The Influence of Perch Tree Distribution and Abundance on Bald Eagle Distribution on the Northern Chesapeake Bay, Maryland

by

Sheri Kay Chandler

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APPROVED:

James D. Fraser
James D. Fraser, Chairman

Roy L. Kirkpatrick
Roy L. Kirkpatrick

Dean F. Stauffer
Dean F. Stauffer

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(ABSTRACT)

Forested shoreline is important perching habitat for bald eagles (Haliaeetus leucocephalus). Bald eagles hunt, feed and loaf on shoreline perches. I measured trees suitable for bald eagle perches along the northern Chesapeake Bay during 1990-1991 to determine the influence of shoreline perch tree availability on bald eagle distribution. The shoreline was divided into 250 x 50 m segments. A segment was considered used if at least 1 eagle had perched on it during 1985-1992. I determined the number of suitable shoreline perch trees, percent forest cover, and distance from the water to the nearest suitable perch tree for each segment.

Segments along the Chesapeake Bay had an average of 1 suitable perch tree per 10 m of shoreline. Shoreline segments used by eagles had more suitable perch trees ($\underline{P}$ = 0.0008) and a larger percent of forest cover ($\underline{P}$ = 0.0008). Suitable trees on segments with eagle use were closer to

water than suitable trees on segments without eagle use ($\underline{P}$ = 0.0087). The differences in segments with and without eagle use appear to be largely due to the lack of trees in marshes which were used only seldomly. Marsh had few suitable perch trees, less forest cover and a greater mean distance from water to the nearest suitable perch tree than the other land types ($\underline{P} \leq 0.0001$). These factors are unfavorable for foraging eagles and most marsh segments (66.7%) were unused, probably for this reason.

The number of suitable perch trees and the percent of forest cover were lower on developed areas than undeveloped, forested areas ($\underline{P} \leq 0.01$ for both tests). Also the distance from water to the nearest suitable perch tree was greater on developed land than forested land ($\underline{P} \leq 0.01$). Thus, development appears to decrease the availability of suitable shoreline perch trees when compared to forested areas.

Logistic regression models were created to predict the probability of eagle use, given the conditions at the time of this study. Varying values of development density, percent forest cover, number of suitable perch trees and distance from water to the nearest suitable tree were inputs used in these models to create curves to predict eagle use under different conditions. These curves indicated that, for a given development density, the probability of eagle use increased as the number of suitable perch trees or percent forest cover on the segment increased. Also, for a given development density, the probably of eagle use increases as the distance to water decreases.

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INTRODUCTION

Historical perspective

In this thesis, I present the results of research on the influence of perch tree distribution and abundance on bald eagle (Haliaeetus leucocephalus) distribution on the northern Chesapeake Bay. This project was part of a long-term study of the factors that regulate eagle distribution on the Chesapeake Bay. I have attempted to integrate my results with the results of other researchers who were a part of this study.

The number of eagles inhabiting the pristine Chesapeake Bay is unknown. However, if the density of breeding pairs was similar to the density in pristine Alaska (1 pair per 4 km of shoreline), then the Chesapeake Bay could have supported as many as 3,000 pairs over it's 13,000 km of shoreline (Fraser et al. 1991).

Although there are no census data, the eagle population almost certainly began to decline following the arrival of

European immigrants during the 1600 and 1700's. The settlers and their successors began large-scale clearing of the shoreline forests for agriculture, which undoubtedly eliminated eagle nests, roosts, and perches at a rapid rate. Shooting eagles was popular during this time because of the widely-held belief that all top predators were dangerous to people and livestock and should be eliminated. Trappers and oologists also were adversely affecting the eagle population (Abbott 1982). At the time of the first breeding population survey in 1936, about 600-800 pairs of eagles were thought to be present on the Chesapeake Bay (Abbott 1978).

After the 1936 estimate, the population continued to decline. In 1946, the pesticide DDT was introduced into the food chain. During this period, DDT had a strongly adverse effect on eagles (Abbott 1982, Wiemeyer et al. 1984). Shooting and habitat destruction also continued and the eagle population was drastically reduced. By 1962, when the next survey of breeding pairs was conducted, the eagles' reproductive rate had dropped from 1.7 young per pair in 1936 to 0.2 young per pair. By 1970 only 80-90 pairs could be located (Abbott 1978).

The use of DDT declined through the 1960's and the chemical was removed from agricultural use in the United States in 1972 (Environmental Protection Agency 1975). By 1977, the reproductive rate had increased to 0.91 young per pair (Abbott 1982) and between 1986-1990 the average reproductive rate was 1.3 young per pair (Buehler et al. 1991a). The survival rate for these birds also was high (86%), resulting in an increasing population (Buehler et al. 1991a). However, the increase in the bald eagle population may be short in duration unless the rate of shoreline development declines (Fraser et al. 1991, Fraser et al. 1992)

The Importance of Shoreline Perch Trees

Eagles feed, perch, roost and nest along the Chesapeake Bay's shores. They feed mostly on live or dead fish, but they are opportunistic feeders and, when fish are scarce, they consume waterfowl, especially those crippled or killed during the fall harvest, and on any carrion available (Mersmann 1989).

The forested shoreline surrounding the Chesapeake Bay and its tributaries is extremely important to eagles. Eagles usually perch within 50 m of the water and roost within 1 km (Stalmaster and Newman 1979, Steenhof et al. 1980, Harmata 1984, Stalmaster 1987, Buehler et al. 1992). Eagles hunt, feed and loaf on shoreline perches. Trees are used for nearly all shoreline perching (Stalmaster and Newman 1979, Steenhof et al. 1980).

Eagles are physiologically and morphologically adapted for perching for extended periods of time. An eagle may spend more than 90% of a 24-hr period perched (Servheen 1975, Gerrard et al. 1980, Stalmaster and Gessaman 1984, Watson et al. 1991). Remaining perched allows eagles to conserve energy (Stalmaster and Newman 1979, Stalmaster 1983, Steenhof 1983, Stalmaster and Gessaman 1984, Craig et al. 1988). This may be especially important during the autumn and winter when food is least abundant on the Chesapeake Bay (Mersmann 1989). Several researchers have suggested that perching habitat is so important for eagles that their distribution and abundance may be determined by the availability of suitable perch trees (Servheen 1975, Stalmaster and Newman 1979, Fielder and Starkey 1980, Steenhof et al. 1980). This has not been tested, however. If true, destroying perching habitat may decrease eagle populations and/or change eagle distributions.

The Future of Shoreline Habitat

The human population in the Chesapeake Bay watershed is increasing rapidly, as are the demands on the Chesapeake Bay for recreation, food production, waste placement, housing along its shores and many other uses (Cronin 1981). A report prepared for the Chesapeake Executive Council predicted 73% and 80% increases in the amount of developed land in the Chesapeake Bay watershed in Maryland and Virginia, respectively, between 1978 and 2020 (Gray et al. 1988).

Shoreline development reduces the use of the Chesapeake Bay shoreline by eagles not only by disturbing habitat but also because the presence of humans near the shore disturbs routine eagle activities. Eagles avoid humans in nest site selection (Nash et al. 1980, Fraser 1981, Jaffee 1981, Andrew and Mosher 1982, Fraser et al. 1985, Grubb and King 1991) and roost site selection (Hansen et al. 1980, Harmata 1984, Chester et al. 1990, Buehler et al. 1991c).

Several studies also have shown that eagles tended to avoid areas of human use and/or development within foraging areas (Servheen 1973, Steenhof 1976, Stalmaster and Newman 1978, Knight and Knight 1984, McGarigal 1988, Smith 1988, Chester et al. 1990). Buehler et al. (1991b) found that nonbreeding eagles on the Chesapeake Bay avoided areas frequented by people, especially areas with buildings and other structures. Using logistic regression, they found that the probability of eagles using a shoreline segment decreased as the number of houses on that segment increased (Tables 1, 2). Also, the closer the development was to the shoreline, the lower was the probability that eagles would use the area. They found that eagles used shoreline with development less than 500 m from the shore less often than expected based on random samples. He concluded that eagles on the Chesapeake Bay almost never used shoreline with > 1 building/ha within 500 m from shore. Eagles on the northern Chesapeake Bay also appeared to avoid shoreline near pedestrian or boat traffic (Buehler et al. 1991b)

Unfortunately, the common approach to bald eagle management of protecting mostly nests and areas immediately surrounding nests (Mathisen et al. 1978) does not appear adequate for preventing the decline of shoreline perching areas. Perching habitat must be specifically protected if it is to be retained. Managers, therefore, need a reliable method to identify usable and restorable shoreline habitats. This study was aimed at developing such a tool. I investigated 2 hypotheses. The first hypothesis was that eagle distribution is limited by shoreline perch tree abundance. I tested 3 predictions that follow from that hypothesis:

1. there are more suitable perch trees on areas used by eagles than on areas not used by eagles,

2. there is a greater percent of forest cover on areas used by eagles than areas not used by eagles,

3. there is a shorter distance from water to the nearest perch tree in shoreline areas used by eagles than in areas not used by eagles,

The second hypothesis was that developed areas and marshes were not as suitable for perching as forested, agricultural fields/pastures and other areas due to a lack of shoreline perch trees. Three predictions followed from this hypothesis:

1. there are fewer suitable perch trees on developed land and marshes than forested, agricultural fields/pastures and other areas,

2. there are smaller percentages of forest cover on developed land and marshes than forested, agricultural fields/pastures and other areas,

3. there are longer distances from water to the nearest perch tree on developed lands and marshes than in forested, agricultural fields/pastures and other areas.

Perching habitat characteristics and human development were incorporated into models that can be used to predict shoreline areas suitable for eagle perching.

STUDY AREA

The Chesapeake Bay

The Chesapeake Bay, bordering Maryland and Virginia, is the largest bay in the United States (5,700 km^2). It also is longer (320 km), has more tributaries (150) and more shoreline (13,000 km) than any other bay in the country (Lippson and Lippson 1984, White 1989).

The Chesapeake Bay was formed after the last glacial period, near the end of the Pleistocene. Twenty thousand years ago, as the climate warmed and the glacial ice began to melt, the Susquehanna River carried the water south toward the Atlantic Ocean. The warming climate also caused the Atlantic to rise and flood its basin. The river and the ocean eventually met causing the mixing of fresh and salt waters and creating a large bay (Cronin 1981, Lippson and Lippson 1984, White 1989).

The Chesapeake Bay is an estuary. It is a semi-closed coastal body of water that has a salinity gradient from fresh in the north to saline at the Ocean. It has daily tides, seasonally variable flow and salinity, and circulation of the lighter fresh water that flows on top of the heavier salt water.

Unlike many estuaries, the Chesapeake Bay is relatively shallow (6.4 m average depth), has many rivers (which are sources of fresh water), and has a wide entrance to the sea, all factors that promote a healthy system (White 1989). In fact, the Chesapeake Bay has been called the most productive estuary in North America (White 1989). Long before John Smith arrived, the native Algonquins named the bay "Chesepiooc" for "great shellfish bay" (White 1989). It has about 243,000 ha of wetlands that produce more than 90 million kg of seafood annually. It produces the largest crops in the nation of blue crabs, soft-shelled clams, American shad and Atlantic menhaden. More than 1,220 plant species and 1,500 species of animals spend some or all of their life in the water or on the shores of the Chesapeake Bay (Cronin 1981).

Study Location

My research was conducted on the northern region of the Chesapeake Bay in Maryland (Figure 1). The study area extended north from the Gunpowder River on the western shore to the mouth of the Susquehanna River. From the mouth of the Susquehanna River it included the northern end of the Chesapeake Bay and extended south on the eastern shore to the mouth of the Chester River. The study area included portions of all creeks and rivers, except the Susquehanna and Chester Rivers. The area contained 580 km of shoreline. I divided the study site into 5 general areas for ease of description (Figure 2).

Western Shore

The Western Shore portion of the study area included Aberdeen Proving Grounds (APG), and the Bush and Gunpowder Rivers (Figure 2). The water was shallow near the shore (approximately 0.2 - 0.6 m) and the sandy bottom sloped gently near most of the shoreline (approximately 5 - 10^0); the shore itself had a very slight slope (approximately 5^0).

The shoreline had small forests and extensive marshes. The Western Shore had the fewest suitable perch trees of the northern Chesapeake Bay areas (Appendix A). This was because the many large marshes extended inland nearly 50 m or more and had few trees (Appendix A).

The marshes contained a large variety of herbaceous species. Emergent plants at the water's edge included arrow arum (Petandra virginica), pickerelweed (Pontederia cordata), and narrow-leaved cattail (Typha angustifolia). Introduced common reed (Phragmites australis) and native marsh grass species including wild rice (Zizania aquatica) and Walter's millet (Echinochola walteri) densely covered many marsh areas. Several species of sedges (Cyperacea spp.) and rushes (Juncaceae spp.) also were associated with marsh areas. These species and others were present in a variety of combinations in different marshes and not all species were present in all marshes.

