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A GIS and Remote Sensing Based Analysis of Impervious Surface Influences on Bald Eagle (Haliaeetus leucocephalus) Nest Presence in the Virginia Portion of the Chesapeake Bay

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A GIS AND REMOTE SENSING BASED ANALYSIS OF IMPERVIOUS SURFACE INFLUENCES ON BALD EAGLE (HALIAEETUS LEUCOCEPHALUS) NEST PRESENCE IN THE VIRGINIA PORTION OF THE CHESAPEAKE BAY.

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Environmental Studies at Virginia Commonwealth University.

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GIS (Geographic Information Systems) and remote sensing techniques were used to predict relationships between bald eagle nest presences and land type, distance to land type and impervious surface cover area. Data plots revealed bald eagle nest presence decreases in response to an increase in area of bareland; increases with an increase in area of forested land; decreases with an increase in distance (m) to shoreline, and decreases in response to an increase in area of impervious surfaces. Logistic regression models identified impervious surfaces as an indicator for bald eagle nest presence ($P < 0.001$). Chi-square analyses were used to develop a threshold model to predict bald eagle nest presence in relation to percent impervious surface cover (6 DF, value 45.0739, $P < 0.0001$). Three threshold levels were identified, 0 – 6% impervious cover as sensitive, 7 – 23% as impacted, and > 24% as unsuitable. Unsuitable area covered 17.82% of the total study area, impacted area covered 13.40%, and, sensitive area covered 68.77%. The projected increase in population in the state of Virginia and subsequent increase in impervious surfaces presents a challenge to the future viability of the Virginia Chesapeake Bay bald eagle population. The threshold analysis identified areas of prime conservation concern for bald eagle nest presence within the defined study area. These areas provide the basis for a conservation management plan and for further scientific study.

Key words: ESRI© ArcGIS, ESRI© ArcINFO, ESRI© ArcView 3.x, Bald eagle, Chesapeake Bay, Chi-square analysis, ERDAS© Imagine, GIS, Geographic Information System, *Haliaeetus leucocephalus*, impervious surface, remote sensing, SAS© System 8.x, Virginia, watershed management

INTRODUCTION

Prior to European settlement, the Chesapeake Bay area provided forested shoreline habitat and ample prey for an estimated 3000 pairs of bald eagles (*Haliaeetus leucocephalus*) (Fraser et al. 1996). In the early 1900s, bald eagle populations began to decline due to hunting, persecution and habitat destruction (Stalmaster 1987, Fraser et al. 1996). Environmental factors, such as the use of the pesticide DDT (dichloro-diphenyl-trichloroethane), along with the effect of its "metabolites", DDE (dichloro-diphenyl-dichloroethylene) and DDD (dichloro-diphenyl-dichloroethane), caused eggshell thinning, which affected the reproductive success of bald eagles and population numbers continued to decline during the 1900s (Stalmaster 1987, Watts 1999). In 1972, DDT and other chemical pesticides were banned in the United States (Watts 1999). Up to that point in time, bald eagles were legally protected under the Lacey Act, The Migratory Bird Treaty Act and The Bald and Golden Eagle Act (Stalmaster 1987, Watts 1999). These acts were effective in protecting the species itself with prohibitions against the sale, trade or hunting of the eagle, but it was not until the Endangered Species Act of 1973, and the subsequent listing of the bald eagle as an endangered species in 1978, that habitat protection was also afforded to the bald eagle. These combined efforts helped contribute to the increase in bald eagle population numbers. In

2001, Virginia had 331 occupied territories and 313 active nests (Watts and Byrd, 2002).

Bald eagles choose nest locations in response to many factors, including prey vulnerability (Hunt and Jenkins, 1992, Dzus and Gerrard, 1993), proximity to open water, suitable nest and roost habitat and human disturbance (Stalmaster 1987, Livingston et al. 1990, Buehler et al. 1994b, Chandler et al. 1995, Watts 1999). Nest trees tend to be the largest trees in the stand, often large loblolly pines, typically found in old growth forests, within one mile (1.6 km) of open water, preferably of a channel width of 250 meters (Andrew and Mosher 1982, Stalmaster 1987, Watts 1999). In Virginia, prime bald eagle habitat is found along the coast of the Chesapeake Bay and it's tributaries.

The Chesapeake Bay Watershed, the largest estuary in North America, has an area of 64,000 square miles providing habitat to thousands of aquatic and terrestrial species of wildlife, and functioning as part of the Atlantic Migratory Bird Flyway (Alliance for the Chesapeake Bay 2005, U.S FWS 2005). With 11,684 miles of shoreline, the Bay provides optimal nesting habitat for bald eagles (Alliance for the Chesapeake Bay 2005), supporting "the second largest breeding population…on the east coast" (Therres et al. 1993). In addition to the ecological significance of the Bay, the Chesapeake Bay shoreline is considered prime real estate for development.

With the impending removal of the bald eagle from the Endangered Species List and the lack of established habitat conservation initiatives, critical habitat for the bald eagle in the Chesapeake Bay Region is in danger of being irretrievably lost to human development. Total population for the state of Virginia in 2000 was 7,078,515 and is projected to be 8.5 million for the year 2025 (U.S. Census Bureau 1997, 2005). The Virginia Conservation Network predicts Virginia "will develop more land in the next 40 years than it has in the past 400 years" (VCN 2002). The increase in population will place humans in direct competition with bald eagles for available land and resources. As shoreline continues to be developed, it cannot be presumed that eagles will learn to adapt to these human disturbances (Fraser et al. 1985, Buehler et al. 1991b, Therres et al. 1993, Steidl and Anthony 1996).

Numerous studies have been conducted across the United States evaluating bald eagle responses to human disturbances (Livingston et al. 1990, Grubb et al. 1992, Therres et al. 1993, Watts et al. 1994, Steidl and Anthony 1996). There is a consistent finding across the landscape that bald eagles exhibit a negative response to human disturbance (Fraser et al. 1996), locating nests away from development to avoid human interaction.

Bowerman et al. (1993) reported relationships between wintering bald eagle perch tree selection and type of "potential human disturbance". The study found bald eagles chose perch trees away from human disturbance, which is supported by Buehler et al. (1991a, 1992) and Chandler et al.'s (1995) findings that bald eagle habitat selection on the Chesapeake Bay was influenced by the combined effect of human activity and perch tree availability. Human activity negatively affects bald eagle distribution whether through the activity itself or the presence of the developed landscape (Fraser et al. 1985, Brown and Stevens 1997, Buehler et al. 1991b, Steidl and Anthony 2000).

Past studies conducted on eagle response to human activity have concentrated on small population studies in a constrained area. These studies have quantified specific parameters at fine details to better understand bald eagle behavior. The difficulty in these studies is the application of the findings across a wide range of landscapes, particularly as bald eagle behavior may be unique to specific populations and can be difficult to quantify (Grubb et al. 1992, Steidl and Anthony 1996).

To evaluate bald eagle presence or absence in relation to human disturbance over a large geographic area, a Geographic Information System (GIS) and remote sensing based analysis was employed. The use of a large spatial area allows for a coarser evaluation of bald eagle presence, providing results that can be applied across a wider scale of habitat. Finer resolute studies concentrate on populations that may exhibit similar intra-population characteristics, but may be unique from other eagle populations. The coarser study combines populations across a wide spatial extent and develops a comprehensive threshold evaluation.

A GIS is defined as "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information" (ESRI 1997). GIS and remote sensing techniques are becoming viable analytical tools with which to assess urban growth with the use of impervious surfaces coverages as indicators of human development (Pathan et al. 1993, Deguchi and Sugio 1994).

Impervious surface area has been a commonly used watershed management tool in the assessment of watershed quality (Martin 2000, Zielinksi 2002). The increase in human population and continued expansion into the landscape results in an increase in impervious surfaces. The state of Virginia has experienced a 44.7% increase in imperviousness from 1990 to 2000 (Chesapeake Bay Program 2004). It can be extrapolated that impervious surfaces can serve as indicators of anthropogenic influences on current habitat, and as measures of human population growth (Arnold et al. 1996) and subsequent development and disturbance.

The continuing increase in human population and impending development requires an assessment of current habitat for eagle nest presence (Buehler et al. 1991b, 1991c). Once these areas have been identified, concentrated studies can be performed and specific management plans enacted to ensure bald eagle carrying capacity in the Virginia portion of the Chesapeake Bay is not breached.

GIS and remote sensing techniques on classified Landsat TM scenes were used to analyze eagle nest presence in response to land type and distance within the Virginia portion of the Chesapeake Bay Watershed. The data were then further analyzed to establish a threshold level of percent impervious area as an indicator of anthropogenic influences and the effect on bald eagle nest presence. The use of thresholds will establish parameters within which further studies can be concentrated to fully explore the level of effect of human disturbance and development has on the bald eagle.

The objectives of this study are to: (1) to examine the relationship between bald eagle nest location and land type; (2) to examine the relationship between bald eagle nest location and distance to defined land types; and (3) to predict percent area impervious surface thresholds in relation to presence of bald eagle nests in the Virginia portion of the Chesapeake Bay watershed. The null hypothesis of the study is that there is no relationship between impervious surfaces and bald eagle nest presence.

STUDY AREA

The study area (Figure 1) was defined as being the Virginia (USA) portion of the Chesapeake Bay, or Tidewater Virginia. The study area encompassed the cities of: Alexandria, Chesapeake, Colonial Heights, Fredericksburg, Hopewell, Newport News, Norfolk, Poquoson, Portsmouth, Richmond City, Suffolk, Virginia Beach, and Williamsburg, and the counties of Arlington, Caroline, Charles City, Chesterfield, Essex, Fairfax, Gloucester, Hampton, Henrico, Isle of Wight, James City, King and Queen, King George, King William, Lancaster, Mathews, Middlesex, New Kent, Northumberland, Prince George, Prince William, Richmond, Spotsylvania, Stafford, Surry, Westmoreland and York. The area was further delineated by a three kilometer buffer of waterway shorelines 250 meters wide, defined by the habitat suitability model developed by Watts, Byrd and Katrimenos (Watts 1994). The total study area was 5,611.39 km^2.

