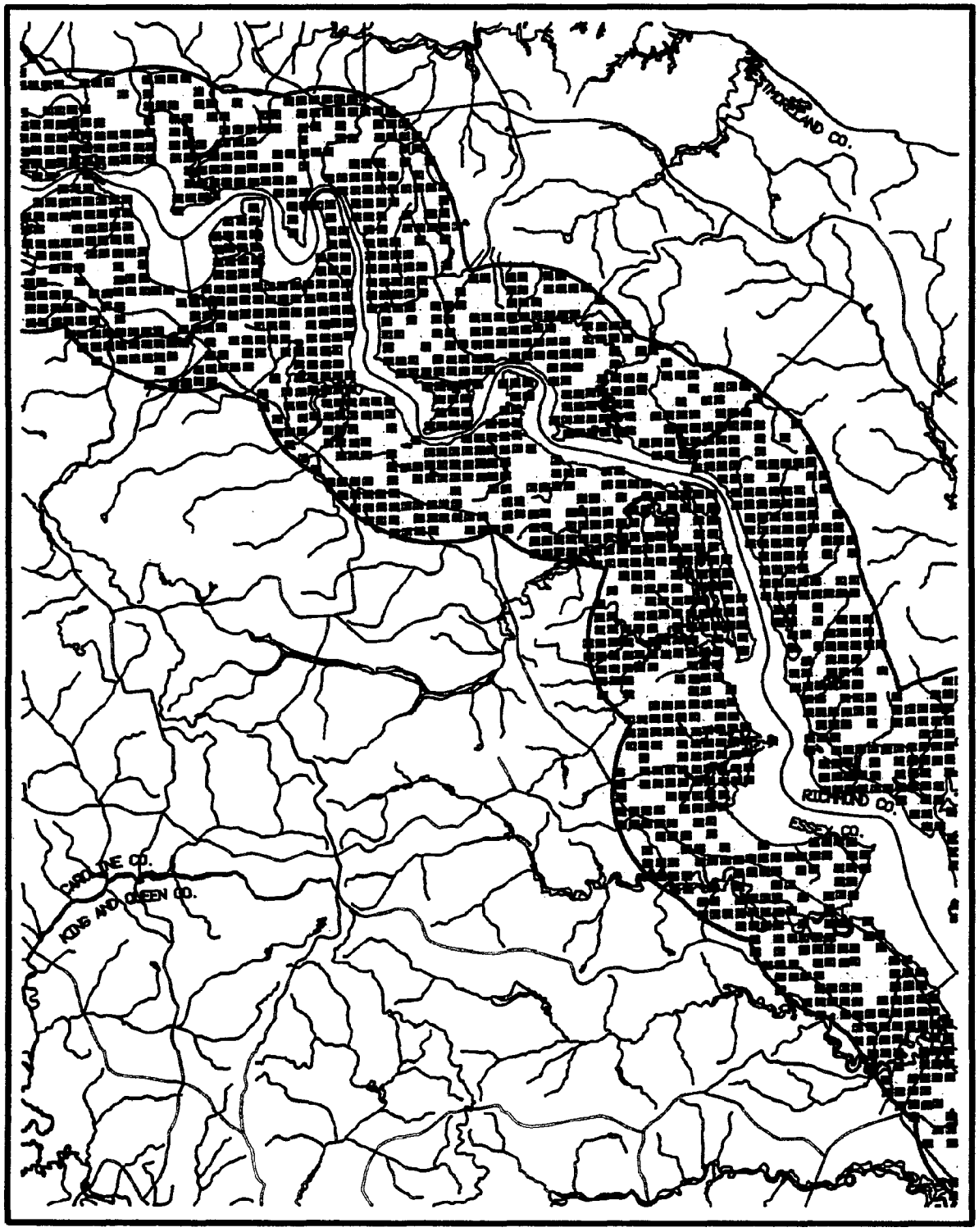
LEGEND

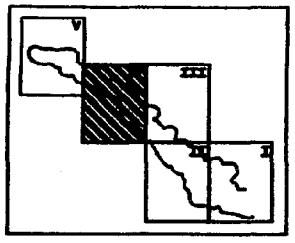
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