Sweetgum (Liquidambar styraciflua) was the most abundant tree species on the wooded shorelines of the western shore (Appendix A). Sweetgum is a fire tolerant species that can survive the many fires caused annually by munitions testing on APG. Other species included oaks (Quercus spp.), black locust (Robinia pseudoacacia), black cherry (Prunus serotina,) and maples (Acer spp.). Little or no tree reproduction was evident in many areas of APG apparently due to the frequent fires and heavy deer browsing.

Susquehanna Flats

The Susquehanna flats region of the study area extended from Swan Creek, northwest of APG past the mouth of the

Susquehanna River and east to the Northeast River (Figure 2). This area had shallow water (0.3 - 1.0 m) and a sandy bottom (Appendix A).

The shoreline was typically steep (approximately 45 - 60^0 slopes and 6 m banks) and forested, although some areas had residential development (Appendix A). Tree species in this area were predominately ash (Fraxinus spp.) and oak with lesser numbers of maples and American beech (Fagus grandifolia).

Eastern Shore

The Eastern Shore of the northern Chesapeake Bay commonly was lined with 6 - 25 m cliffs. The clay bottom had an approximately 10 - 20^0 slope and the near-shore water was deeper than the western shore (approximately 0.6 - 1.2 m). The land was mostly developed or forested with few marshes and pastures (Appendix A). The most common tree species were oak, sweetgum and black cherry. Ash, hickory and other species were less common (Appendix A).

Stillpond, Churn, Worton and Fairlee Creeks

Stillpond, Churn, Worton and Fairlee Creeks, located on the Eastern Shore (Figure 2), were generally shallow near the shore (approximately 0.3 - 1.0 m), with silty substrates and steep banks (approximately 60^0 slopes and 6 m banks). Most of the shoreline was forested, but development was common (Appendix A). In addition to residential development, large marinas were located in Worton and Fairlee creeks. All three creeks were heavily used for recreational boating and nearly all shoreline houses had boat docks.

The creeks' shorelines had more suitable perch trees and more forest cover than the other areas. Average tree DBH and height were greater in these creeks than in other locations on the study area (Appendix A). Most trees were oak. Elm (Ulmus spp.), black locust and ash were among the other species present (Appendix A).

Northeast, Elk and Sassafras Rivers

The Northeast, Elk and Sassafras Rivers were on the northeastern end of the bay (Figure 2). These rivers supported a diversity of land uses, but most of the shoreline was forested (Appendix A). Some areas were developed, usually with residential housing. There were few marshes along these rivers (Appendix A).

The shorelines of the rivers varied; some areas were fairly steep (approximately 40 - 60^0 slopes and 5 - 8 m banks), while others were relatively flat (10 - 20^0 slopes and 0.5 - 1 m banks). The most common tree species was oak. Ashes, black locust, tuliptree (Liriodendron tulipifera) and others also were present (Appendix A).

METHODS

Overview of Methods

Eagles were radio-tagged and relocated and the shoreline of the study area was surveyed for eagles during 1985-1992 to determine eagle use of the study area shoreline. The shoreline was divided into 250 m long x 50 m wide segments. Shoreline segments used by eagles ≥ 1 time were considered used; segments with no eagle use were considered unused. During 1990-1991, 103 segments randomly selected from the used segments and 126 segments randomly selected from the unused segments were investigated. The number of segments selected. Vegetative characteristics of the segments were recorded. The percent of forest cover on each segment was determined from aerial photographs. The number of human developments within 500 m of each segment was determined by computer, and the density of developments and distance from the shoreline to the nearest development within 1000 m was calculated for each segment. I then investigated the relationship between these shoreline characteristics and eagle use of the segments using a variety of statistical techniques.

Capture and Radio Tagging

Floating noose-fish (Cain and Hodges 1989) and padded leghold traps (Young 1983) were used from 1984-1988 to trap 32 free-flying eagles throughout the northern Chesapeake Bay. In addition, 78, 8-10 week-old eaglets were radio-tagged during 1984-1991. Eagles were fitted with 65g radio transmitters with solar-charged, nickel-cadmium batteries (Telemetry Systems, Inc., Mequon, WI). The radios were mounted dorsally on the eagle in a back-pack configuration and attached with 1 cm-wide, dark brown teflon ribbon (Bally Ribbon Mills, Bally, PA).

I determined that shoreline segments were frequented by eagles using telemetry flights and aerial shoreline surveys. Telemetry flights were conducted on the northern Chesapeake Bay twice weekly during 1985 - 1988, and twice monthly from 1989 - 1992 in fixed-wing Cessna aircraft.

During telemetry flights, the study area was flown from the north to the south over the western shore. At the Gunpowder River, on the western shore, we turned east and flew over the eastern shore, along the Chesapeake Bay, to the southern boundary of the study area. From this point, we turned north and flew further inland (approximately 5 km) to the northern end of the Chesapeake Bay and back around to the starting point. To minimize pilot and observer fatigue, 10 eagles were randomly selected for relocation when more than 10 radio-tagged birds were present on the study area. Telemetry flights ranged between 80-130 km/h at altitudes between 30-300 m depending on weather and tracking activity.

Because the number of radio-tagged eagles was small relative to the number of eagles using the study area, shoreline survey flights also were used to locate eagles that were perched along the shoreline. All of the study area shoreline was systematically surveyed. Shoreline surveys were flown with fixed-wing aircraft once a month from September 1985 to August 1988 and September 1991 to May 1992. Surveys were flown between 80 and 110 km/h at approximately 30-50 m altitude and 50 m from shoreline trees. Surveys began about 30 min after sunrise. They were flown from south to north along the eastern shore and north to south along the western shore. The western shore was always surveyed on Sundays due to munitions testing on APG during the remainder of the week. Eastern shore surveys were conducted either on Saturday or Monday, determined randomly but modified based on weather and pilot availability. Each survey required approximately 2.5 hours.

The locations of the 4,312 perched eagles sighted on the shoreline during telemetry and survey flights were recorded on 7.5 minute U.S. Geological Survey topographic maps. Universal Transverse Mercator (UTM) coordinates of each location were later recorded to the nearest 10 m and entered into a computer database.

Selecting Shoreline Segments

The study area shoreline was divided into 2,340 segments using a computer-digitized version of the U.S.G.S. 7.5 minute topographic maps. I separated the segments into 2 categories according to eagle use. I considered a segment "used" if, during any flight, at least 1 eagle was perched there. If no eagles were recorded on a segment, it was considered "unused." I randomly selected 110 segments of the 742 used segments and 131 of the 1,598 unused segments for further investigation (Figures 3, 4). Each selected segment was 250 m long and 50 m wide. The number of segments selected was limited by available resources.

One hundred additional segments were selected for verifying the final logistic regression equation. These segments were selected randomly from the remaining 2,099 surveyed segments without regard to eagle use. Eagle use of the segments was noted after selection. Thirty-three of these segments were used and 67 were unused.

Locating shoreline segments

To sample shoreline vegetation, it was necessary to locate selected segments on the ground. I located one end of each selected segment with the aid of a computer-generated map of the selected segments, 7.5 minute U.S.G.S. topographic maps, and navigational charts. The other end was located by measuring 250 m from the starting point with a 50m tape. I marked the ends of each segment with florescent orange wooden stakes (6.0 x 40.0 cm) or blue vinyl flagging. Because the shape of the Chesapeake Bay shoreline is dynamic, and some of the U.S.G.S. topographic maps used to create the computer maps were not recent (1953-1985), the computer maps and the actual shoreline did not always match in shape. If the computer map and topographic maps did not match the shape of the actual shore, I did not investigate the segment further, because direct comparisons of the 2 were important for this study. Five unused segments and seven used segments were not investigated for this reason.

Identifying suitable perch trees

I distinguished trees suitable for perching from those not suitable using criteria based on a northern Chesapeake Bay study by Buehler et al. (1992). They found that perch trees were larger than random trees in diameter at 1.4 m from the ground (diameter breast height, DBH) and height (Table 3). The accessibility of perch trees for eagles was defined as the estimated total arc (0-360°) unobstructed by other trees for a distance of 10 m from the trunk and 3 m below the crown. Perch trees were more accessible than random trees (Table 3).

Based on these results, I considered a tree to be a possible perch tree if it was at least as large as the smallest perch tree observed by Buehler et al. 1992 (viz. height ≥6.1 m and DBH ≥20.0 cm) and had ≥30° accessibility from the shoreline (99.0% of all known perch trees had accessibility ≥ 30°).

Characterizing Shoreline Segments

For each tree meeting the above criteria, I recorded height, DBH and accessibility. Trees were classified as live (including live trees with dead branches and dead topped trees) or dead (snags). I measured the shoreline height, defined as the height of the base of the tree above mean high tide for each tree, with a clinometer. I calculated the average shoreline height and the range of shoreline heights for each segment. I also measured the horizontal distance from the mean high tide line to the closest tree to water.

I classified terrestrial habitat based on the habitat type covering the largest proportion of the segment. Segments were categorized as forest, marsh, agricultural field or pasture, developed or other. "Other" included 4 APG munitions test ranges, 3 lawns, 2 beaches, and 1 fence row. Because I was interested in the localized vegetative changes caused by human development, I considered a segment developed if a house or other development (such as a marina or APG test facility) occurred anywhere on it. The area of each segment was approximately 1.25 ha. Segments considered "developed", therefore, had a density of $\geq$ 1 building/1.25 ha or 0.8 buildings/ha.

I estimated the percent of the segment that was forested by covering a 1:12,500 color aerial photo with an acetate sheet and tracing the outline of the segment. A 1 x 1mm dot grid was then overlaid on the photo and acetate and the percentage of dots on the forested area was calculated.

Modeling Shoreline Eagle Use

Because human development at least 500 m beyond the shore affects eagle use of the shoreline (Buehler et al. 1991b), I included all human development within 500 m of the segments when modeling eagle shoreline use. All developments within 1000 m of the shoreline midpoint were digitized using 1985, 1:12,500 color aerial photographs and topographic maps using a Microvax II computer with ARC/INFO Geographic Information System (GIS) software (Environmental Systems Research Institute, Inc., Redlands, CA). Advanced Revelation computer software was used to determine the distance from each segment midpoint to all developments within 500 m. The density of developments within 500 m of any point on the segment and the distance from the segment to nearest development within 1000 m were then calculated for each segment (Figure 5). [Under this scheme, a segment that was not "developed" (because there were no houses on the 250 x 50 m segment) can still have a development density and a distance to development if there are buildings within 500 m of the segment].

Statistical Analysis

All data were non-normal based on box plots, stem leaf plots, normal probability plots, and measures for skewness and kurtosis. Hence, nonparametric Kruskal-Wallis and Wilcoxon rank sum statistical procedures were used. A χ^2 test was used to test if the proportions of the land types were equal between eagle-used segments and segments without eagle use.

Logistic regression models were developed using the SAS LOGIST procedure (SAS Institute, Inc., Cary, North Carolina) to predict the probability of eagle use of a shoreline segment. Using logistic regression equations, I investigated the effect on eagle use of the number of suitable perch trees, percent forest cover, distance from the water to the closest suitable perch tree, average shoreline height, range in shoreline height and number of snags using stepwise variable selection. I also included in the models the effect of shoreline development reported by Buehler et al. (1991b) by allowing the development density and the distance from the shore to the nearest development variables to compete in the stepwise variable selection. The models predicted the probability of eagle use given the conditions existing at the time of the study and investigational methods (eagle use index). The final logistic regression equation was validated using 100 randomly selected shoreline segments that were not used to create the original equations. The eagle use index was calculated for 3 models by substituting a range of values for the model variables into the models.

I also used logistic regression to predict the probability that trees identified in this study as suitable perch trees would be used by eagles based on the perch study by Buehler et al. (1992). The diameters, heights and accessibilities of the trees were included as parameters in the model.

RESULTS

Identification of Suitable Perch Trees

Of the 103 used segments, 41.8% were identified as used by radio-telemetry; 9 (8.7%) were identified as used from telemetry data only. Shoreline surveys identified 91.3% of used segments, 60 (58.3%) were identified as used only by shoreline surveys. Thirty-three percent of used segments were identified as used by both methods.

Based on the criteria of DBH, height and accessibility, I identified 5,928 suitable perch trees on the 57.3 km of shoreline studied (1 tree/10 m). To test whether these trees would be classified as suitable perch trees in a logistic regression model, I created a logistic regression model using data collected by Buehler et al. (1992). This model predicted the probability that a given tree is suitable for perching based on DBH, height and accessibility (Table 5). The model distinguished between known perch trees and the randomly selected trees used to create the model in 77.1% of the trees (Table 6). I used the model to predict the probability that the trees I identified as suitable perch trees would be used by eagles. Of the trees I identified, 89.8% (5239/5832 trees) were identified by the model as having a probability ≥ 0.5 of eagle use. At least one size criterion (DBH, height or accessibility) was not available for 96 trees.