METHODS

Dr. Mitchell Byrd and Dr. Bryan Watts of the Center for Conservation Biology at William and Mary, in collaboration with the Virginia Department of Game and Inland Fisheries (DGIF), conducted surveys of bald eagle nest locations in 2000 for the entire state of Virginia. Surveys were conducted from an aircraft and recorded on United States Geological Survey (USGS) topographic maps in the Universal Transverse Mercator (UTM), Zone 18 North American Datum (NAD) 1927, in units of meters. UTM is a coordinate system based on the Transverse Mercator projection where the world is divided into sixty zones (ESRI 1997). The study area fell completely within UTM Zone 18 of the UTM projection, which minimizes distortion of area and distance and preserves shape and direction (ESRI 1997, ESRI 1994). Bald eagle nest location data were obtained from the Center for Conservation Biology in DBASE IV (.dbf) format. Coordinates were converted from .dbf format into a GIS point coverage using the Create Feature Class from X, Y Table in ESRI© ArcCatalog. The points were then reprojected to UTM 18 NAD WGS84 projection in ESRI© ArcGIS, using the Project command with datum transformation.

The 2000 Impervious Surfaces Classification was obtained from the Center for GIS at Towson University in Maryland. The classified image is 2000 Landsat 7 TM imagery and was tiled by county in .gis format. Available data for the study area were imported to image form using the Imagine Import tool under the Import / Export menu in ERDAS© IMAGINE.

Raw Landsat ETM+ scenes 14/34 (path / row) and 15/33 were downloaded from the Chesapeake Bay from Space Program image repository as individual bands for Virginia Beach and the surrounding areas. These files were needed to fill in the missing area in the classified 2000 data from the *Chesapeake Bay from Space* classification. Bands one through five and band seven have a spatial resolution of 30 meters and are useful in evaluating land use types (USGS 2004). The thermal IR band 6 has a coarser resolution of 60 meters, and is generally used to assist in thermal mapping (USGS 2004). Band 6 was subset from each scene in Imagine using the Layerstack Utility, to help decrease file size.

A supervised classification was used to process the spectral reflectance of the images, based on decision rules that defined spectral reflectance values and their associated land type. The goal of a supervised classification is to have the computer use defined parameters to automatically categorize, or group, pixels into specific land classes, based on the pixel reflectance values (Lillesand and Kiefer 1994). Spectral reflectance values of individual pixels in an image are based on the "inherent spectral reflectance and emittance properties" of the features (Lillesand and Kiefer 1994).

Land types for the classification scheme were defined as Impervious Surfaces, Deciduous Forest, Water, Coniferous Forest, Bareland, Agricultural Lands, Cloud and Beach (Table 3).

The impervious surfaces class consisted of areas defined as a road, parking lot or airport, and residential development where pixels of high imperviousness were interspersed with non-impervious pixels, such as residential areas where houses and driveways were interspersed with gardens and yards. Cloud and beach signatures were collected to ensure that these signatures would not misclassify as bareland or low imperviousness.

Supervised classifications (Appendix B) were run on each Landsat scene, using the Signature File created for each scene with the Maximum Likelihood Parametric Rule. This rule assumes a normal distribution of the training data, and calculates the probability that a pixel belongs to each class before assigning the pixel to the class with the highest probability (ERDAS 2004, Lillesand and Kiefer 1994). This method is seen as the "most accurate classifier in the ERDAS IMAGINE system" (ERDAS 2004, Lillesand and Kiefer 1994). An accuracy assessment was run in Imagine, 35 points were generate for each class for a total of 210 points. Points were generated based on a stratified random sampling. DOQQ's were used as the ancillary data source for the accuracy assessment.

The final scenes were recoded to standardize the classification. Recoding was done in ESRI© ArcEdit and in the IMAGINE Raster Attributes Editor on the Viewer Menu. Necessary scenes were exported from IMAGINE to grid format using the Import / Export function. The grid was converted to a polygon in ESRI© ArcINFO workstation using the Gridpoly command. Weed tolerance was set to "0.02 inches (0.0508 cm) or equivalent coverage units" which was calculated to be 0.0000508 meters

(ESRI 2004). Weed tolerance is the minimum distance between vertices for arcs that are added to a coverage (ESRI 2004).

Grid codes were recalculated and saved in ArcEdit using the Select and Calculate commands. The polygon was converted from a coverage to a grid using the ArcGRID Polygrid command. The grid was then imported to an image to run the mosaic in Imagine. The Impervious Surfaces Classification was recoded with the Raster Attribute Editor to reflect the defined classification classes in IMAGINE.

All individual scenes were merged into one seamless image using the Mosaic Tool under the IMAGINE Data Prep menu with the Overlay function and with the output set to a common lookup table. Scenes that had cloud cover were overlaid with scenes with no cloud cover, replacing most of the cloud cover with a classified area. The mosaiced image was subset with an AOI (Area of Interest) in IMAGINE.

The AOI was considered "the first constraint of the final" land classification model. The model was developed by Dr. Bryan Watts of the Center for Conservation Biology at the College of William and Mary (Watts et al. 1994). The pre-defined working area was developed in GIS by Dr. Watts using editing techniques in ESRI© ArcView 3.2. Open water channels of at least 250 m wide were digitized into an arc shapefile. The coverage was buffered at 3 km using the Buffer Tool in ArcGIS to create the working area AOI. The AOI was then clipped to exclude large water bodies, rivers and the Bay water. This AOI was used to subset the final classified images in IMAGINE using Subset command under the Data Prep menu with the working area as the input AOI. The final image was considered the study area. The final mosaiced

2000 classification was exported to a grid with the Export Utility in IMAGINE. The grid was exported to an ArcINFO coverage in Arc using the Gridpoly command. The polygon coverage was then exported to a personal geodatabase feature class in ArcCatalog to ensure the area values were automatically updated with any geographic alteration during post processing. The conversion from grid to coverage to personal geodatabase was necessary to retain topological integrity of the data and was done in this order to utilize the best software tools for each conversion. Topological integrity deals with the spatial relationships of each piece of data to another, and to the associated attribute information (ESRI 2004, ESRI 2002).

Post processing on the classification was done in the ESRI© ArcMap editing environment. Digital Orthophoto Quarter Quadrangles (DOQQ) were used to classify the polygon according to land use based on the defined classification scheme. A Union was run in ArcGIS with the classified study area and the DOQQ grid as the input layers. This was done to break the study area into regions for regression and Chi-Square analyses. The output feature class was called study area regions (Figure 2). The DOQQ grid represented regions within the study area. The region area boundaries were 3 ¼ minute USGS quarter quadrangle. The feature class generated by the Union was exported to a Microsoft© Access database for statistical work.

To determine the distance from each land type to the closest Eagle nest, the 2000 classified grids were converted to polygon ArcINFO coverages. An AML script was generated and executed to export each land type (by grid code value) into a separate coverage. The Near command was then used to calculate the distance from individual Eagle nest points to the nearest impervious land type, nearest deciduous forest, shoreline, nearest coniferous forest, nearest bare land and nearest agricultural land types. The output of the Near command was stored in the ArcINFO Eagle point attribute table (.pat), which was exported into Excel.

The Select by Location function was used in ArcMap to identify the total number of Eagle nests occurring within the study area. Eagle nests with the center located within the study area were selected for analyses. A total of 210 Eagle nests were within the study area. The Select by Location tool in ArcMap was used to calculate numbers of Eagle nests occurring in each study area regions.

Two queries were run on the study area region feature class in Access to generate a table with the grid code number (representing land type), the sum of the total area of each unique quarter quad, the total area for each unique grid code within the specific quarter quad region, the total area of the quarter quad and the percent area of the study area. The percent area of a grid code was calculated by dividing the total area of a grid code by the sum the total area of all polygons within a quarter quad region study area with grid code > 0.

Study areas that were calculated to be less than ten percent of the total study area were considered fragment areas. A Create Table Query was used in Access to identify these study areas and were removed from the final regression database.

The SAS© System for Windows Version 8 was used for statistical analyses. Data were grouped according to defined statistical goals. Univariate statistics were run to test for normality using the Proc Univariate command. Correlations were run to test for interactions. Logistic regressions were run on the data in SAS using the Proc Logistic command. Various models were tested with percent area of land type, number of Eagle nests, distance from Eagle nest to each land type and shoreline and all interaction terms. Stepwise selection was run on the model.

Eagle nest and percent area impervious surfaces were evaluated using Chi-Square analyses using Proc Freq in SAS. Eagle nest data were grouped into four categories; 0 for zero nests, 1 for one nest, 2 for two nests and 3 for greater or equal to three nests. Percent impervious area was grouped into various combinations based on a Watershed Vulnerability Analysis conducted by the Center for Watershed Protection.

Validation was run on the threshold levels with 914 nest locations surveyed from 2001 to 2004 in ArcMap. Nest code is the unique identifier assigned to and associated with each particular Eagle nest surveyed. Validation nests were overlaid on the threshold grid to assess what threshold the nests were found to be present.

RESULTS

Landscape Characteristics

The 2000 Impervious Surfaces Classification was obtained from the Center for GIS at Towson University in Maryland. The overall classification accuracy for the 2000 image was 85% (per communication with David Sides of Towson University, Fall 2002).

Landsat TM scenes 14/34 and 15/33, downloaded to supplement missing areas in the 2000 classification, had a signature separability for scene 14/34 of 1998, and 2000 for scene 15/33. Overall classification accuracy for the VA Beach area was 63.3% with Overall Kappa Statistics = 0.4176 and an impervious surface Kappa Statistic = 0.7141.

Study area size was equal to approximately 38 square kilometers (14.67 square miles). Total area evaluated for the study was 5,611.39 square kilometers (2,166.56 square miles). Land type area in the study area totaled 2.09 % bareland, 4.86% inland water, 13.12% impervious surface, 18.64% coniferous forest, 26.15% agricultural and 35.14% deciduous forest (Table 1).