RAPPAHANNOCK RIVER

IV

HABITAT SUITABILITY FOR BREEDING EAGLES





1 0 1 2 3 4 Miles

N

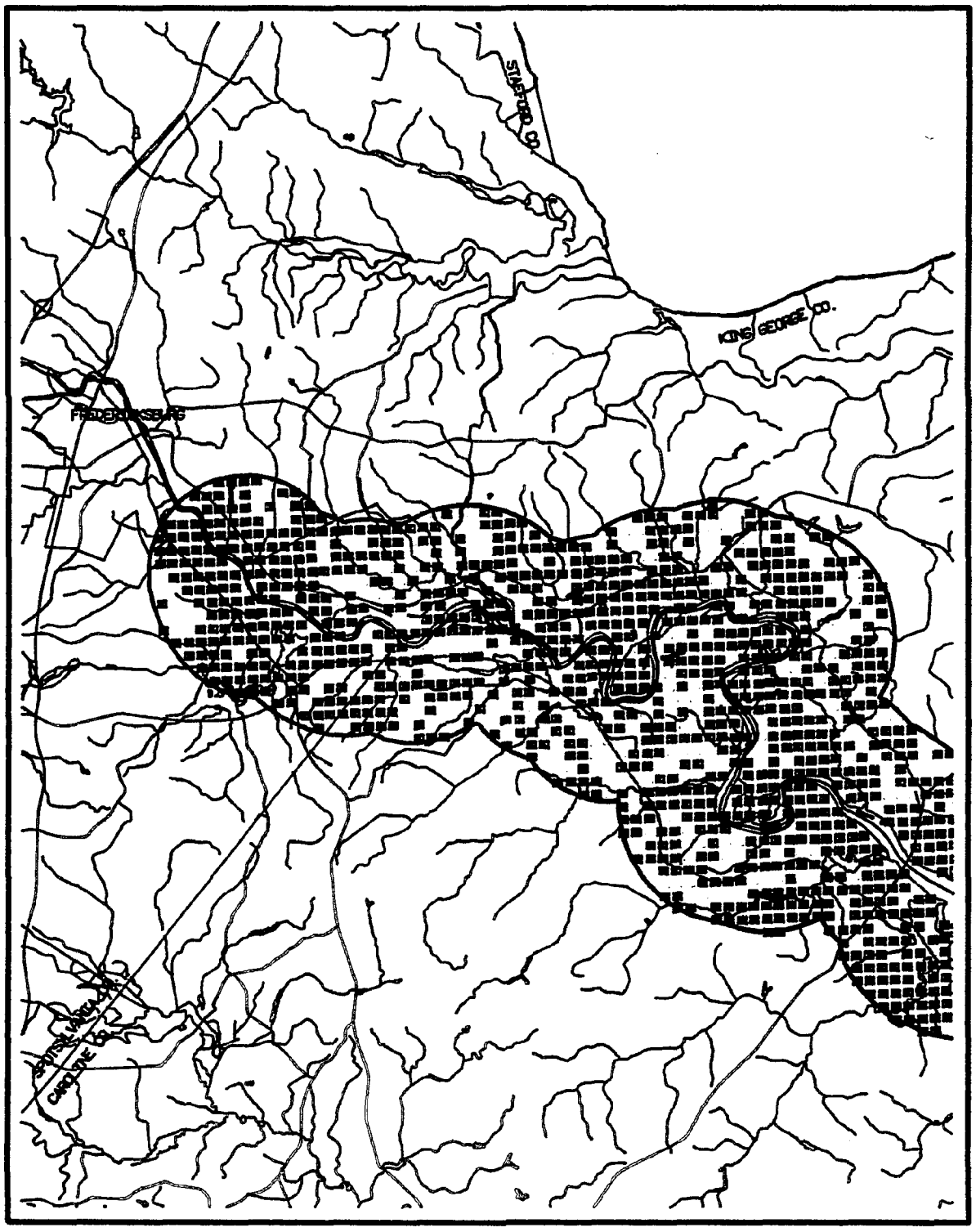
LEGEND

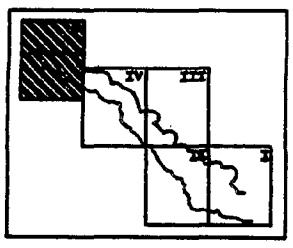
- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

RAPPAHANNOCK RIVER

V

HABITAT SUITABILITY FOR BREEDING EAGLES





1 0 1 2 3 4 Miles

N

LEGEND

- Unsuitable (Constr. 1)
- Unsuitable (Constr. 2)
- Questionable Habitat
- Usable Habitat
- Good Habitat

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