Shoreline Segment Use and Distribution of Suitable Perch Trees

Ninety percent of perched eagles seen (3481/3887) along the Chesapeake Bay were in trees. Shoreline segments with eagle use had more suitable perch trees than segments that were not used by eagles ($\overline{x}$ = 30.3 vs. 22.0 trees, n = 103 and 126 respectively, Wilcoxon rank sum $\underline{P}$ = 0.0008, Table 7). There were more dead trees of suitable dimensions on used segments than on unused segments ($\overline{x}$ = 1.1 vs. 0.8 respectively, Wilcoxon rank sum $\underline{P}$ = 0.0187, Table 7). The percent of forest cover was greater on segments with eagle use than on segments without eagle use (Wilcoxon rank sum, $\overline{x}$ = 54.9% vs. 39.4%, $\underline{P}$ = 0.0008, Table 7).

The distance from open water to the nearest suitable perch tree was shorter for segments with eagle use than for segments where no use was recorded ($\overline{x}$ = 8.4 m vs. 17.0 m respectively, Wilcoxon rank sum $P = 0.009$; Table 7). Of the radio-tagged eagles located within 50 m of the shoreline, 84.9% were within 10 m.

Land Type and Distribution of Suitable Perch Trees

Eagles used forest segments more than expected and marsh and developed segments less than expected under the model of homogeneity of proportions (χ^2, 4 df, $\chi^2 = 20.04$, $P \leq 0.001$, Table 8). The number of suitable perch trees differed among land types (Kruskal-Wallis, 4 df, $P \leq 0.0001$, Table 9). As expected, forested shoreline had more suitable perch trees than developed, agricultural field/pasture, other and marsh shoreline ($\bar{x} = 42.8$, 26.5, 26.5, 18.5 and 7.5 trees respectively, Wilcoxon rank sum $P \leq 0.01$ for all tests, Table 9). Of 42 segments with no trees, 41 (97.6%) were classified as marsh.

The percent of forest cover differed among land types (Kruskal-Wallis, 4 df, $P \leq 0.0001$, Table 10). As expected, forested segments had a greater percent of forest cover than developed, agricultural field/pasture, other and marsh segments ($\bar{x} = 79.8\%$, 51.6%, 40.7%, 27.3% and 11.5% respectively, Wilcoxon rank sum $P \leq 0.01$ for all tests, Table 10). Marsh segments had the least amount of forest cover (Table 10).

Likewise, the distance from open water to the nearest suitable tree differed among land types (Kruskal-Wallis, 4 df, $\underline{P} \leq 0.0001$; Table 11). The distance from open water to the nearest suitable perch tree was greater on marsh shoreline than other, developed, forest or pasture land types ($\bar{x}$ = 33.1 m, 6.7 m, 5.5 m, 1.5 m and 1.1 m respectively, Wilcoxon rank sum $\underline{P} \leq 0.01$ for all tests, Table 11).

Used marsh segments had more trees, a larger percent of forest cover and a larger distance from water to the closest tree than unused marsh ($\bar{x}$ = 10.8 and 5.8, 18.0 and 8.1, and 26.2 and 36.6 respectively, Wilcoxon rank sum $\underline{P} = 0.023$, 0.007 and 0.038 respectively, Tables 9-11). Most of the marsh shoreline segments (64.9%, 50/77) were not used by eagles. Except that used "other" segments had more suitable perch trees than unused "other" segments ($\bar{x}$ = 10.7 and 32.0 trees respectively, Wilcoxon rank sum $\underline{P} \leq 0.030$, Table 9), no other land type had a significant difference between used and unused segments in any of the perch tree availability measures.

Predicting the Probability of Shoreline Eagle Use

Stepwise logistic regression resulted in an equation that contained variables for development density and distance from the water to the closest tree (Tables 12, 13). The equation predicted eagle shoreline use correctly for 68.9% of 222 segments.

When the distance from water to the closest tree variable was removed from the group of possible dependent variables, stepwise selection produced a model that included development density and the percent forest cover (68.7% correct, Tables 14, 15). Similarly, when distance from water to the closest tree and percent forest cover were removed, stepwise selection substituted the number of suitable perch trees/segment into the model (Tables 16, 17) resulting in a slightly less predictive equation (65.9% correct). None of the 3 variables that were measures of perch tree availability (distance from water to the closest tree, percent forest cover and number of suitable perch trees/segment) was significant in the equation simultaneously, indicating that these variables were redundant. None of the other variables (development distance, mean shoreline height, range in shoreline height or number of dead trees) was significant ($\underline{P} \geq 0.05$).

Model validation

The logistic regression model containing percent forest cover and development density was used to predict eagle use on 100 newly selected segments in an independent validation. The eagle use of 71.0% of the segments was correctly predicted by the equation (Table 18).

Values for distance from water to the nearest tree (ranging from 0 to 50) were substituted into the model containing distance to water and development density at various development densities, producing a series of curves for the eagle use index (Figure 6). The curves were downward sloping indicating that, for a given development density, as the distance to water increased, the eagle use index (probability of eagle use) decreased. At development densities ≥ 1 building/ha the eagle use index was extremely low. Only with a development density of 0 buildings/ha and ≤ about 20 m to water was the eagle use index above 0.5.

Values also were substituted into the equations containing the percent of forest cover and development density, and number of suitable perch trees and development density (Figures 7, 8). Both of these equations produced upward sloping curves indicating that, for a given development density, as the number of suitable perch trees or percent forest cover increased, the eagle use index increased. For these equations, the eagle use index was very low at development densities ≥ 1 building/ha.

The equation containing percent forest cover and development density produced eagle use indices above 0.5 at a development density = 0.0 buildings/ha and forest cover above 30% (Figure 7). An eagle use index of 0.5 also was reached at development density of 0.25 buildings/ha and $\geq$ 70.0% forest cover.

The equation with development density and number of suitable perch trees produced eagle use indices above 0.5 at a development density of 0.0 buildings/ha and > 15 suitable perch trees (figure 8). An eagle use index of 0.5 was also reached at a development density of 0.25 buildings/ha and > 45 suitable perch trees.

DISCUSSION

Shoreline Area Selection

Suitable perch trees and forest cover

The bald eagles on the northern Chesapeake Bay selected shoreline that had more large trees, more forest cover and fewer buildings than unused areas. The number of suitable perch trees and percent forest cover were significant variables in logistic regression models, which is consistent with the hypothesis that a decrease in suitable perch trees decreases the probability of eagle use of the segments. For example, the models predicted that > 15 perch trees or > 30% forest cover/segment were necessary for a probability of use ≥ 0.5.

The overall differences between used and unused segments in the number of suitable perch trees, percent of forest cover, and distance from water to the nearest tree appear to be largely influenced by the differences between marshes with and without eagle use; when analyzed by land type, only marsh had significant differences between used and unused segments.

Other researchers on the Chesapeake Bay also reported that eagles prefer shoreline with a large number of trees. Wallin and Byrd (1984) concluded that eagle perching along the Potomac River, in the middle Chesapeake Bay, was related to the presence of perches. Similarly, Clark (1992) found that along the James River, in the southern Chesapeake Bay, the abundance of shoreline eagles was positively correlated with the length and width of forested areas and the number of snags.

Differences in the morphology among raptor species results in better adaptations for some foraging techniques than others. Janes (1985), in his studies of western Buteos, related the higher density of perches found in red-tailed hawk hunting areas with their sit-and-wait hunting behavior. He found that the wing morphology and hunting behavior of red-tailed hawks adapted that species to foraging from perches; thus they preferred habitat with a high density of suitable perches. Ferruginous (B. regalis) and Swainson's hawks (B. Swainsonii) in the same area are better adapted for aerial foraging and accordingly selected habitat with a much lower perch density (Janes 1985).

Species with a small wing area relative to body mass and a rapid wing beat tend to be more maneuverable than species with a relatively large wing area and slow wing beats, such as bald eagles (Appendix B). Eagles are morphologically adapted for acquiring food from perches through hunting, scavenging and kleptoparasitism. They have a high aspect ratio (ratio of the wingspan squared to the wing area), high wing loading (weight/unit wing area), long wings and slow wingbeats (Gerrard et al. 1980). These characteristics result in relatively low maneuverability (Janes 1985). The structure of their wings also is not well adapted for the slow flight between thermals used by most aerial foragers (Janes 1985). In addition, the flapping flight used in aerial foraging is energetically more costly than stationary perch foraging (Stalmaster and Gessaman 1984). Although eagles sometimes forage while flying, eagle wing structure appears better adapted for sit-and-wait opportunistic foraging.

It is to be expected, then, that eagles select habitat containing many suitable perches from which to forage. Although eagles may perch on a variety of substrates (rocks, ice, logs, fences, etc.) tree perching is most common (Southern 1963, Stalmaster and Newman 1979, Steenhof et al. 1980, Fielder and Starkey 1986, Stalmaster 1987, Caton et al. 1992, this study). Trees are thus important for foraging activity in most areas.

Used segments of the Chesapeake Bay also had a larger number of dead trees. Although dead and dying trees are preferred, most trees used for perching on the northern Chesapeake Bay are live (Buehler et al. 1992). The larger number of snags on used segments than unused areas may reflect the larger number of trees on used sections in general.

Distance from water to suitable perch trees

That the distance from the water to the nearest suitable tree was shorter for eagle-used segments than unused segments emphasizes the need for perch trees near the shoreline. The distance from water to the nearest suitable perch tree was the most significant of the perch tree availability measures in the logistic regression equations. The probability of eagle use was < 0.5 if suitable perch trees were > 20 m from water (development density = 0 buildings/ha). Eagles tend to perch within 50 m of the shore (Stalmaster and Newman 1979, Steenhof et al. 1980, Buehler et al. 1992). On the northern Chesapeake Bay, 84.9% of eagles perched within 50 m of the shore were within 10 m of the water. Proximity to water probably allows eagles good visibility of the water and a high likelihood of quickly capturing observed prey.

Modeling Suitable Perch Trees and Shoreline Use

The models I developed may aid in identifying bald eagle perching habitat on the Chesapeake Bay shoreline. The first model identifies trees suitable for shoreline perching. The perch tree model was developed from data collected on perch and random trees identified in the northern Chesapeake Bay area (Buehler et al. 1992). This model is useful for determining the number of trees suitable for perching along a shoreline if the tree dimensions are known or can be measured.

The remainder of the models help to identify shoreline areas that possess the characteristics of eagle-used shoreline on the northern Chesapeake Bay. These logistic regression models provide a probability that a tree or shoreline segment will be used. Strictly interpreted, the index is an estimate of the probability that an eagle would be observed on a tree or segment under the conditions (survey methods and frequency, eagle population level, etc.) existing during this study.

These models can be used to determine if shoreline is potential eagle habitat. The models vary slightly in their ability to predict shoreline suitability. The model using the independent variables, development density and distance from water to the closest tree, was the best (correct 68.9%

of the time) at distinguishing between eagle-used and unused shoreline. However, gathering data for this model is expensive. The distances must be measured in the field because it is difficult to distinguish suitable perch trees on most aerial photos.

Fortunately, the model based on percent forest is almost as predictive and data for this model are readily obtained from most aerial photos. Based on the segments used to create the models, this model possessed the second-best overall ability to correctly classify segments as to eagle use, predicting use correctly for 68.7% of the segments. When tested on 100 additional segments, this model was able to distinguish between eagle-used segments and unused segments for 71.0% of the segments (71/100, Table 18).

Another advantage of this model is that the data could be gathered on a GIS from developments and forests digitized from aerial photographs or detailed maps. Using a GIS has the advantage of rapid data generation without extensive data collection at the site (Chandler et al. 1993). I attempted to generate this information from a GIS using ARC/INFO software and found that the currently available data for the Chesapeake Bay were not adequate for this analysis (Appendix C). The coverages of the Chesapeake Bay shoreline and forested areas were not consistent, prohibiting the necessary analyses (Aronoff 1989, Chandler et al. 1993). However, this model could be used in conjunction with a GIS to predict the amount of suitable shoreline when additional data sources for the GIS become available.

Future research to improve shoreline models

The models correctly predicted eagle shoreline use for 66 - 69% of the segments. While this level of accuracy can assist in land management for eagles, further improving the accuracy of the models is desirable. Because Chesapeake Bay shoreline is expensive, knowing which areas should be set aside for eagles and which can be developed, without decreasing the amount of shoreline for eagles, is important. It is possible that the addition of variables such as the depth of the water adjacent to the segment, human activity not associated with development, or other factors would improve the predictability of the models.