Eagle Nest Location Results

Average distances (meters) were calculated from eagle nest point to nearest land type and range from a minimum to maximum distance of 1.34 to 1119.77 m to nearest deciduous land type, 1.19 to 556.70 m to nearest coniferous land type, 1.19 to 7772.71

m to nearest agricultural land, 21.90 to 2880.52 m to the shoreline, 40.72 to 1914.13 m to nearest impervious surface, and 61.95 to 4434.65 m to nearest bare land (Table 2). Exploratory statistics indicate a negative correlation between number of eagle nests and percent impervious surface area (-0.32077, $p < .0001$). Data plots revealed bald eagle nest presence decreases in response to an increase in bareland (Figure 5); increases with an increase in forested land (Figure 7); decreases with an increase in distance to shoreline (Figure 8), and, decreases in response to an increase in impervious surfaces (Figure 9).

Logistic regression yielded significant parameters at $p < .05$ (Table 4) for percent area impervious, deciduous forest, bareland, agricultural land; distance from eagle nest to: agricultural land, bareland, coniferous forest, deciduous forest, impervious land and shoreline; interactions percent impervious and distance from eagle nest to: agricultural land, bareland, coniferous forest, deciduous forest, impervious and shoreline; interactions percent deciduous forest and distance from eagle nest to: agricultural land, bareland, coniferous forest, deciduous forest, impervious land and shoreline; interactions percent inland water and distance from eagle nest to: agricultural land, bareland, coniferous forest, deciduous forest, impervious land and shoreline; interactions percent coniferous forest and distance from eagle nest to agricultural land, bareland, coniferous forest, deciduous forest, impervious land, and shoreline; interactions percent bareland and distance from eagle nest to: agricultural land, bareland, coniferous forest, impervious land and shoreline; and, interactions agricultural land and distance from eagle nest to: agricultural land, bareland, coniferous forest and impervious land. When percent area coniferous forest and deciduous forest were combined, the parameter tested significant at $p < .0001$ with a percent concordant of 64.0.

Logistic regression for all land types (forested not combined) run with Stepwise Selection at $p < .25$ yielded six significant parameters and one interaction term, including the percent area impervious, distance from eagle nest to agricultural land, distance to bareland, distance to coniferous forest, distance to impervious land, distance to shoreline and the interaction term percent area impervious and distance to coniferous land. Overall percent concordant was 91.1%, indicating the model predicted the presence of an eagle nest 91.1% of the time.

Logistic regression for land types with deciduous and coniferous forest combined run with Stepwise Selection at $p < .25$ yielded similar results: percent area impervious, distance from eagle nest to agricultural land, distance to bareland, distance to forest, distance to impervious land, distance to shoreline; and, the interaction terms percent area impervious and distance to bareland and percent area impervious and distance to impervious land.

Parameter estimates indicated positive and negative relationships for the logistic regression formula predicting eagle nest presence; however, results of the full model indicated multicollinear data.

Logistic regression results for the model eagle nest presence = percent impervious surfaces ($p < .0001$ and percent concordant = 65.7) indicated a strong relationship with which to evaluate threshold effects.

Impervious Thresholds

Chi-square tests run on eagle nest presence and suitability groups resulted in percent area of impervious surface groupings where 0 – 6% impervious surface area was classified with a suitability rating of 2 (sensitive area), 7 – 23% impervious surface area was classified with a suitability rating of 1 (impacted), and ≥ 24% impervious surface area was classified with a suitability rating of 0 (not suitable) for bald eagle nest presence (Table 5). Chi-square tests (6 DF, value 45.0739) were significant at $p < .0001$ (Table 6).

Of the total study area, unsuitable area constituted 17.82%, impacted area constituted 13.40%, and, sensitive area constituted 68.77% (Figure 4, Table 7).

There were a total of 284 study areas within the region. Of the 284 areas, 55 were classed in suitability group 0, 37 were classed in suitability group 1 and 192 were classed in suitability group 2 (Appendix A). Chi-Square tests results (Table 6) indicate 52 occurrences where 0 eagle nests are present in suitability group 0, 18 occurrences in suitability group 1, and 88 occurrences in suitability group 2; 2 occurrences where 1 eagle nest presence occurs in suitability group 0, 13 occurrences in suitability group 1, and 53 occurrences in suitability group 2; 1 occurrence where 2 eagle nests present occurs in suitability group 0, 5 occurrences in suitability group 1, and 33 occurrences suitability group 2; and, 0 occurrences where 3 or more eagle nests present occurs in suitability group 0, 1 occurrence in suitability group 1, and 18 occurrences in suitability group 2.

Threshold Test

Threshold tests yielded a total of 22 nests present in suitability group 0. Of the 22 nests, 12 were unique nests (several nests surveyed were present multiple years). 115 nests were present in suitability group 1, with 70 distinct nest codes; and 777 nests were present in suitability group 2 with 432 distinct nest codes.

Suitability group 0 (Impaired / Not Suitable) had 2% of the total nests present, suitability group 1 (Impacted) had 13% present and suitability 2 (Sensitive) had 85% of total nests present.

DISCUSSION

Bald eagles choose nest habitat comprised of forest stands situated close to shoreline (Stalmaster 1987, Livingston et al. 1990, Buehler et al. 1992, Watts 1994 et al., Chandler et al. 1995). The location of the nest, while strongly influenced by habitat types is also affected by proximity to human activity and development. The results of this study indicate there is a relationship between bald eagle nest presence and impervious surfaces, measured as human activity and development. Bald eagle nest presence was affected at three threshold levels of percent area of impervious surface.

Bald eagles must have the appropriate habitat available to support their perch, nest and prey requirements. This analysis indicates that bald eagle nest presence is not only affected by distance from nest to shoreline, but also the amount of impervious surfaces, deciduous forest, bareland, and agricultural land.

Land Type Area and Distance

In evaluating the area of specific land types present and the effect on eagle nest presence, coniferous forests did not have a significant impact. Combining deciduous and coniferous forest land types into a forested type proved significant. Results from this study show an increase in bald eagle nest presence with an increase in forested land. A possible explanation for the significance of the combined forested classes and non-significance of coniferous forests may be the 25 meter resolution of the Landsat TM scenes used for the classification. At this resolution, mixed forest stands of coniferous and deciduous forest may be classed according to the dominant type found in a pixel area. Because this study dealt with a coarser resolution of observation, deciduous and coniferous forests can be combined into one forested class. Another explanation may be that eagles are not showing a preference for forest types as much as a preference for suitable nest and perch trees. Bowerman et al. (1993) reported finding no distinct difference between perch use of coniferous versus deciduous tree type for wintering adult eagles.

Results indicate bald eagle nest presence decreased in response to an increase in area of bareland. Eagles may nest close to bareland for flight take off, but when a certain level of buffer is not available, it exposes eagles to human activity and disturbance causing eagle nest abandonment (Grubb et al. 1992, Therres et al. 1993, Steidl and Anthony 2000, Fernández-Juricic and Schroeder 2003). Eagles may choose forested type next to agricultural lands instead of bareland as the agricultural landscape may provide the preferred flight path without the human disturbance element (Figure 6). In addition, bareland does not provide the nest substrate or habitat preference for bald eagle nest presence.

Presence of bald eagle's nests decreases with an increase in distance to shoreline. Bald eagles avoid development and typically nest within one to two kilometers of shoreline (Watts et al. 1994). The Bay provides an optimal prey base for the bald eagle, which feed almost exclusively on fish along the Bay shoreline (Abbott 1978).

Impervious surfaces have a strong negative effect on the presence of bald eagle nests. Bald eagles exhibit negative responses to human development avoiding developed shoreline for perch habitat and foraging use and do not appear to habituate to human disturbance (Therres et al. 1993, Watts et al. 1994, Fraser et al. 1985, Buehler et al. 1991a, Buehler et al. 1991b). The effect of human disturbance on eagles is difficult to quantify and may be manifested in various ways. Human activity may startle eagles, particularly dangerous during nesting which may cause nest abandonment (Therres et al. 1993). Residential and commercial development destroys and fragments habitat buffer areas increasing exposure to human activity.

The full model test of all significant parameters yielded significant results, but the models were multicollinear (Kleinbaum and Klein 2002). When one independent land type increased, another independent land type would be affected making a full model based on land type and distance to land type ineffective. Based on this analysis, impervious surfaces were the best parameter to develop a model to predict bald eagle nest presence.

Impervious Surfaces Thresholds

It can be presumed that as a population, species will respond to a specific parameter up to a particular threshold, after that particular threshold is breached, the habitat can be considered unsuitable or degraded at such a level to cause a population response (Van Horne 1991). Thompson and McGarigal (2002) evaluated "scale-dependant relationships in wildlife habitat" and found critical threshold values for "eagles' response to shoreline development" indicating not only a relationship, but the effect of using threshold analyses at particular scales of study. To develop a threshold for bald eagles that would be applicable across the Chesapeake Bay Watershed, a larger spatial extent was evaluated. Evaluating individual nest areas or groups of small nest areas may not provide enough inter-species rich data to establish the threshold relationship.

The results of this analysis indicate that impervious surface thresholds for bald eagle nest presence along the Virginia portion of the Chesapeake Bay do exist. Bald eagles presence can be grouped into three response levels: 0 – 6% impervious surface area as sensitive habitat (suitability rating of 2), 7 – 23% impervious surface area as impacted habitat (suitability rating of 1), and ≥ 24% impervious surface area classified as unsuitable (suitability rating of 0). The threshold results are closely tied to the Center for Watershed Protection's Watershed Vulnerability Analysis (Zielinski 2002) that measured stream quality based on percent impervious surface within a subwatershed. The Vulnerability Analysis categorized a subwatershed area with 0 to 10% impervious cover as a Sensitive Stream with "excellent habitat structure, good to excellent water quality, and diverse communities of both fish and aquatic insects" (Zielinski 2002). A subwatershed with 11 to 25% impervious cover is categorized as an Impacted Stream, showing signs of habitat "degradation due to watershed urbanization"; and, a subwatershed that exceeds 25% impervious cover is categorized as a Non-Supporting Stream (Zielinski 2002).

Ecologically, the health of a watershed represents the ecological integrity of an area to support species richness.

In areas classed as sensitive in this study, the ecological integrity exists to support bald eagle presence. The area has the habitat to support bald eagle roosting and nest preference, and prey requirements. In addition, these areas have low human disturbance effects, seen as low impervious surface area.

Impacted habitat supports bald eagle presence, but the ecological integrity of the area is negatively affected. The area's available eagle habitat is decreasing due to human development. These areas are also prone to human activity disturbance effects. This particular threshold represents time sensitive areas for habitat conservation.

Unsuitable habitat represents areas that are not suitable for eagle nest presence. The high impervious surface cover in these areas indicates a high human disturbance level. These areas do not support the nesting and / or foraging habitat needed for eagle nest presence.

While all suitable land for eagle presence represents important conservation areas, the impacted threshold areas are in particular danger of becoming lost to development, and subsequently unsuitable. These areas represent time-sensitive conservation areas, as the area may cross the threshold to unsuitable in less time than a suitable area. Identifying these particular areas alerts scientists and local land planners to the sensitivity of these areas and the danger associated with introducing development in the area.

MANAGEMENT IMPLICATIONS

The Endangered Species Act has given the bald eagle the habitat conservation measures necessary to ensure eagle habitat conservation and protection. With the impending removal of the species from Threatened status, management practices must be adapted at a local scale to ensure habitat and species conservation.

Long term management plans need to be developed in response to current eagle habitat and existing development pressures. Watts (1999) has indicated that a "20% increase in the human population" for the year 2020 "will result in a 60% increase in developed land". Bald eagles and humans are in direct competition for habitat. Watts has predicted that the bald eagle population in Virginia will reach carrying capacity at 550 pairs (Springston 2005). At that point, the eagle population will begin to decline. Species specific management for the bald eagle helped bring the eagle back from its endangered status. However, there is a need to develop a coarser tool with which to manage the ecological integrity of an area to support many species.

Local governments are responsible for land use planning with open space management, an existing component of land use planning. These requirements deal with the amount of impervious surface allowed in a defined area (i.e. lot area). Taking a watershed management approach to land use planning, with the incorporation of species specific thresholds will provide planners with an effective sustainable growth plan for their locality and for the bald eagle.

The threshold analysis identified areas of prime conservation concern for bald eagle nest presence within the defined study area. These areas provide the basis for a conservation management plan and for further scientific study. The particular threshold level areas should be further analyzed to quantify what effect(s) are causing the breach of an area that once acted to support bald eagle nest presence to become unsuitable. In understanding these cause and effect relationships change can be made to support smart growth, conservation goals, and the ecological integrity of our environment.

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Table 1. Percent area of land types.

BARELAND	WATER (INLAND)	IMPERVIOUS	CONIFEROUS	AG	DECIDUOUS
2.0850	4.8645	13.1231	18.6402	26.1510	35.1363

Table 2. Average distance (meters) from Bald Eagle nest to land type.

LAND TYPE	DECIDUOUS	CONIFEROUS	AG	SHORELINE	IMPERVIOUS	BARELAND
MINIMUM	1.3440	1.1880	1.1880	21.898	40.7190	61.9460
MAXIMUM	1119.7650	556.7015	772.71	2880.5166	1914.1270	4434.6520

Table 3. Classification Scheme and Grid Code

CLASS	GRID CODE
Impervious Surfaces	1
Deciduous Forest	4
Water	5
Coniferous Forest	6
Bareland	7
Agricultural Lands	8
Cloud	11
Beach	12

Table 4. Logistic Regression Results

Parameter	Pr > ChiSq	Percent Concordant
Impervious	< .0001	65.7
Deciduous Forest	< .0001	65.1
Bareland	< .0001	62.5
Agricultural	0.0009	59.2
Deciduous and Coniferous Forest Comb	< .0001	64.0
Distance to AG	< .0001	90.6
Distance to BARE	< .0001	91.6
Distance to CONIFEROUS FOREST	< .0001	91.1
Distance to DECIDUOUS FOREST	< .0001	91.3
Distance to IMPERVOUS	< .0001	91.6
Distance to WATER	< .0001	91.9
Imperv*Distance to AG	0.0002	86.4
Imperv*Distance to BA	< .0001	89.1
Imperv*Distance to FCON	0.0001	83.4
Imperv*Distance to FDEC	0.0044	78.3
Imperv*Distance to IMPERV	< .0001	89.6
Imperv*Distance to WATER	0.0023	74.3
DECID*Distance to AG	< .0001	90.1
DECID*Distance to BA	< .0001	91.8
DECID*Distance to FCON	< .0001	90.8
DECID*Distance to FDECID	< .0001	91.5
DECID*Distance to IMPERV	< .0001	92.0
DECID*Distance to SHORELINE	< .0001	92.3
WAT*Distance to AG	< .0001	90.0
WAT*Distance to BA	< .0001	90.0
WAT*Distance to FCON	< .0001	90.3
WAT*Distance to FDECID	0.0031	88.7
WAT*Distance to IMPERV	< .0001	89.8
WAT*Distance to SHORELINE	< .0001	91.6
CONIF*Distance to AG	< .0001	90.2
CONIF*Distance to BA	< .0001	90.8
CONIF*Distance to FCON	< .0001	91.1
CONIF*Distance to FDEC	< .0001	91.3
CONIF*Distance to IMPERV	< .0001	90.9
CONIF*Distance to SHORELINE	< .0001	91.5
BARELAND*Distance to AG	0.0001	79.7
BARELAND*Distance to BA	< .0001	84.0
BARELAND*Distance to FCON	0.0094	60.6

BARELAND*Distance to IMPERV	< .0001	83.6
BARELAND*Distance to SHORELINE	0.0004	72.9
AG*Distance to AG	< .0001	90.4
AG*Distance to BA	< .0001	90.8
AG*Distance to FCON	< .0001	90.6
AG*Distance to IMPERV	< .0001	91.0

Table 5. Suitability Ranks for Threshold Levels for Impervious Surfaces

PERCENT AREA IMPERVIOUS SURFACE	SUITABILITY RANK	DESCRIPTION
0 - 6%	2	Sensitive area.
7 - 23%	1	Impacted area.
$\geq$ 24%	0	Impaired / Not Suitable.

Table 6. Chi-Square Results

[illegible]

Table 7. Total area (meters and %) of suitability rankings.

Ranking	Suitability 0	Suitability 1	Suitability 2
Total Area	988552900.36	743172050.94	3814220446.18
Percent of Study Area	17.82	13.40	68.77