Several researchers have found that eagles forage more often in shallow water. Mersmann (1989) found that eagles on the northern Chesapeake Bay attempted to capture fewer fish with increasing distance from the shore. He found that all live fish captured by eagles were in water less than 1.2 m deep. Wallin and Byrd (1984) also found that water depth adjacent to perching areas was shallower than water near unused areas of the Potomac River, Virginia. In Arizona, Brown (1983) found that eagles foraged most often and were most successful at capturing prey in water < 3 m deep. Similarly, Watson et al. (1991) found that eagles in the lower Columbia River foraged most commonly in water < 4 m deep. Given that eagles tend to forage in shallow water and often forage from perches, it is likely that inclusion of near-shore water depth would increase the ability of the model to predict suitable shoreline perching areas. Other factors related to food availability may also improve the model.

That I did not find eagle use on some forested lands where suitable perch trees existed suggests that other factors deterred eagles from using these segments. It seems possible that some segments are not used because eagles are frightened by the presence of humans not associated with development. Eagles respond to human presence by flushing from the shoreline or by avoiding shoreline where humans are present (Steenhof 1976, Stalmaster and Newman 1978, Fraser 1981, Jaffee 1981, Andrew and Mosher 1982, Knight and Knight 1984, Fraser et al. 1985, Smith 1988, Buehler et al. 1991b, Grubb and King 1991, McGarigal et al. 1991).

Pedestrian and boat traffic has been shown to prevent normal eagle activity along the shoreline. Eagles on the northern Chesapeake Bay flushed at the approach of a boat at an average distance of 215 m (Buehler et al. 1991b). Other researchers have found eagle disturbance resulting from similar human activity along shorelines.

Stalmaster and Newman (1978) reported that eagles in Washington flushed at 25 to 300 m when a pedestrian approached and then moved 50 to 500 m to more remote areas. In addition, they found that moderate human activity caused a shift in eagle distribution resulting in more birds in marginal habitat and confining the population to a smaller area.

Smith (1987) showed that eagles in North Carolina used different foraging areas on weekends than on weekdays, apparently in response to human recreational use of the shoreline. McGarigal (1988) found that eagles along the Columbia River rarely were flushed by boating activity. Instead eagles apparently avoided areas where boats were present. Thus, including a measure of human shoreline activities not associated with buildings, such as boating and pedestrian activity, in the logistic regression models may improve the ability of the models to predict suitable shoreline.

Predictability of the models will never reach 100%. Despite extensive surveys, I undoubtedly failed to observe eagles on some suitable shoreline segments.

Effect of Development on Perch Tree Availability

The number of suitable perch trees and the percent forest cover were lower in human affected habitats (i.e. developed and agricultural field/pasture) than on forested shoreline. The distance from water to the closest tree was greater on human developed shoreline than on forested shoreline.

A much smaller proportion of shoreline segments with development (11/103) than without development (92/103) were used by eagles and developed segments were used less than expected in the χ^2 analysis. Also the indices to perch tree availability (i.e. number of suitable perch trees, percent forest cover, and distance from suitable perch trees to water) are generally lower on human affected land than on forested land. In addition, development was an important variable in all the logistic regression models. In fact, a probability of eagle use above 0.5 was never reached if the density of human developments was > 0.25 buildings/ha. This is consistent with eagles well-known avoidance of developed areas (Servheen 1973, Steenhof 1976, Stalmaster and Newman 1978, Knight and Knight 1984, McGarigal 1988, Smith 1988, Chester et al. 1990, Buehler et al. 1991b).

The few developed shoreline segments that were used by eagles had more large trees than other segments. In the logistic regression models, when the development density was increased from 0 to 0.25 developments/ha, the number of suitable perch trees needed to obtain a 0.5 probability of use increased from 15 to 45 and the percent forest cover needed increased from 30% to 70%. Perhaps these trees provide visual screening that prevented eagles from seeing people near the developments, and therefore kept eagles from being frightened away

Human disturbance reduces the energetic efficiency of eagles, causing them to use energy when they flush from the shoreline (Stalmaster and Newman 1979). This is especially important during periods of food shortage and extreme cold weather when eagles depend on limited energy reserves (Stalmaster and Gessaman 1983, Steenhof 1983). When the shoreline is frequently used by humans, eagles either expend energy to move when disturbed or forage in areas with fewer humans, possibly sacrificing the use of better foraging areas. Because eagles appear to avoid areas of frequent human activity, the shoreline may be considered destroyed as eagle habitat where human use is chronic (Fraser 1984).

Eagle population size is affected more by adult survivorship than by the ability to reproduce (Young 1983, Buehler et al. 1991a). Human disturbance that reduces foraging efficiency and can decrease adult survival (Stalmaster 1983, Steenhof 1983) and therefore can reduce eagle populations. Coupled with the destruction of nesting and roosting habitat due to development, reduced eagle populations are likely as long as eagle habitat is not protected from these human activities. Although eagles may adapt to human presence, no evidence exists at the present to suggest that this is taking place on the Chesapeake Bay (Buehler et al. 1991b).

Effect of Marsh on Perch Tree Availability

Eagle use was not recorded on most (66.2%) marsh segments and marsh segments were used less than expected based on the χ^2 analysis. Most of the segments with large distances from water to the nearest perch tree had marsh habitat along the shoreline. Marsh shoreline segments contained the fewest suitable perch trees, and the lowest percent forest cover of all the land types. Of the unused segments without human development, 53.7% contained large expanses of marsh. Many (35.1%) of these segments were marsh that contained no forest cover and many (33.7%) had no suitable perch trees at all. The scarcity of suitable perch trees and the longer distance from the shore to suitable perches apparently created conditions that are not favorable for foraging eagles who must be able to clearly see and quickly capture observed prey.

Shoreline Perch Tree Selection

Eagles select diurnal perching habitat along shorelines for foraging and loafing. They favor particular tree species for perching in any one area, but the species preferred vary across geographic regions (McClelland 1973, Lish 1973, Korhel and Clark 1978, Stalmaster and Newman 1979, Steenhof 1976, Steenhof et al. 1980, Hansen and Bartelme 1980, Wood 1980, Fielder and Starkey 1986, Chester et al. 1990, Buehler et al. 1992, Caton et al. 1992). Hence, eagles appear to select for tree form rather than species. Perch trees tend to possess an accessible crown with stout branches and good visibility, regardless of species (Stalmaster and Newman 1979, Steenhof et al. 1980, Andrew and Mosher 1982, Stalmaster 1987, Chester et al. 1990, Buehler et al. 1992).

Because eagles select perch trees according to form, and in a given region several species are suitable, eagles are generally viewed as being more flexible in selecting perching habitat than roosting or nesting habitat (Gerrard et al. 1975, Stalmaster and Gessaman 1984, Stalmaster 1987). Although this may be true, eagles do select specific, identifiable habitat for diurnal shoreline perching. Shoreline that does not possess the proper habitat is, of course, not suitable.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Eagles appear to perch in areas with many large trees. Lack of suitable perches may limit eagle distribution in the Chesapeake Bay region. Shoreline areas with many large trees, but with human development are rarely used. Eagles on the Chesapeake Bay also appear to avoid areas with human activity along the shore (Buehler 1990).

Optimal foraging habitat, then, contains suitable perch trees, adequate food, and lack of human disturbance. Suitable perching areas had an average of 10 perch trees per 100 m of shoreline or 54.9% forest cover along the shoreline; 89% of actual perch trees were within 10 m of the shore (this study).

Management of eagle foraging areas, therefore, should focus on maintaining and creating forested shoreline as close as possible to the water. Trees should be located in regions of adequate forage. Trees along the shore > 20 cm in DBH should be protected. Smaller trees should be maintained to assure a continual presence of suitable large trees. Several silvicultural methods can be employed to accomplish this goal (Smith 1986). Dead trees should be allowed to stand since they are preferred perches (Buehler et al. 1992).

Aberdeen Proving Grounds, on the western shore, currently has many large trees and frequently is used for eagle perching (Buehler 1990). However regeneration is largely absent along the shore, apparently due to frequent fires and heavy deer browsing. Unfortunately, the lack of regeneration and the predominance of one tree species (sweetgum) creates a tenuous situation for the future. Actions should be taken in this area to extinguish fires, reduce the deer herd and encourage the growth of saplings.

Although shoreline trees are preferred for creating a natural, self-perpetuating environment, artificial perches placed along the shore may increase eagle use of treeless areas. Artificial perches have been accepted by other species of raptors (Stahlecker 1978, Hall et al. 1981, Reinhert 1984). Although researchers' success with bald eagle use of artificial perches has been limited (Platt 1976, Steenhof 1978, Vanderah 1987), Fielder and Starkey (1986) reported frequent use of artificial perches along several rivers in eastern Washington. Artificial perches may be useful for encouraging the use of undeveloped, treeless shoreline until trees can be established. It also is possible that the installation of these perches near the shorelines of marshes could promote use of these areas. Artificial perches may be more suitable if placed in numbers similar to natural shoreline trees (i.e. 10 per 100 m of shoreline). Because of the questionable success of artificial perches, designs should be researched before a large investment is made in the construction and installation of these structures.

The models presented can be used to identify additional suitable shoreline areas in the northern Chesapeake Bay area. Where developments are present, Figures 6 - 8 will provide a general idea of the probability of eagle use of these areas. The inclusion of water depth and human activity variables may improve the model. Additional research is necessary to determine if the accuracy of the model can be increased by adding variables relating to foraging habitat, human disturbance or other factors.

Given the increasing human population surrounding the Chesapeake Bay (Gray et al. 1988), the future of the eagle population is threatened with increased levels of human disturbance and development. Models such as the ones created here, or improved versions, should be used to draw a map of shoreline currently used by eagles and areas with use potential. Potentially used areas should be preserved to accommodate the increase in the number of eagles as the population continues to grow. Restorable areas (principally uplands with little vegetation) also should be identified. Maps of suitable shoreline should be used to plan and implement population-wide habitat protection.

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Tables

Table 1. Logistic regression[a] parameter estimates for bald eagle use of shoreline segments based on development density ($\leq$ 500 m) and distance from the water to developments ($\leq$ 1000 m) on the northern Chesapeake Bay, Maryland, 1985-1992 (based on Buehler et al. 1991b).

	Parameter Estimates[b]			
Variable	Beta	SE	χ^2	P
Intercept	-0.9331	0.101	84.64	≤0.0001
Development Density	-1.1484	0.226	25.78	≤0.0001
Development Distance	0.000851	0.000	27.52	≤0.0001

[a] The logistic regression equation is:

$$\theta = 1/(1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]) \quad i = 1,2,\ldots,n$$

where θ is the probability of eagle use, β_0 is the beta value of the intercept, β_j is the beta value of the j dependent variables and x_{ij}'s are the data values for the k independent variables.

[b] Parameter estimates are different from Buehler et al. 1991b due to the inclusion of development distances between 500 and 1000 m from shore.

Table 2. Logistic regression classification table for bald eagle use of shoreline segments and the development density (≤ 500 m) and distance of the development off the shoreline (≤ 1000 m) on the northern Chesapeake Bay, Maryland, 1985-1992 (based on Buehler et al. 1991b).

	Predicted Use (Segments)[a]		Total Correct	
Observed Use	Eagle Use	No Eagle Use	_n_	(%)
Eagle Use	0	790	790	0.0
No Eagle Use	128	1555	1683	92.4
Total (_n_)	128	2345	2473	
Correct (%)	0.0	66.5		62.9

[a] Values differ from those calculated from Buehler et al. 1991b, due to the inclusion of development distances between 500 and 1000 m from shore.

Table 3. Habitat characteristics of bald eagle perch trees (n = 208 and random trees (n = 168) on the northern Chesapeake Bay, Maryland, 1984-1989, from Buehler et al. (1992).

Characteristic	$\bar{x}$	SE	Range
Dbh (cm)[a]			
Perch Tree	54.31	1.36	19.5 - 132.5
Random Tree	34.80	1.01	19.5 - 84.5
Tree Height (m)[b]			
Perch Tree	19.94	0.79	6.1 - 38.1
Random Tree	12.15	0.32	4.6 - 31.7
Accessibility (n°)[c]			
Perch Tree	255.46	6.27	0 - 360°
Random Tree	214.86	7.46	0 - 360°

[a] Wilcoxon rank sum test of the null hypothesis that the DBH of perch trees and random trees are equal $P \leq 0.0001$.

[b] Wilcoxon rank sum test of the null hypothesis that the height of perch trees and random trees are equal $P \leq 0.0001$.

[c] Wilcoxon rank sum test of the null hypothesis that the accessibility of perch trees and random trees are equal $P \leq 0.0001$.

Table 4. Form class of bald eagle perch trees ($\underline{n}$ = 240) and random trees ($\underline{n}$ = 180) on the northern Chesapeake Bay, Maryland, 1984-1989, from Buehler et al. (1992).

	Form Class[a]			
Tree Type	Completely Live	Live With Dead Branches	Live With Dead Top	Completely Dead
	%	%	%	%
Perch Tree	52.9	10.4	10.8	25.8
Random Tree	92.8	1.7	1.1	4.4

[a] Tree form class of perch trees and random trees are different $\underline{P} < 0.001$ based on χ^2 tests.

Table 5. Logistic regression[a] parameter estimates based on known perch trees and randomly selected trees (Buehler et al. 1992) for predicting bald eagle use of shoreline trees on the northern Chesapeake Bay, Maryland, using tree DBH (cm), accessibility (n^0) and height (m).

	Parameter Estimates			
Variable	Beta	SE	χ^2	*P*
Intercept	-5.0319	0.5611	80.4223	≤0.0001
DBH	0.00387	0.000713	29.4390	≤0.0001
Accessibility	0.00513	0.00128	15.9533	≤0.0001
Height	0.0502	0.00714	49.4301	≤0.0001

[a] The logistic regression equation is:

$$\theta = 1/(1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]) \quad i = 1,2,\ldots,n$$

where θ is the probability of eagle use, β_0 is the beta value of the intercept, β_j is the beta value of the j dependent variables and x_{ij}'s are the data values for the k independent variables.

Table 6. Logistic regression equation predictions developed from known perch trees and random trees (Buehler et al. 1992) for predicting bald eagle use of shoreline trees along the northern Chesapeake Bay, Maryland 1990-1992, based on DBH (cm), height (m), and accessibility (n^0).

	Predicted Use (trees)		Total Correct	
Observed Use	Eagle Use	No Eagle Use	(n)	(%)
Eagle Use	128	51	179	71.5
No Eagle Use	46	199	245	81.2
Total (n)	174	214	424	
Correct (%)	73.6	93.0		77.1

Table 7. Characteristics of selected 250 x 50 m shoreline segments classified by eagle use, on the northern Chesapeake Bay, Maryland, 1990-1992.

Characteristic	n	$\bar{x}$	SE	Range
Suitable trees (#)[a]				
Eagle Use	103	30.3	1.82	0 - 67.0
No Eagle Use	126	22.0	1.67	0 - 69.0
Dead Trees (#)[b]				
Eagle Use	103	1.2	0.14	0 - 7.0
No Eagle Use	126	0.8	0.12	0 - 8.0
Forest Cover (%)[c]				
Eagle Use	102	54.9	3.39	0 - 100
No Eagle Use	125	39.4	3.18	0 - 100
Distance to Water (m)[d]				
Eagle Use	100	8.4	1.59	0 - 50+
No Eagle Use	122	17.0	1.97	0 - 50+

Table 7 cont'd.

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[a] Wilcoxon rank sum test of H_0: numbers of suitable perch trees between use categories are equal. $\underline{P}$ = 0.0008.

[b] Wilcoxon rank sum test of H_0: numbers of suitable dead trees between use categories are equal. $\underline{P}$ = 0.0187.

[c] Wilcoxon rank sum test of H_0: percent of forest cover between use categories is equal. $\underline{P}$ = 0.0008.

[d] Wilcoxon rank sum test of H_0: distances from suitable perch trees to water between use categories are equal. $\underline{P}$ = 0.009.

Table 8. Land types of segments with and without recorded eagle use on the northern Chesapeake Bay, Maryland, 1990-1992.

	Land type[a]									
	Forested		Developed		Marsh		Pasture		Other[b]	
Observed	n	%	n	%	n	%	n	%	n	%
Eagle Use	51	60.0	11	26.2	26	33.8	8	57.1	7	63.6
Expected	38	44.7	19	45.2	35	45.5	6	42.9	5	44.5
No Eagle Use	34	40.0	31	73.8	51	66.2	6	42.9	4	36.4
Expected	47	55.3	23	54.8	42	54.5	8	57.1	6	55.5
Total	85		42		77		14		11	

[a] Land types differed between used segments and segments without recorded eagle use, based on χ^2 test of equal proportions, χ^2 = 20.04, 4 df, $P \leq 0.001$.

[b] The "other" land type included 4 APG test ranges, 3 lawns, 2 beaches and 1 fence row.

Table 9. Number of suitable perch trees by land type and eagle use on selected segments of the northern Chesapeake Bay, Maryland 1990-1992.

	Perch Trees (#)							
	Used Segments[a]			Unused Segments			Total[b]	
Land Type[c]	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	n	$\bar{x}$
Forest	42.9	1.61	22-67	42.6	1.93	14-69	85	42.8A
Developed	33.1	4.43	5-54	24.1	2.22	2-48	42	26.5B
Pasture	27.3	3.71	14-41	25.3	7.64	3-50	14	26.4B
Other[d]	10.7	3.61	0-25	32.0*	7.01	15-44	11	18.5B
Marsh	10.8	2.48	0-43	5.8*	1.34	0-42	77	7.5C

[a] Used and unused segments overall were different using Wilcoxon rank sum, $P = 0.0008$.

[b] Land types were different using Kruskal-Wallis, 4 df, $P \leq 0.0001$. Values followed by the same letter were not statistically different at $P \leq 0.01$ based on Wilcoxon rank sum.

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[c] Values for used and unused segments within rows followed by an asterisk (*) were statistically different at $\underline{P} \leq 0.05$ using Wilcoxon rank sum test.

[d] The "other" land category included 4 APG munition test ranges, 3 lawns, 2 beaches and 1 fence row.

Table 10. Percent of forest cover on selected segments by land type and eagle use on the northern Chesapeake Bay, Maryland 1990-1992.

	Forest Cover (%)							
	Used Segments[a]			Unused Segments			Total[b]	
Land Type[c]	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	$\bar{x}$	x
Forest	78.7	2.72	30-100	84.1	3.24	34-100	84	79.2A
Developed	64.5	9.70	6-100	47.0	4.96	0-97	42	51.6B
Pasture	47.1	7.07	25-77	32.2	6.80	6-56	14	40.7BC
Other[d]	15.6	6.02	0-45	47.8	12.89	15-78	11	27.3C
Marsh	18.0	3.80	0-50	8.1*	1.97	0-53	76	11.5D

[a] Used and unused segments were different overall using Wilcoxon rank sum, $P = 0.0008$.

[b] Land types were different using Kruskal-Wallis, 4 df, $P \leq 0.0001$. Values followed by the same letter were not statistically different at $P \leq 0.01$ based on Wilcoxon rank sum.

Table 10 cont'd.

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[c] Values for used and unused segments within a row followed by an asterisk (*) were statistically different at $\underline{P} \leq 0.05$ using Wilcoxon rank sum test.

[d] The "other" land category includes 4 APG munitions test ranges, 3 lawns, 2 beaches and 1 fence row.

Table 11. Distance from open water to the closest suitable perch tree for selected segments by land type and eagle use on the northern Chesapeake Bay, Maryland 1990-1992.

	Distance to Tree (m)							
	Used Segments[a]			Unused Segments			Total[b]	
Land Type[c]	$\bar{x}$	SE	Range	$\bar{x}$	SE	Range	n	$\bar{x}$
Pasture	0.7	0.38	0-2.4	1.6	1.61	0-9.7	14	1.1A
Forest	1.9	0.55	0-15.9	0.8	0.41	0-10.0	83	1.5A
Developed	3.6	1.69	0-18.0	6.3	2.10	0-43.4	40	5.5B
Other[d]	7.4	4.69	0-29.9	5.7	2.97	0-11.9	10	6.7B
Marsh	26.2	4.57	0-50.0+	36.6*	2.91	0-50.0+	75	33.1C

[a] Used and unused segments overall were different using Wilcoxon rank sum, $P = 0.009$.

[b] Land types were different using Kruskal-Wallis, 4 df, $P \leq 0.0001$. Values followed by the same letter were not statistically different at $P \leq 0.01$ based on Wilcoxon rank sum.

Table 11 cont'd.

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[c] Values for used and unused segments within a row followed by an asterisk (*) were statistically different at $\underline{P} \leq 0.05$ using Wilcoxon rank sum test.

[d] The "other" land type included 4 APG test ranges, 3 lawns, 2 beaches and 1 fence row.

Table 12. Logistic regression[a] parameter estimates for predicting bald eagle use of 250 x 50 m shoreline segments on the northern Chesapeake Bay, Maryland, using development density (buildings/ha) and distance from water to the closest tree (m).

	Parameter Estimates			
Variable	Beta	SE	χ^2	P
Intercept	0.6857	0.2084	10.8286	0.0010
Development Density	-3.4036	0.9341	13.2770	0.0003
Distance to Tree	-0.0333	0.00809	17.0118	≤0.0001

[a] The logistic regression equation is:

$$\theta = 1/(1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]) \quad i = 1,2,\ldots,n$$

where θ is the probability of eagle use, β_0 is the beta value of the intercept, β_j is the beta value of the j dependent variables and x_{ij}'s are the data values for the k independent variables.

Table 13. Logistic regression equation predictions of bald eagle use of selected shoreline segments based on development density (buildings/ha) and distance from the water to the closest tree (m) on the northern Chesapeake Bay, Maryland, 1990-1992.

	Predicted Use (Segments)		Total Correct	
Observed Use	Eagle Use	No Eagle Use	(n)	(%)
Eagle Use	75	25	100	75.0
No Eagle Use	44	78	122	63.9
Total (n)	119	103	222	
Correct (%)	63.0	75.7		68.9

Table 14. Logistic regression[a] parameter estimates for predicting bald eagle use of 250 x 50 m shoreline segments on the northern Chesapeake Bay, Maryland, 1990-1992, using development density (buildings/ha) and percent forest cover (%).

	Parameter Estimates			
Variable	Beta	SE	χ^2	P
Intercept	-0.5040	0.2392	4.4402	0.0351
Development Density	-3.0160	0.8984	11.2707	0.0008
Percent Forest Cover	0.0155	0.00413	13.9748	0.0002

[a] The logistic regression equation is:

$$\theta = 1/(1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]) \quad i = 1,2,\ldots,n$$

where θ is the probability of eagle use, β_0 is the beta value of the intercept, β_j is the beta value of the j dependent variables and x_{ij}'s are the data values for the k independent variables.

Table 15. Logistic regression equation predictions of bald eagle use of selected shoreline segments based on development density (buildings/ha) and percent forest cover (%) on the northern Chesapeake Bay, Maryland, 1990-1992.

	Predicted Use (Segments)		Total Correct	
Observed Use	Eagle Use	No Eagle Use	(n)	(%)
Eagle Use	61	41	102	59.8
No Eagle Use	30	95	125	76.0
Total (n)	91	136	227	
Correct (%)	67.0	69.8		68.7

Table 16. Logistic regression[a] parameter estimates for predicting bald eagle use of 250 x 50 m shoreline segments on the northern Chesapeake Bay, Maryland, 1990-1992, using development density (buildings/ha) and number of suitable perch trees.

	Parameter Estimates			
Variable	Beta	SE	χ^2	P
Intercept	-0.4999	0.2446	4.1789	0.0409
Development Density	-3.0554	0.8964	11.6190	0.0007
Number of Perch Trees	0.0280	0.0077	12.2931	0.0003

[a] The logistic regression equation is:

$$\theta = 1/(1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]) \quad i = 1,2,\ldots,n$$

where θ is the probability of eagle use, β_0 is the beta value of the intercept, β_j is the beta value of the j dependent variables and x_{ij}'s are the data values for the k independent variables.

Table 17. Logistic regression equation predictions of bald eagleuse of 250 x 50 m selected shoreline segments based on development density (buildings/ha) and number of suitable perch trees on the northern Chesapeake Bay, Maryland, 1990-1992.

	Predicted Use (Segments)		Total Correct	
Observed Use	Eagle Use	No Eagle Use	(*n*)	(%)
Eagle Use	59	44	103	57.3
No Eagle Use	34	92	126	73.0
Total (*n*)	93	136	229	
Correct (%)	63.4	67.6		65.9

Table 18. Logistic regression equation predictions of bald eagle use of 100 randomly selected 250 x 50 m shoreline segments based on development density (buildings/ha) and percent of forest cover (%) variables developed from 229 shoreline segments in the same area of the northern Chesapeake Bay, Maryland, 1990-1992.