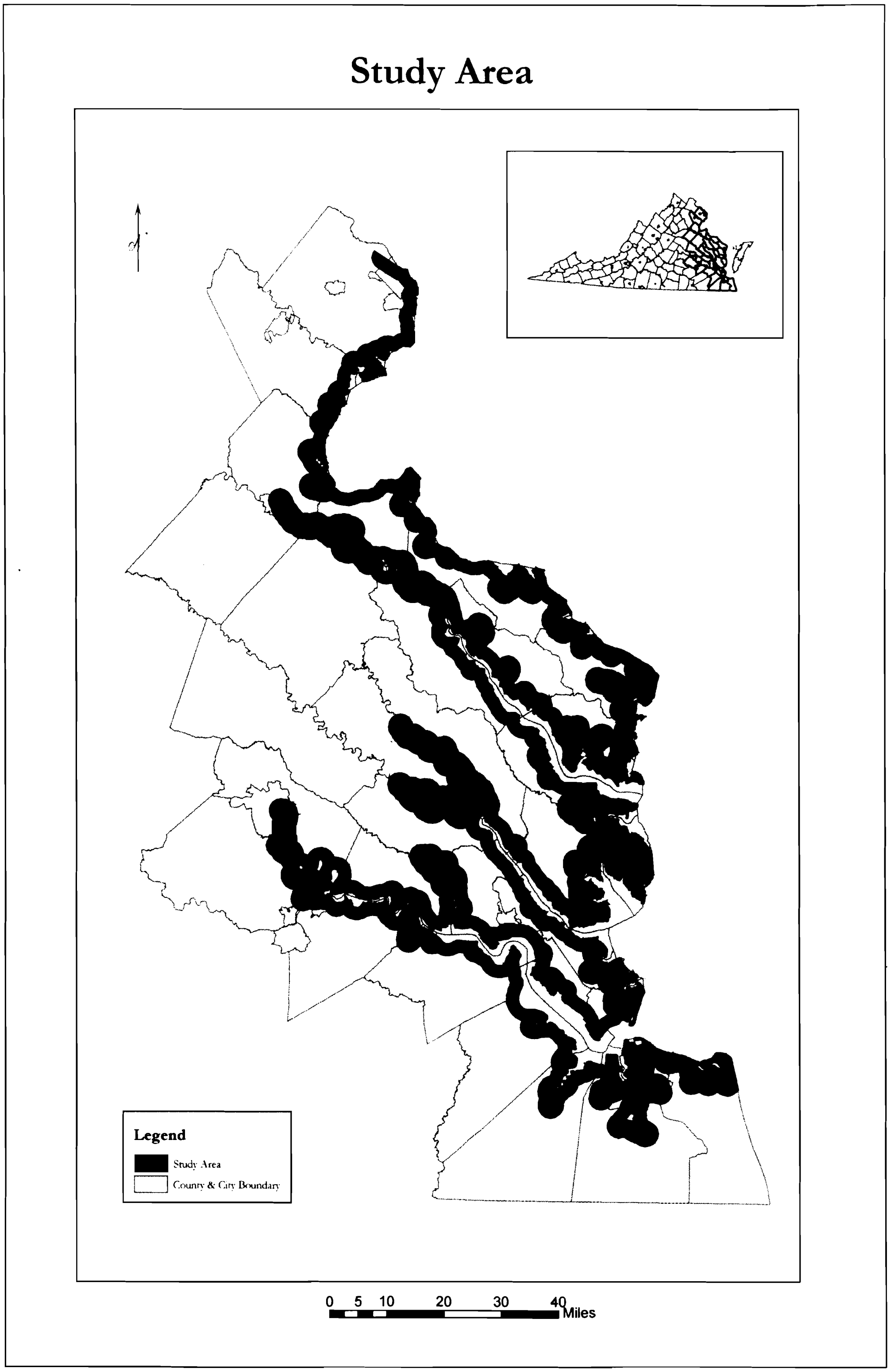

Figure 1. Study Area

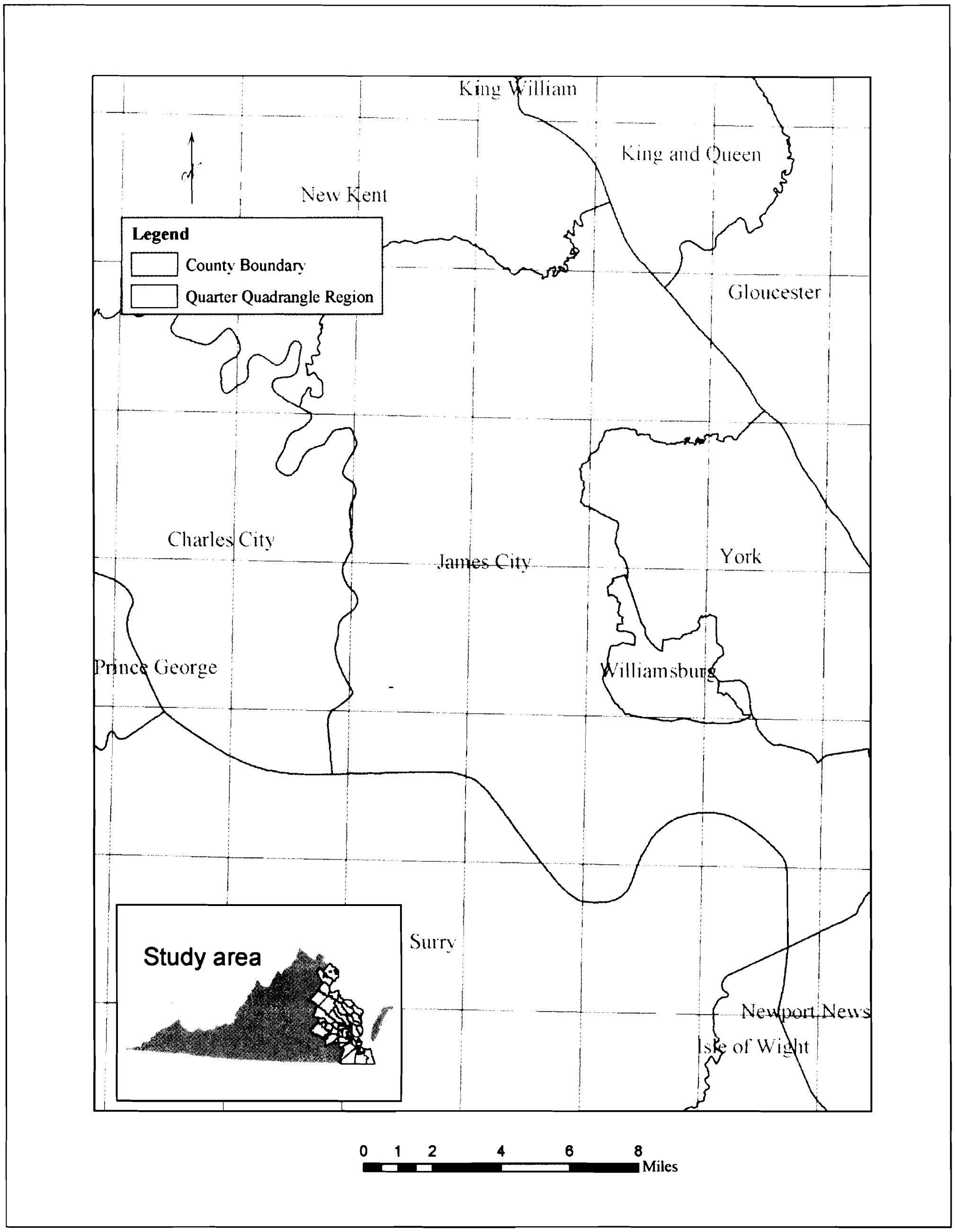

Figure 2. Study Area Regions

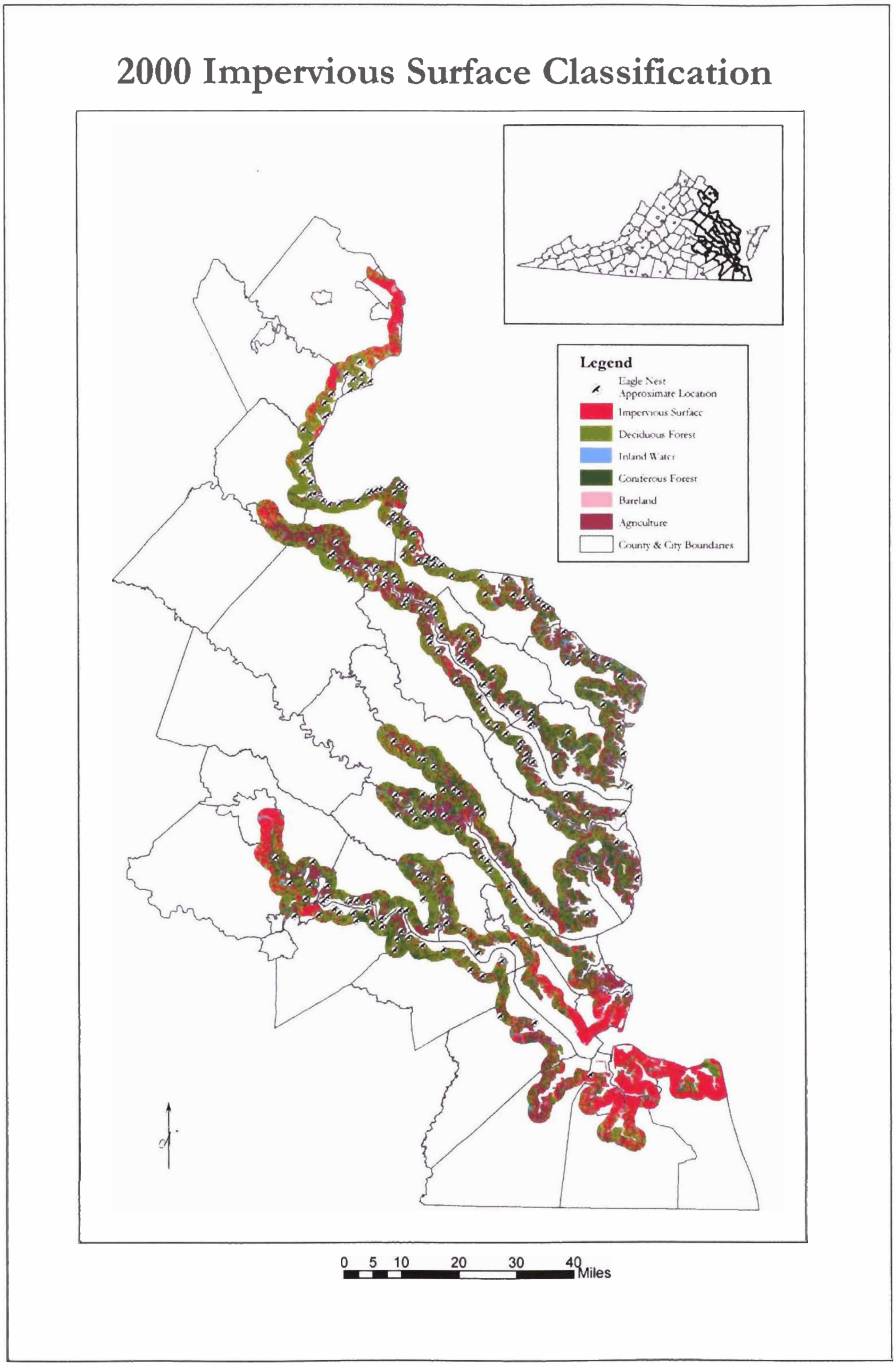

Figure 3. 2000 Impervious Surface Classification

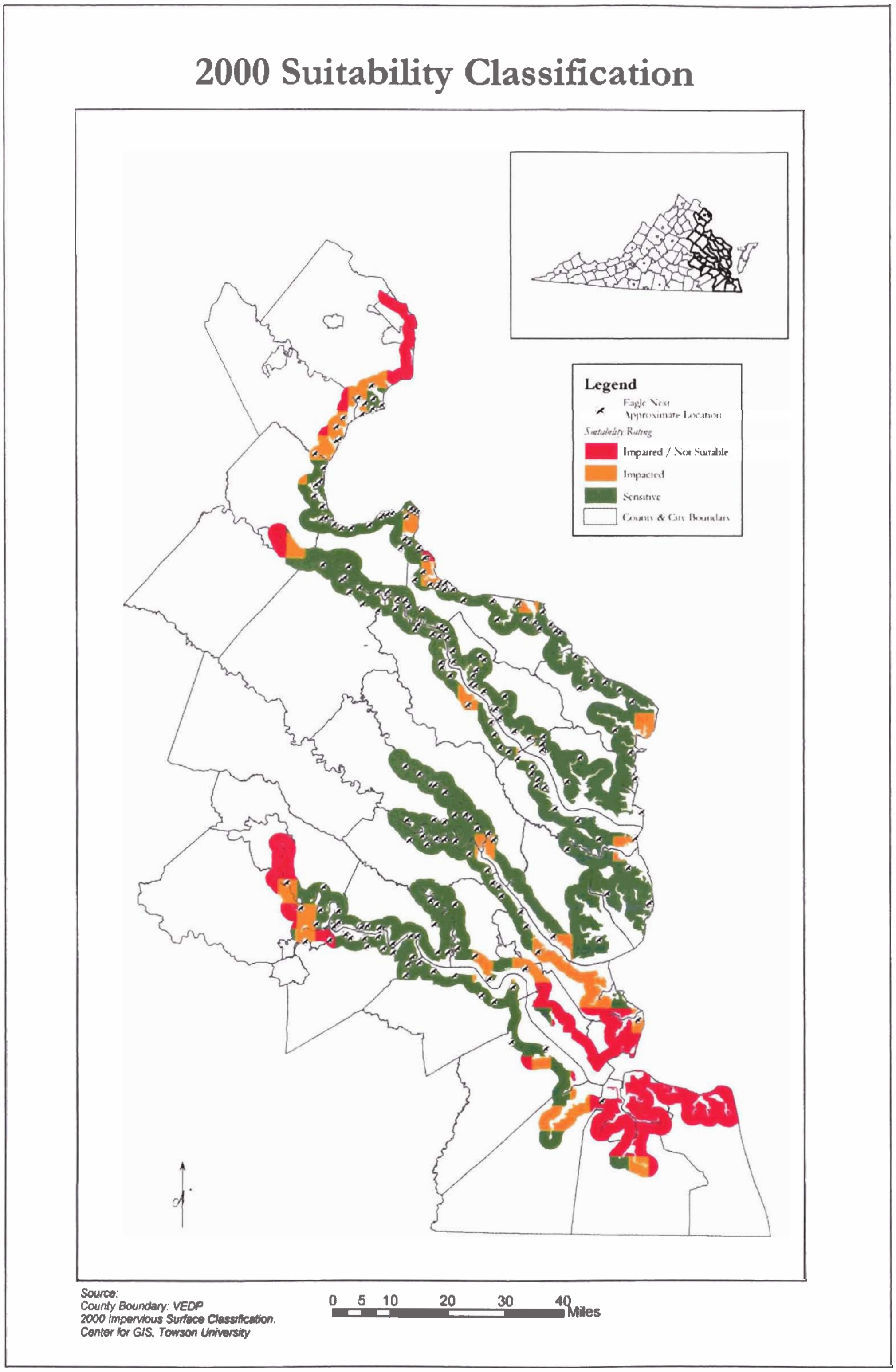

Figure 4. Impervious Surface Suitability Threshold

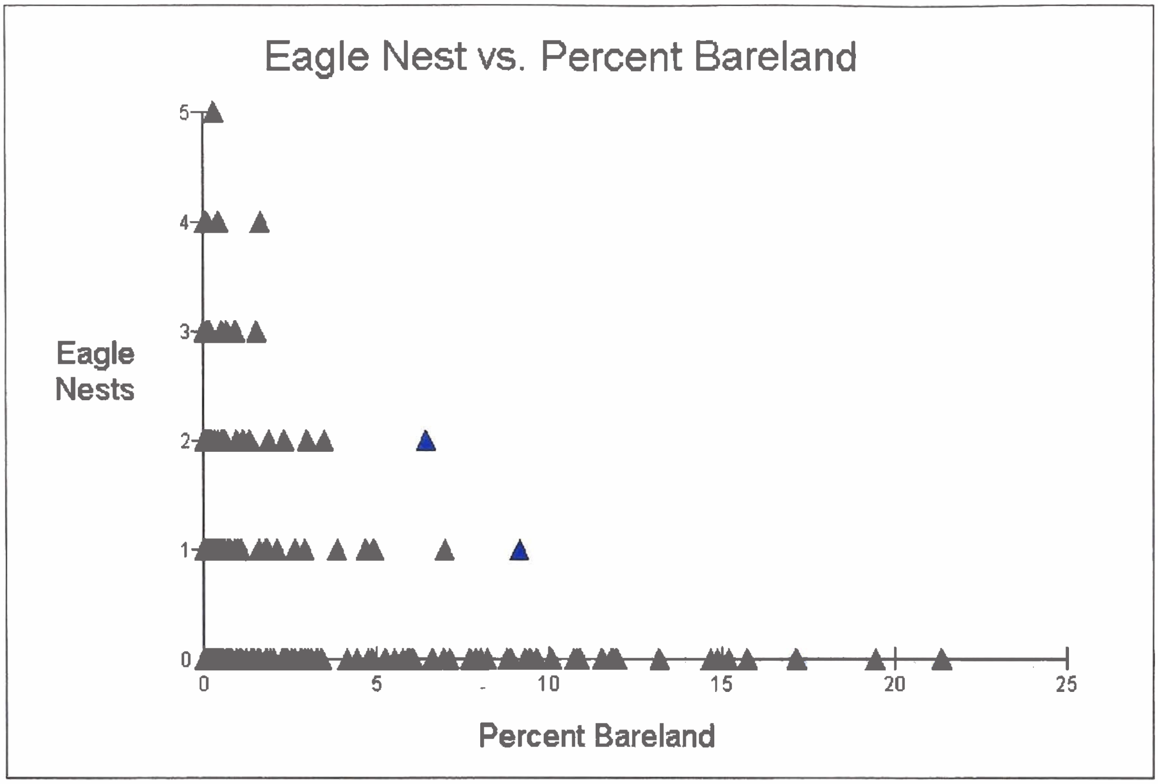