	Predicted Use (Segments)		Total Correct	
Observed Use	Eagle Use	No Eagle Use	(n)	(%)
Eagle Use	18	15	33	54.5
No Eagle Use	14	53	67	79.1
Total (n)	32	68	100	
Correct (%)	56.3	78.0		71.0

Figures

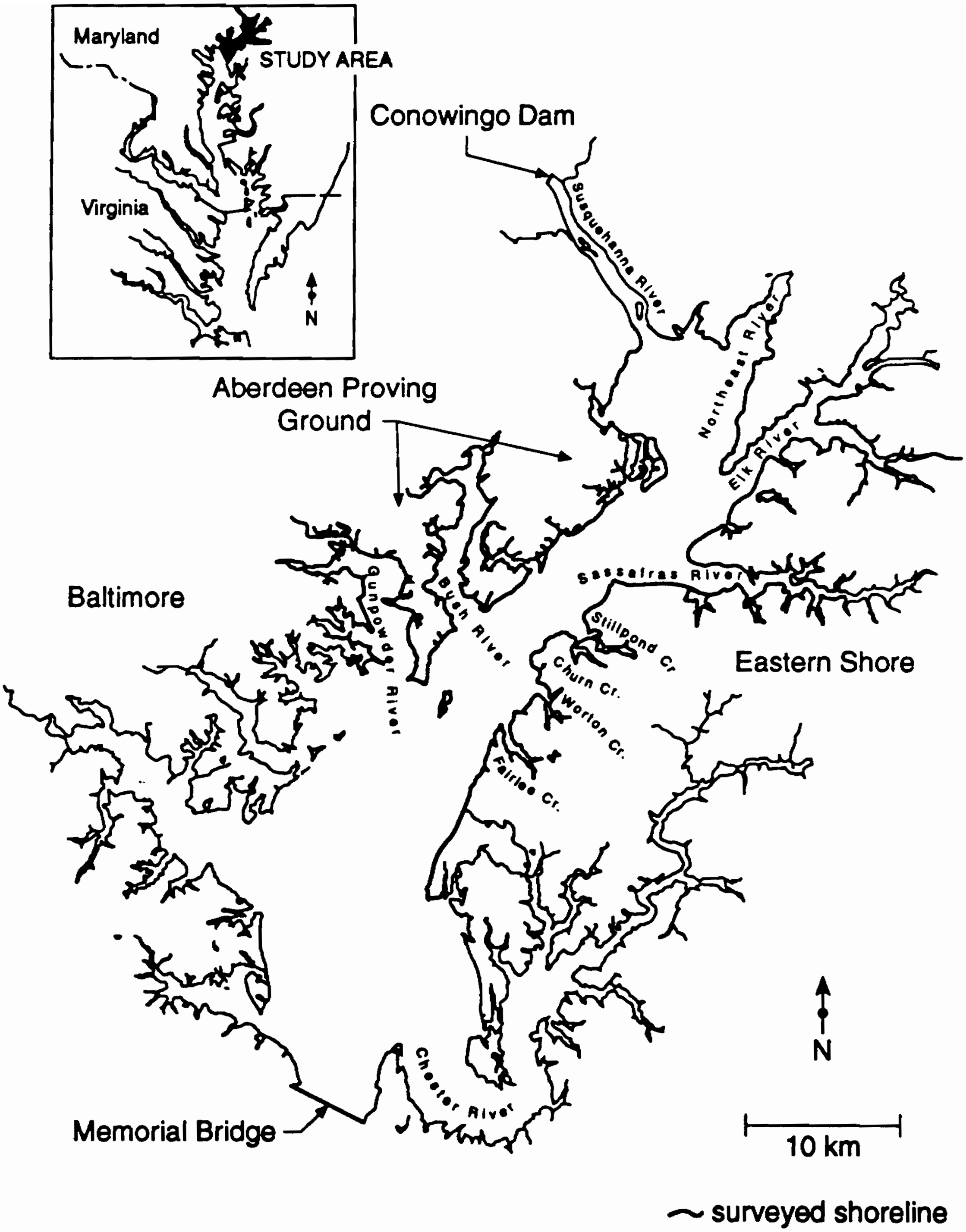

Figure 1. Study area location on the northern Chesapeake Bay. The 580 km of shoreline surveyed for eagles is delineated by a bold line.

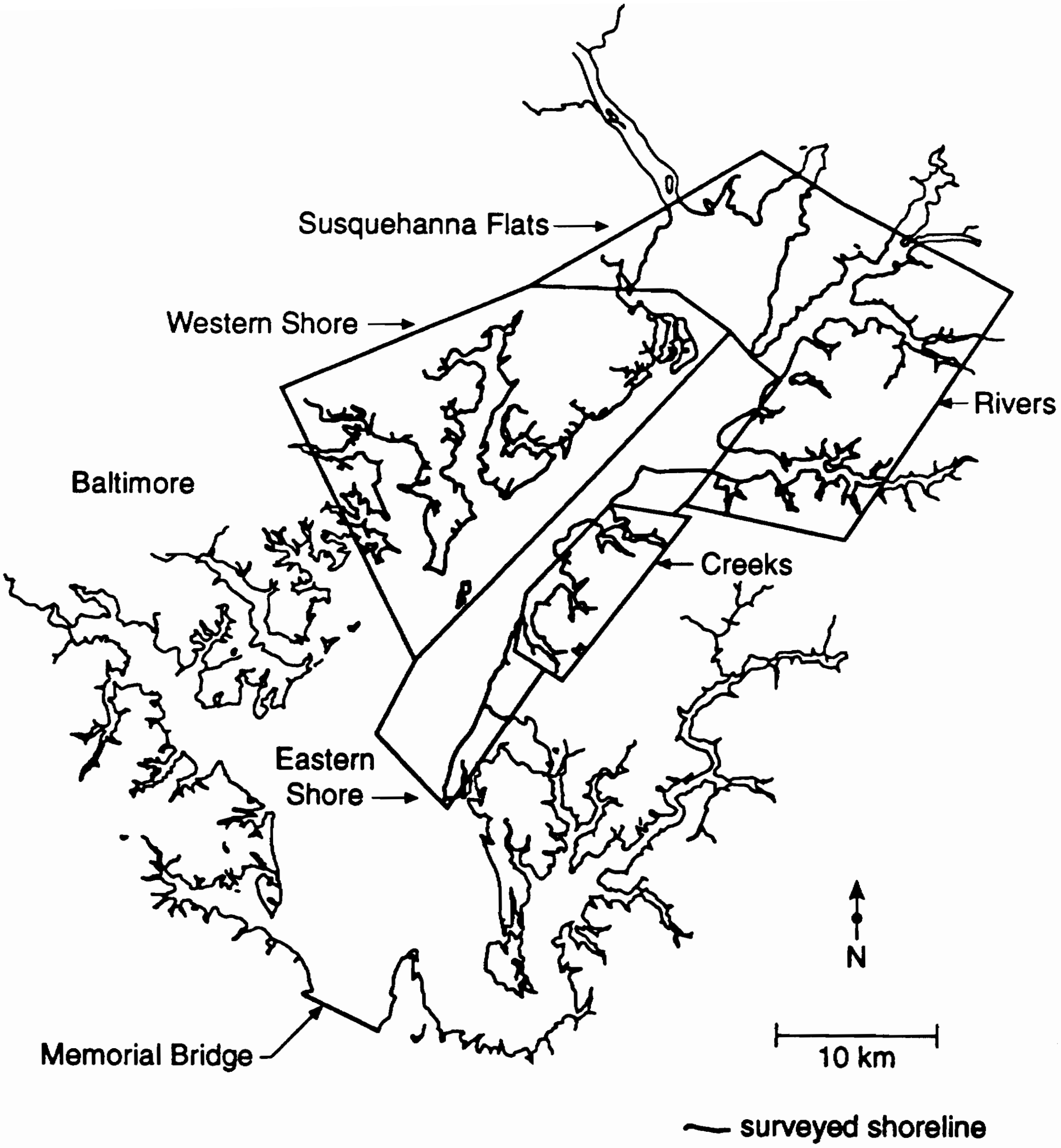

Figure 2. The northern Chesapeake Bay study area divided into similar regions for description.

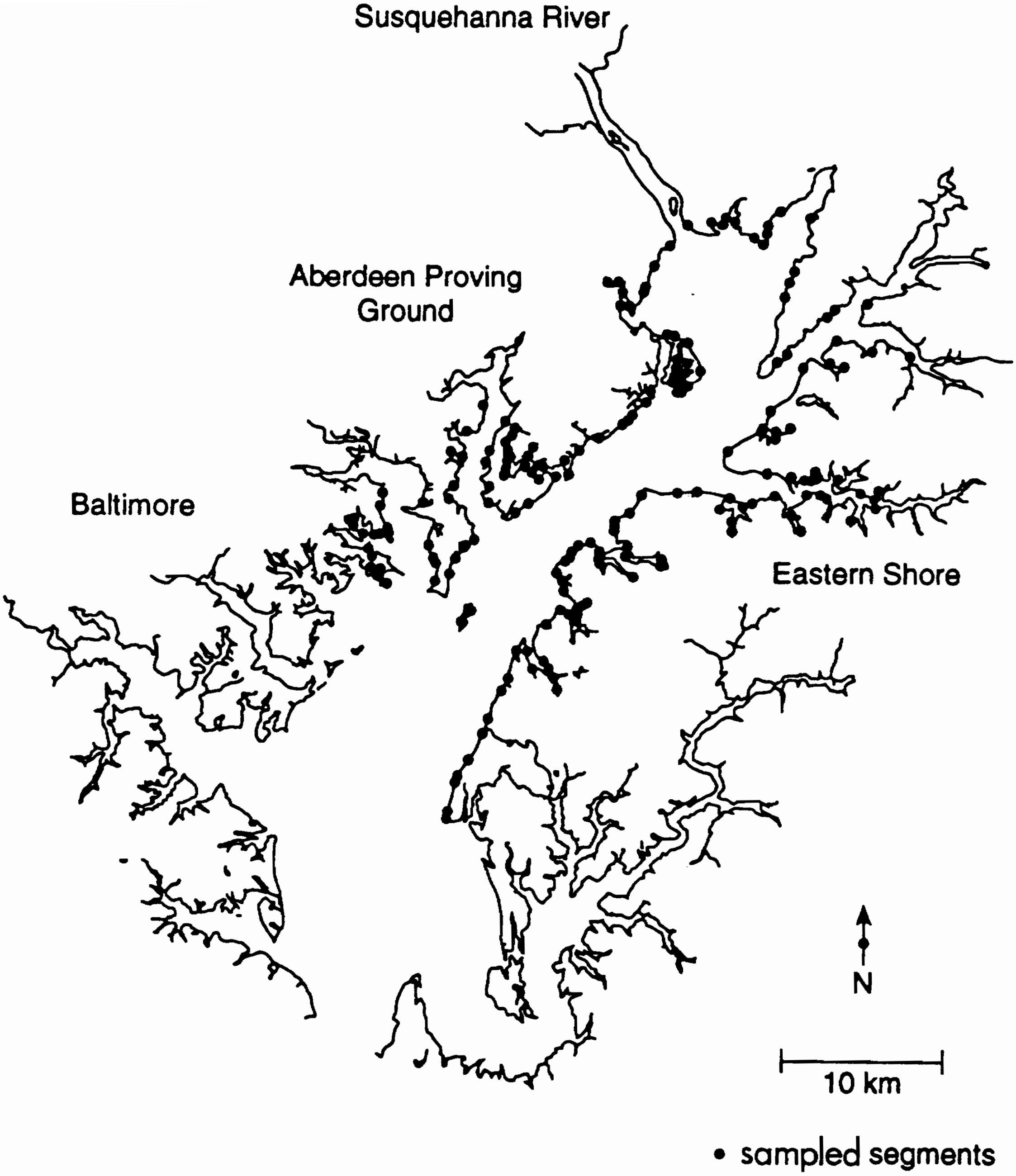

Figure 3. Locations of sampled shoreline segments on the northern Chesapeake Bay study area. Segments were sampled during 1990-1991.

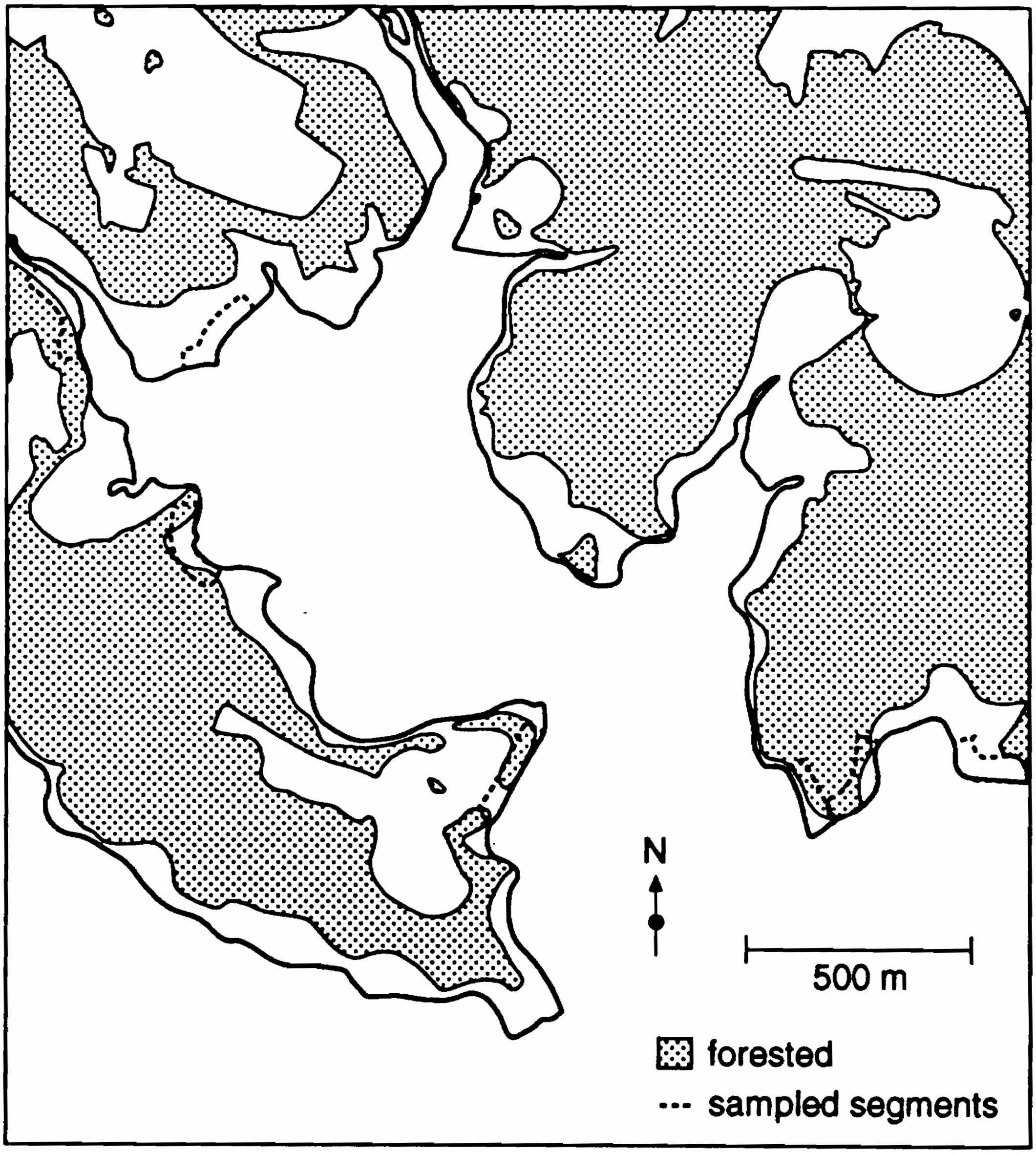

Figure 4. Example of a few of the 250 x 50m shoreline segments located along the Gunpowder River, northern Chesapeake Bay. Forested areas, based on 1985 aerial photographs, are shaded.

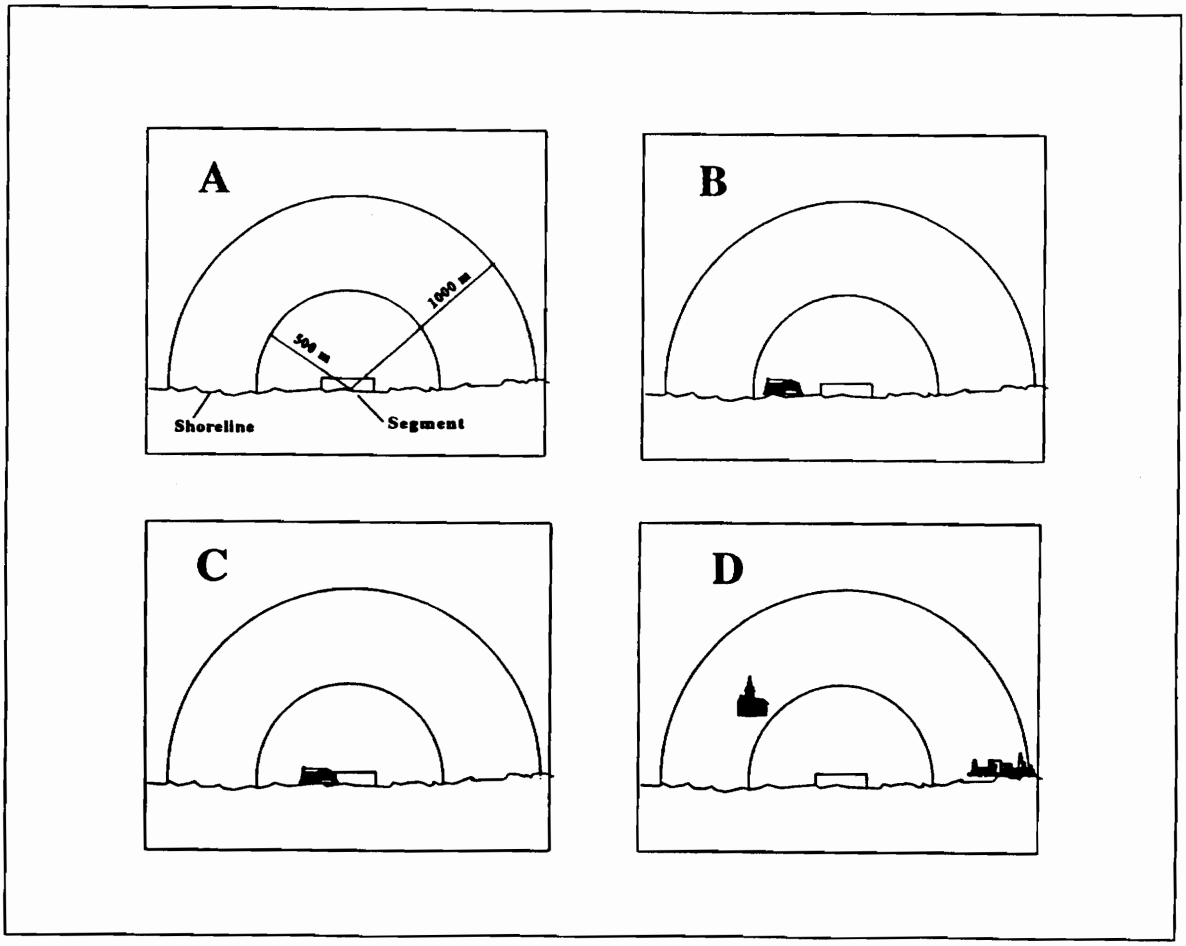

Figure 5. Sampling scheme for shoreline segment building and development data. A) Distance to the nearest building was calculated for all buildings within 1000m of the front center of the segment. Building density was calculated based on all buildings within 500m of the front center of the segment. A segment was considered developed if all or part of a building or structure was on the segment. B) Example 1. The segment is undeveloped (no structure on the segment) but the building density is 1 building/78.5 ha or 0.013 builings/ha.The distance to the closest building is about 250m. C) Example 2. The segment is developed and the building density = 0.013 buildings/ha and the distance to the nearest building is about 10 m. D) Example 3. The segment is undeveloped, has a building density of 0, and a distance to the nearest building (the church) of about 510 m.

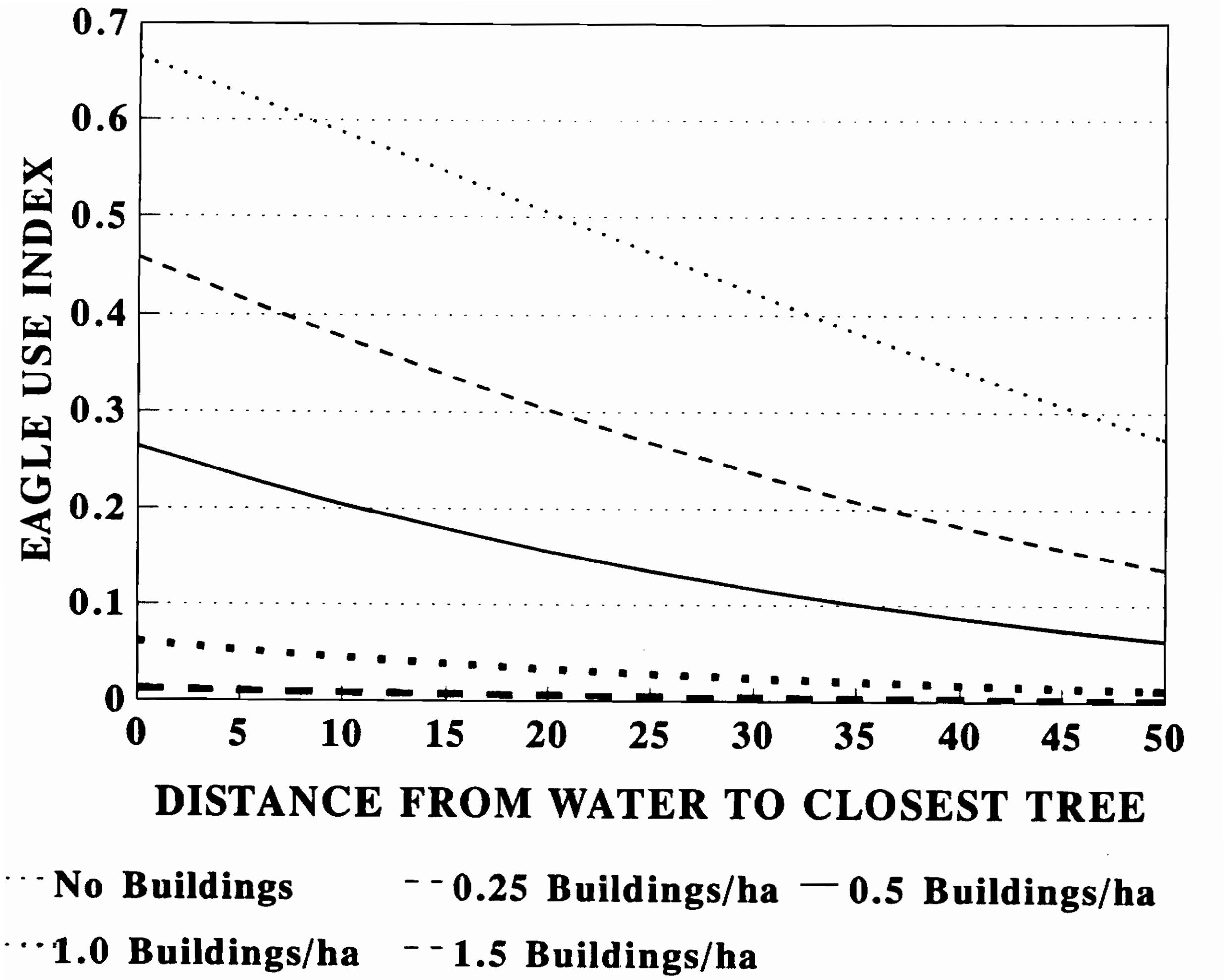

Figure 6. Effect of the distance from water to the nearest suitable perch tree on the probability of eagle use of shoreline segments for different development densities. The eagle use index is the probability of observing at least one eagle using the methods described and under the conditions existing at the time of this study. Suitable trees were ≥ 20 cm DBH, ≥ 3 m height and ≥ 30° accessible to the shore. Building density was calculated from the number of buildings located within 500 m from the front center of the segment.

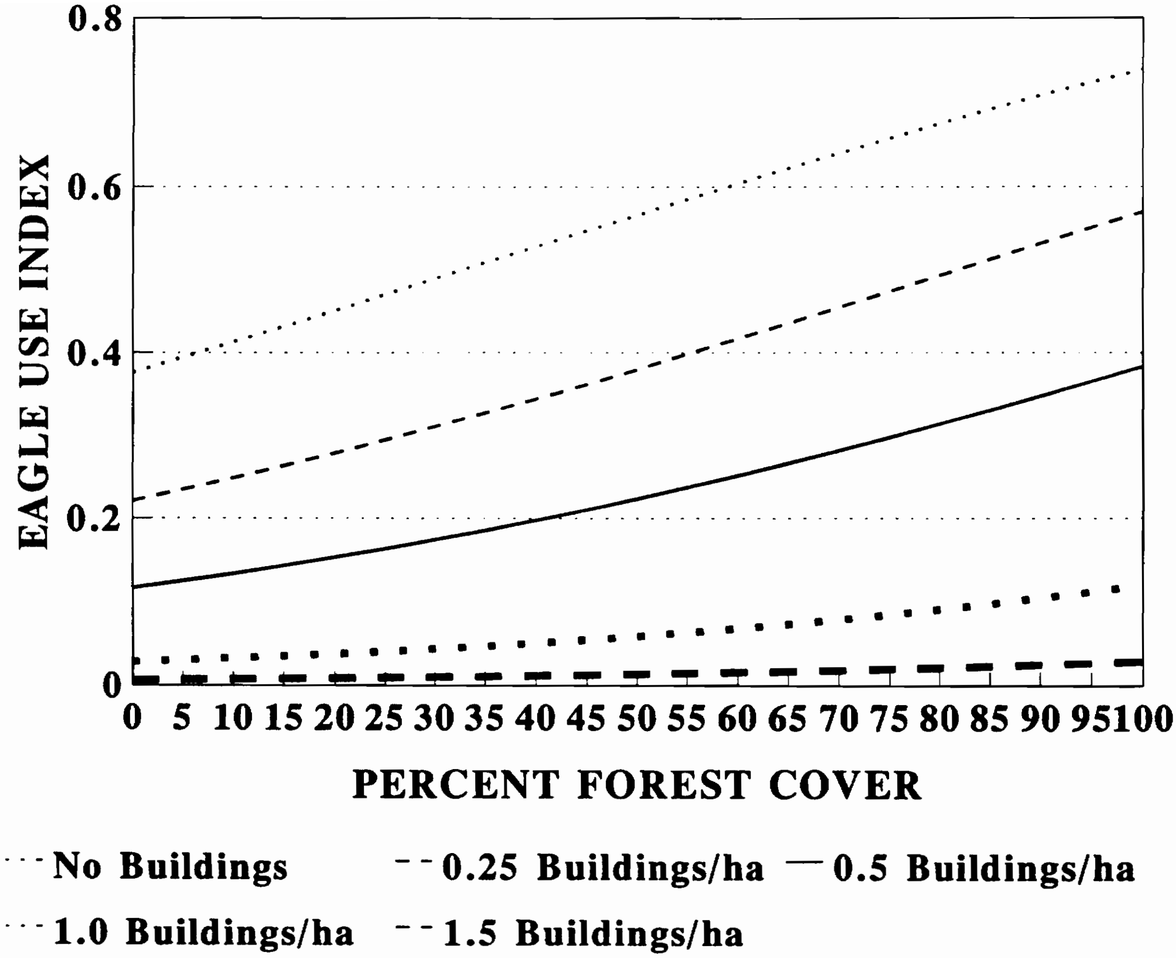

Figure 7. Effect of forest cover (%) on the probability of eagle use of shoreline segments for different development densities. The eagle use index is the probability of observing at least one eagle using the methods described and under the conditions existing at the time of this study. Percent forest cover was calculated for 250 x 50 m segments along the shoreline. Building density was calculated from the number of buildings located within 500 m from the front center of the segment.