Figure 5. Bald eagle nests plotted against percent area bareland within a study area region. One triangle represents one bald eagle nest, triangles may be stacked representing one or more eagle nest.

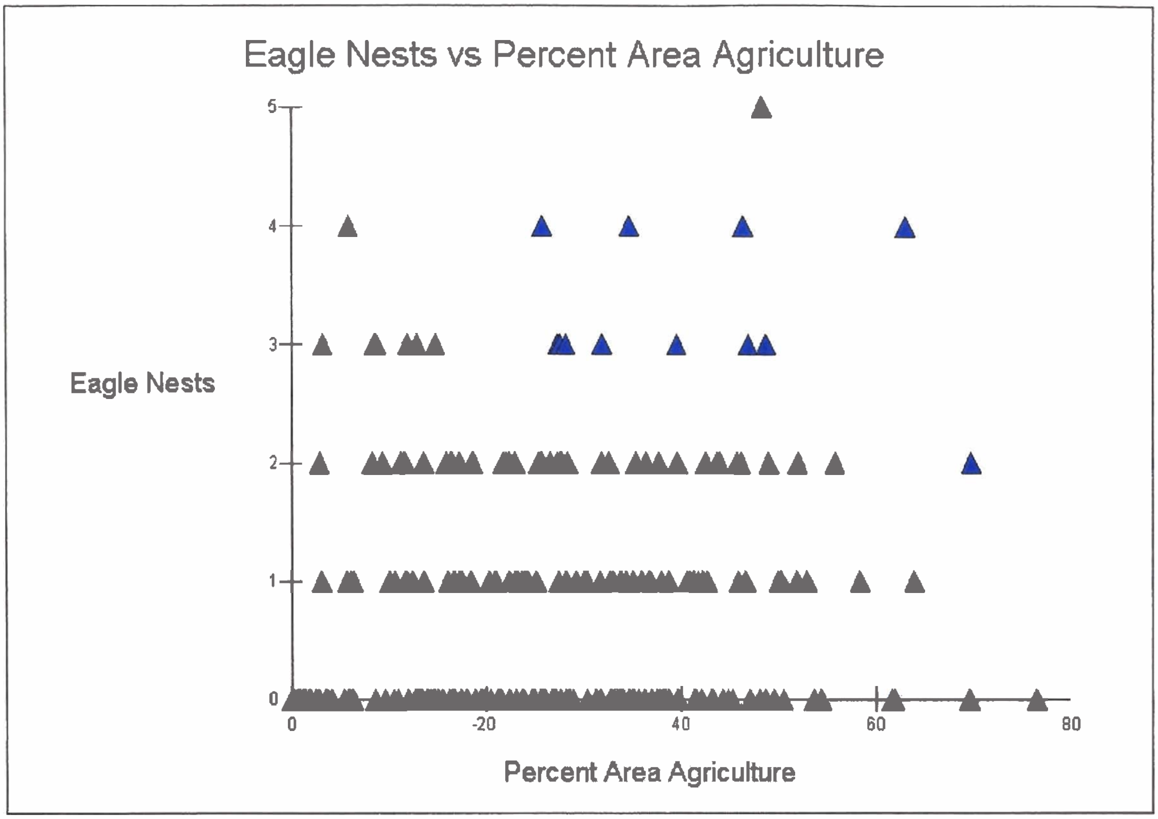

Figure 6. Bald eagle nests plotted against percent area agricultural land within a study area region. One triangle represents one bald eagle nest, triangles may be stacked representing one or more eagle nest.

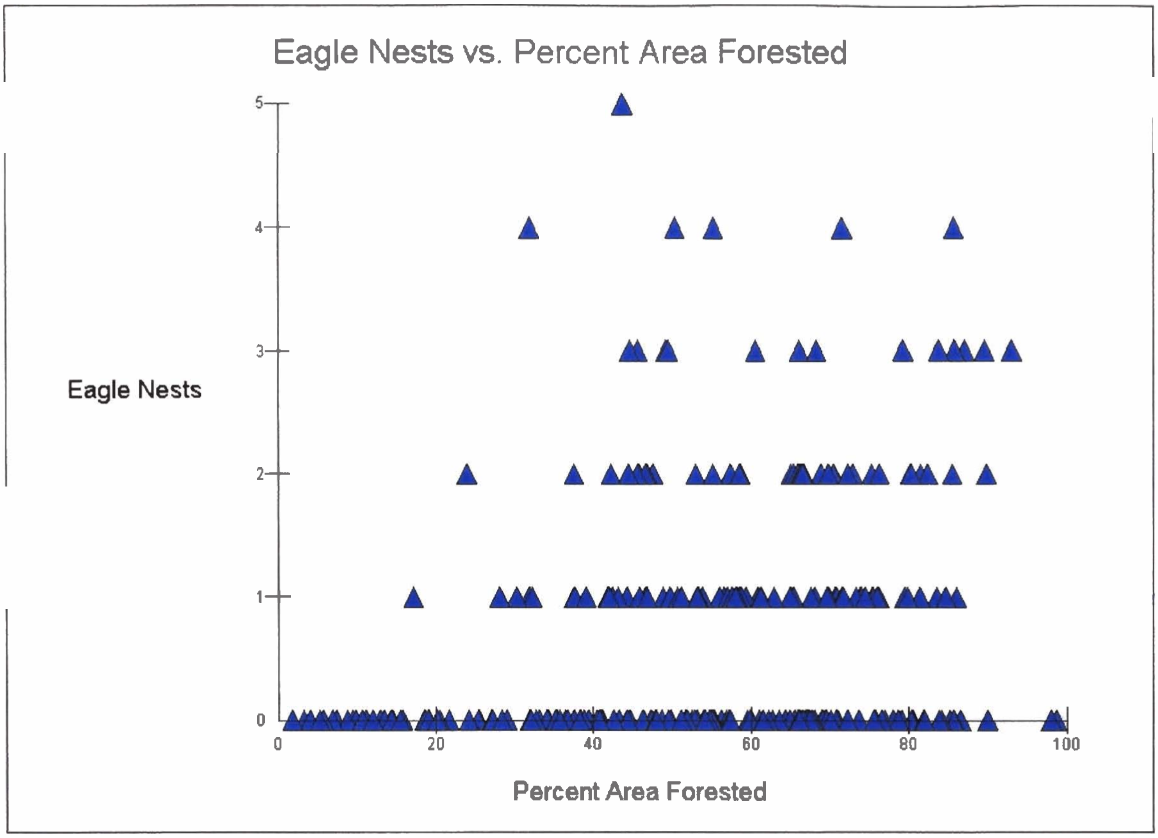

Figure 7. Bald eagle nests plotted against percent area forested within a study area region. One triangle represents one bald eagle nest, triangles may be stacked representing one or more eagle nest.

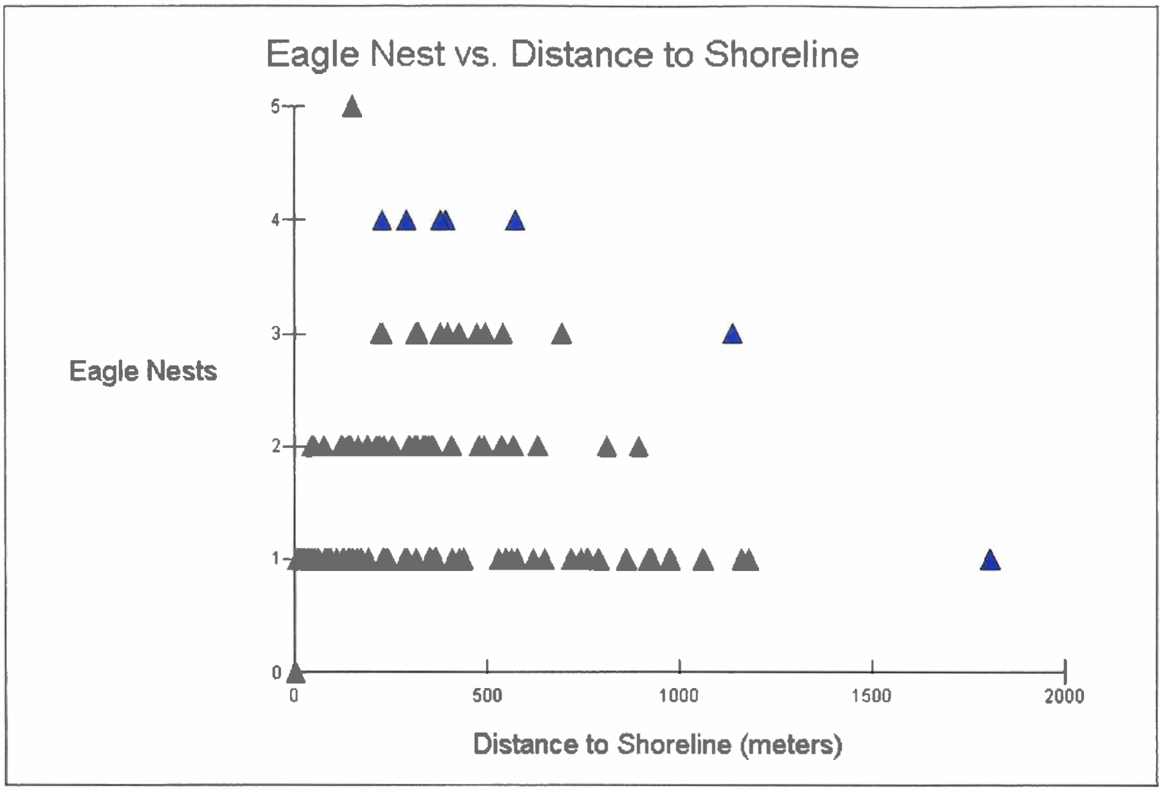

Figure 8. Bald eagle nest plotted against distance to shoreline (meters) within a study area region. One triangle represents one bald eagle nest, triangles may be stacked representing one or more eagle nest.

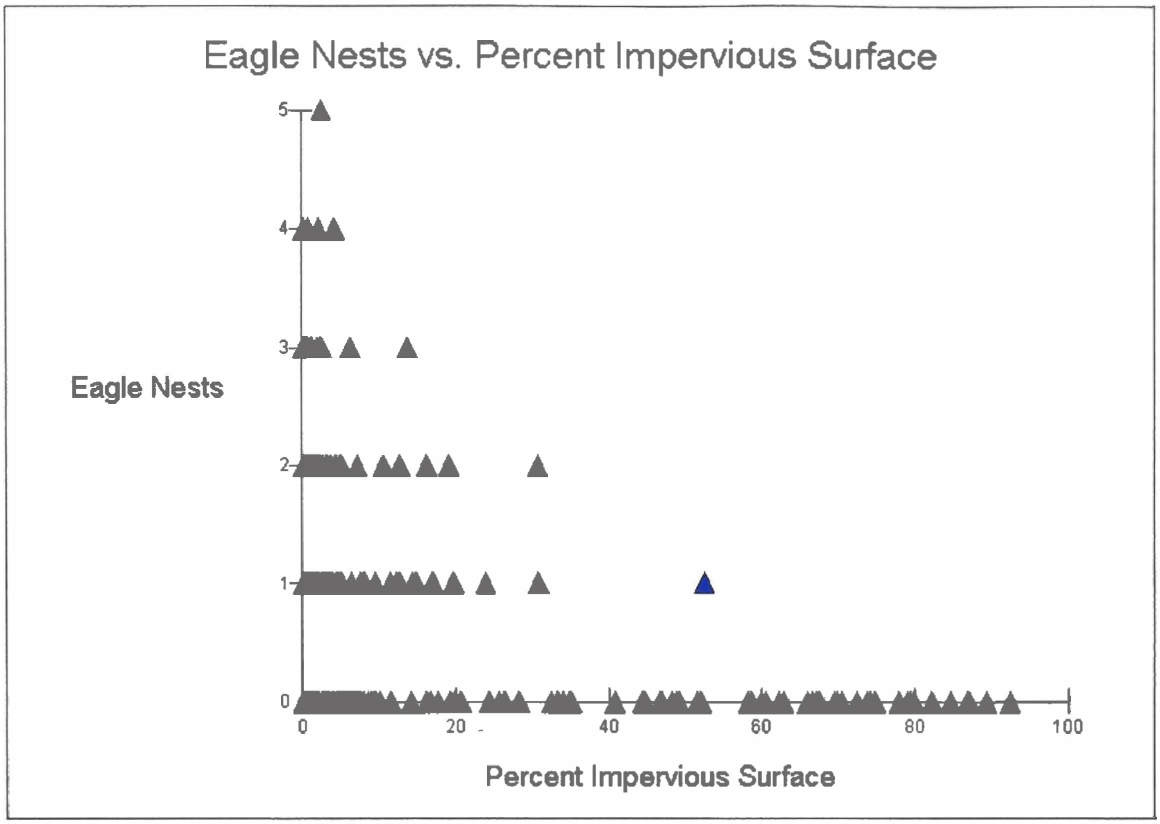

Figure 9. Bald eagle nest plotted against percent impervious surface within a study area region. One triangle represents one bald eagle nest, triangles may be stacked representing one or more eagle nest.

APPENDIX A. Suitability Ranking of Study Area

QNAME	SUITABILITY
ALEXANDRIA NE	0
ALEXANDRIA NW	0
ALEXANDRIA SE	0
ALEXANDRIA SW	0
BOWERS HILL NE	0
BOWERS HILL SE	0
CAPE HENRY SE	0
CAPE HENRY SW	0
CHESTER NE	0
COLONIAL BEACH NORTH SW	0
DREWRYS BLUFF NE	0
DREWRYS BLUFF NW	0
DREWRYS BLUFF SW	0
FALLS CHURCH SE	0
FENTRESS NW	0
FREDERICKSBURG NW	0
FREDERICKSBURG SW	0
HAMPTON NW	0
HAMPTON SE	0
HAMPTON SW	0
HOPEWELL SE	0
KEMPSVILLE NE	0
KEMPSVILLE NW	0
KEMPSVILLE SW	0
LITTLE CREEK SE	0
LITTLE CREEK SW	0
MOUNT VERNON NE	0
MOUNT VERNON NW	0
MULBERRY ISLAND NE	0
NEWPORT NEWS NORTH NE	0
NEWPORT NEWS NORTH NW	0
NEWPORT NEWS NORTH SE	0
NEWPORT NEWS NORTH SW	0
NEWPORT NEWS SOUTH NE	0
NEWPORT NEWS SOUTH NW	0
NEWPORT NEWS SOUTH SE	0
NORFOLK NORTH NE	0
NORFOLK NORTH SE	0
NORFOLK NORTH SW	0

NORFOLK SOUTH NE	0
NORFOLK SOUTH NW	0
NORFOLK SOUTH SE	0
NORFOLK SOUTH SW	0
NORTH VIRGINIA BEACH SW	0
OCCOQUAN SE	0
PRINCESS ANNE NE	0
PRINCESS ANNE NW	0
QUANTICO NW	0
RICHMOND SE	0
RICHMOND SW	0
SMITHFIELD NE	0
VIRGINIA BEACH NW	0
WASHINGTON WEST SW	0
YORKTOWN SE	0
YORKTOWN SW	0
BENNS CHURCH NW	1
BOWERS HILL NW	1
CHUCKATUCK NE	1
CHUCKATUCK NW	1
CLAY BANK SE	1
CLAY BANK SW	1
COLONIAL BEACH SOUTH NW	1
DAHLGREN NE	1
DEEP CREEK NE	1
DELTAVILLE SW	1
DREWRYS BLUFF SE	1
FORT BELVOIR NE	1
FORT BELVOIR NW	1
FORT BELVOIR SW	1
FREDERICKSBURG SE	1
HAMPTON NE	1
HOG ISLAND NE	1
HOPEWELL NW	1
HOPEWELL SW	1
MORATTICO SE	1
NEWPORT NEWS SOUTH SW	1
NORGE SE	1
POQUOSON WEST NE	1
POQUOSON WEST NW	1
POQUOSON WEST SE	1
POQUOSON WEST SW	1
QUANTICO NE	1

QUANTICO SE	1
QUANTICO SW	1
REEDVILLE NE	1
SAINT CLEMENTS ISLAND SE	1
STAFFORD NE	1
SURRY NE	1
TAPPAHANNOCK SW	1
WEST POINT SE	1
YORKTOWN NE	1
YORKTOWN NW	1
ACHILLES NE	2
ACHILLES NW	2
ACHILLES SE	2
ACHILLES SW	2
AYLETT SE	2
AYLETT SW	2
BACONS CASTLE NE	2
BACONS CASTLE NW	2
BACONS CASTLE SE	2
BENNS CHURCH NE	2
BENNS CHURCH SE	2
BRANDON NE	2
BRANDON NW	2
BRANDON SE	2
BRANDON SW	2
BURGESS NW	2
BURGESS SE	2
BURGESS SW	2
CHAMPLAIN NE	2
CHAMPLAIN NW	2
CHAMPLAIN SE	2
CHAMPLAIN SW	2
CHARLES CITY NE	2
CHARLES CITY NW	2
CHARLES CITY SE	2
CHARLES CITY SW	2
CHESTER SE	2
CHUCKATUCK SE	2
CHUCKATUCK SW	2
CHURCH VIEW NE	2
CHURCH VIEW SE	2
CLAREMONT NE	2
CLAREMONT NW	2

CLAREMONT SE	2
CLAY BANK NE	2
CLAY BANK NW	2
COLONIAL BEACH SOUTH SE	2
COLONIAL BEACH SOUTH SW	2
DAHLGREN NW	2
DAHLGREN SE	2
DAHLGREN SW	2
DEEP CREEK NW	2
DELTAVILLE NW	2
DUNNSVILLE NE	2
DUNNSVILLE SE	2
DUTCH GAP SE	2
DUTCH GAP SW	2
FLEETS BAY NW	2
FLEETS BAY SW	2
FORT BELVOIR SE	2
FREDERICKSBURG NE	2
GLOUCESTER SE	2
GLOUCESTER SW	2
GRESSITT NE	2
GRESSITT NW	2
GRESSITT SE	2
GRESSITT SW	2
GUINEA NE	2
HAYNESVILLE SW	2
HEATHSVILLE NE	2
HEATHSVILLE NW	2
HEATHSVILLE SE	2
HEATHSVILLE SW	2
HOG ISLAND NW	2
HOG ISLAND SE	2
HOG ISLAND SW	2
HOPEWELL NE	2
IRVINGTON NE	2
IRVINGTON NW	2
IRVINGTON SE	2
IRVINGTON SW	2
KING AND QUEEN COURT HOUSE NE	2
KING AND QUEEN COURT HOUSE NW	2
KING AND QUEEN COURT	2

HOUSE SE	
KING AND QUEEN COURT	2
HOUSE SW	
KING GEORGE NE	2
KING GEORGE NW	2
KING GEORGE SW	2
KING WILLIAM NE	2
KING WILLIAM NW	2
KINSALE NE	2
KINSALE NW	2
KINSALE SE	2
KINSALE SW	2
LANCASTER NE	2
LANCASTER NW	2
LANCASTER SE	2
LANCASTER SW	2
LIVELY NW	2
LIVELY SE	2
LIVELY SW	2
LORETTO NE	2
LORETTO NW	2
LOTTSBURG NE	2
LOTTSBURG NW	2
MACHODOC NE	2
MACHODOC NW	2
MATHEWS NE	2
MATHEWS NW	2
MATHEWS SE	2
MATHEWS SW	2
MATHIAS POINT SE	2
MONTROSS NE	2
MONTROSS SE	2
MONTROSS SW	2
MORATTICO NE	2
MORATTICO NW	2
MORATTICO SW	2
MOUNT LANDING NE	2
MOUNT LANDING NW	2
MOUNT LANDING SE	2
MULBERRY ISLAND NW	2
MULBERRY ISLAND SW	2
NEW KENT NE	2
NEW KENT NW	2

NEW KENT SE	2
NEW KENT SW	2
NEW POINT COMFORT NE	2
NEW POINT COMFORT NW	2
NORGE NW	2
NORGE SW	2
PASSAPATANZY NE	2
PASSAPATANZY NW	2
PASSAPATANZY SE	2
PASSAPATANZY SW	2
PINEY POINT SW	2
POQUOSON EAST SW	2
PORT ROYAL NE	2
PORT ROYAL NW	2
PORT ROYAL SE	2
PORT ROYAL SW	2
PROVIDENCE FORGE SE	2
RAPPAHANNOCK ACADEMY NE	2
RAPPAHANNOCK ACADEMY NW	2
RAPPAHANNOCK ACADEMY SE	2
REEDVILLE NW	2
REEDVILLE SW	2
ROLLINS FORK NE	2
ROLLINS FORK SE	2
ROLLINS FORK SW	2
ROXBURY SW	2
SAINT CLEMENTS ISLAND SW	2
SALUDA NE	2
SALUDA NW	2
SALUDA SE	2
SAVEDGE NE	2
SHACKLEFORDS SW	2
ST GEORGE ISLAND SW	2
STAFFORD SE	2
STRATFORD HALL SE	2
STRATFORD HALL SW	2
SURRY NW	2
SURRY SE	2
SURRY SW	2
TAPPAHANNOCK NE	2
TAPPAHANNOCK NW	2

TAPPAHANNOCK SE	2
TOANO NE	2
TOANO NW	2
TOANO SE	2
TOANO SW	2
TRUHART SW	2
TUNSTALL NE	2
TUNSTALL NW	2
TUNSTALL SE	2
URBANNA NE	2
URBANNA NW	2
URBANNA SE	2
URBANNA SW	2
WALKERS NW	2
WALKERS SE	2
WALKERS SW	2
WARE NECK NE	2
WARE NECK NW	2
WARE NECK SE	2
WARE NECK SW	2
WEST POINT NE	2
WEST POINT NW	2
WEST POINT SW	2
WESTOVER NE	2
WESTOVER NW	2
WESTOVER SE	2
WESTOVER SW	2
WIDEWATER NW	2
WIDEWATER SW	2
WILLIAMSBURG NE	2
WILLIAMSBURG NW	2
WILLIAMSBURG SE	2
WILTON NE	2
WILTON NW	2
WILTON SE	2
WILTON SW	2

APPENDIX B. Supervised Classification Procedure

Signature files were collected for each image for the Supervised Classification using the Imagine AOI Tools and the Signature Editor. Band combination was set to False Color Red-Green-Blue composite, band combination 4, 3, 2, with band 4 (near infra-red) set to the red layer, band 3 (red) set to the green layer and band 2 (green) set to the blue layer. The false color composite combination was chosen for vegetation and habitat analysis.

Digital Orthophotography Quarter Quadrangles (DOQQ) were the ancillary data source, aiding in collection of signature files. The DOQQs are aerial photographs flown in 1994 or 1996 and have a one meter resolution, meaning each pixel in the image represents one square meter on the ground. The DOQQs used for this project were in a Multi-resolution Seamless Image Database (MrSID) format, and were obtained from the Virginia Economic Development Partnership. In ERDAS Imagine, the USGS quarter quadrangle index overlaid on the Landsat TM scene of interest was used to identify the desired quadrangle file names. The resulting four DOQQs were added to a second viewer to visually choose signatures for each class of the classification scheme. Twenty Area of Interests (AOI) were created using the AOI tools under the Viewer menu AOI option for each grid code, and these AOIs were added as individual signatures to the Signature Editor. The 20 signatures for each class were then merged to one final signature in the Signature Editor, and the final file saved as hrf_rowpath.sig. The full spectral reflectance of each class throughout the image had to be accurately represented to set the model for the supervised classification for a particular land type (Lillesand and Kiefer 1994). Signatures were collected systematically on a grid pattern through the Landsat TM scene to ensure accurate class type representation.

Separability was performed on each final signature file for each Landsat scene to evaluate the "statistical distances" between signatures using the Evaluate Separability function in the Signature Editor (ERDAS 2004). Signature separability was run using the Transformed Divergence as the distance measurement, with a 6-layer combination, 36-pairs per combination, and output in ASCII format for evaluation. Signature separability has a maximum divergence value of 2000; values that fall below 1500 indicate signatures that are not spectrally unique (Lillesand and Kiefer 1994).

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