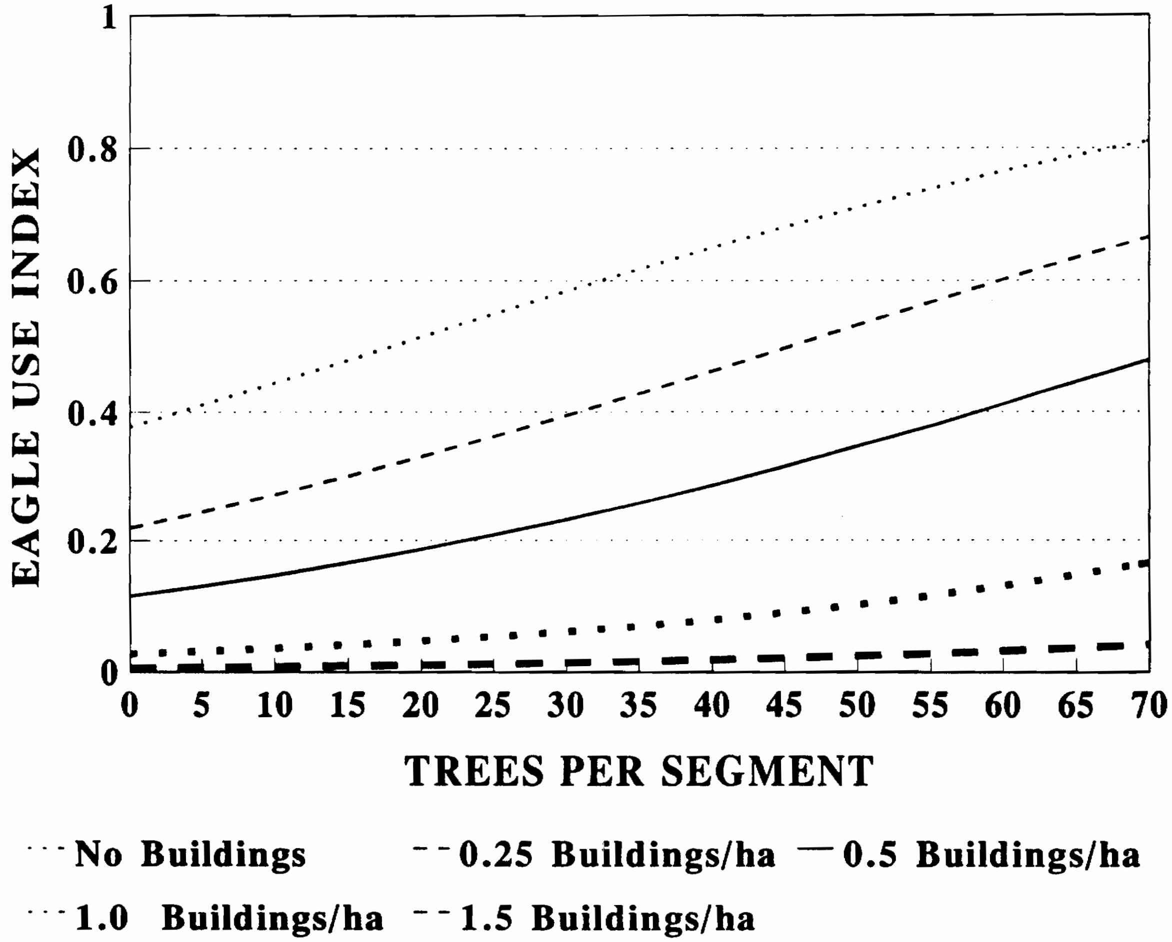

Figure 8. Effect of the number of suitable perch trees on the probability of eagle use of shoreline segments for different development densities. The eagle use index is the probability of observing at least one eagle using the methods described and under the conditions existing at the time of this study. Suitable trees were $\geq$ 20 cm DBH, $\geq$ 3 m height and $\geq$ 30° accessible to the shore. Building density was calculated from the number of buildings located within 500 m from the front center of the segment.

Appendix A. Description of the northern Chesapeake Bay, Maryland study area based on 103, 250 x 50 m shoreline segments used by eagles and 126, 250 x 50 m shoreline segments not known to be used by eagles.

	Area of Northern Bay				
Description	Western Shore	Susquehanna Flats	Eastern Shore	Northeast, Elk Sassafras River	Stillpond, Worton, Churn, Fairlee Cr.
Segments (n)	99	18	28	59	25
Developed (%)	4.0	16.7	32.1	30.5	32.0
Forest (%)	28.3	50.0	39.3	42.4	48.0
Marsh (%)	60.0	11.1	10.7	17.0	8.0
Ag./pasture (%)	1.0	11.1	10.7	8.5	12.0
Other (%)	6.1	11.1	7.1	1.7	0.0
Eagle-used (%)	53.5	27.8	60.7	35.6	28.0
Trees Sampled (n)^{a}	1795	615	794	1725	999
Trees/Segment (x)^{b}	17.8	34.3	28.4	29.3	40.0
Forest/Segment (x%)^{c}	28.2	65.0	51.3	60.1	66.7
Dead Trees/Segment (n)^{d}	0.7	0.9	0.8	1.0	1.7
Area DBH (x, cm)^{e}	38.0	43.5	38.9	43.4	40.6
Area Tree Ht. (x, m)^{f}	17.1	19.0	16.6	17.9	18.0
Area tree Access. $(^{\circ})^{g}$	178.2	168.0	156.4	164.4	163.3

Appendix A. cont'd.

Description	Area of Northern Bay Western Shore	Susquehanna Flats	Eastern Shore	Northeast, Elk Sassafras River	Stillpond, Worton Fairlee Creeks
Water Substrate	sand/silt	sand/silt	clay/sand	sand/silt/pebble	silt
Tree Species (n)	30	20	33	37	28
Common Tree Spp.					
American Beech (%)	0.2	8.0	1.1	4.9	4.5
Ash Species (%)	3.7	25.0	10.7	11.1	4.4
Black Cherry (%)	9.0	4.6	15.7	9.5	5.5
Black Locust (%)	6.7	1.5	6.1	6.5	4.7
Hickory Species (%)	2.6	0.8	9.6	1.5	4.6
Maple Species (%)	5.1	10.4	3.4	8.9	2.3
Oak Species (%)	19.0	23.1	19.0	28.0	41.0
Sweetgum (%)	35.9	6.3	13.0	3.8	6.6
Tulip Poplar (%)	2.3	5.4	6.6	1.6	1.8
Other (%)	15.5	14.9	14.8	24.2	24.6
Total Trees (n)	5928				
Total Tree Species	48				

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[a] Trees sampled were $\geq$ 20 cm DBH, $\geq$ 3 m height and had $\geq 30^0$ of the crown accessible to the the shoreline as described in the Methods section.

Appendix A. cont'd.

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[b] Kruskal-Wallis test of the null hypothesis that the number of trees is not different between areas, df =4, $\underline{P} \leq 0.0001$.

[c] Kruskal-Wallis test of the null hypothesis that the percent of forest cover is not different between areas, df = 4, $\underline{P} \leq 0.0001$.

[d] Kruskal-Wallis test of the null hypothesis that the number of snags is not different between areas, df = 4, $\underline{P} = 0.08$.

[e] Kruskal-Wallace test of the null hypothesis that the DBH of trees is not different between areas, df = 4, $\underline{P} \leq 0.0001$.

[f] Kruskal-Wallace test of the null hypothesis that the accessibility for trees is not different between areas., df = 4, $\underline{P} \leq 0.0001$.

[g] Kruskal-Wallace test of the null hypothesis that the height of trees is not different between areas, df = 4, $\underline{P} \leq 0.0001$.

Appendix B. Raptor Morphology and Foraging Behavior

The morphology of raptors is related to their foraging behavior and habitat selection (Janes 1985, Brown and Amadon 1989). Janes (1985) summarized the relationship of body mass to wing area (wing loading) and the ratio of the wing span squared to the wing area (aspect ratio, A) which determine a bird's ability to glide through thermals. The ratio of the forward velocity to the sinking velocity in a glide (glide ratio) is important in aerial foraging. If a species possesses a high glide ratio, it can cover large distances while losing little height. The maximum glide ratio is proportional to the aspect ratio ($A^{1/2}$, Janes 1985). Also the slower the glide at the maximum glide ratio, the better the bird's ability to detect prey. The forward velocity is proportional to $W^{1/2}$ and $A^{-1/4}$ (Janes 1985).

High wing loading and aspect ratios provide different abilities. Soaring within thermals is mostly influenced by wing loading. Species which posses a large wing area relative to body size can utilize smaller thermals and ascend faster (Janes 1985, Brown and Amadon 1989). Intrathermal soaring is not commonly associated with foraging. The aspect ratio is more closely associated with the ability to aerial forage. Species with a low aspect ratio are better able to forage from the air (Janes 1985, Brown and Amadon 1989). Aspect ratio is inversely related to wing beat frequency and directly related to wing length. Hence species with relatively short wings and rapid wing beats such as the peregrine falcon (Falco peregrinus) tend to be more maneuverable than species with long wings and infrequent wing beats such as the bald eagle and red-tailed hawk (Buteo jamaicensis).

Appendix C. Comparison of Geographic Information System and Aerial Photo Methods for Estimating Forest Cover

INTRODUCTION

The Chesapeake Bay currently is one of the most important areas of habitat for the endangered bald eagle (Haliaeetus leucocephalus). In addition to a resident population of bald eagles, the Chesapeake Bay provides habitat for hundreds of migrating eagles from the north during the winter and south during the summer (Buehler et al. 1991).

Bald eagles are fish-eating birds which forage from forested areas along the shoreline of the bay and its tributaries. Feeding and loafing perch sites found in forested areas are a critical component of bald eagle habitat. In fact, eagles may spend as much as 94% of a 24-hour period perched (Gerrard et al. 1980).

On the Chesapeake Bay, eagles use tree perches more often than all other types of perches (ie. rocks, ice, logs, utility poles) combined; 89.5% of 3887 perched eagles were in trees. The location of trees suitable for perching greatly influences eagle distribution (Steenhof et al. 1980). The amount of forest along the shoreline also seems to influence eagle use of a shoreline area. Shoreline with eagle use has more forested area than shoreline that is not used by eagles.

Currently, the greatest threat to eagles in the Chesapeake Bay area is the disappearance of suitable habitat. Buehler et al. (1991) found that the use of shoreline sections by non-breeding eagles on the Northern Chesapeake Bay was inversely related to the density of shoreline development and directly related to the distance from development to water. In a report prepared for the Chesapeake Executive Council, Gray et al. (1988) predicted a 73% increase in the amount of developed land in the Bay watershed in Maryland and an 80% increase in Virginia between 1978 and 2020. Given the bald eagle's dependence on undeveloped, forested shoreline, the rapid and extensive development of the Chesapeake Bay shoreline could reduce eagle population levels.

Thus, the ability to predict and identify shoreline areas that will be used by eagles is important for the preservation of bald eagles on the Chesapeake Bay. However, it is difficult to directly evaluate all potential shoreline habitat in the Chesapeake Bay area because of the large size of the Bay. We tried using the ARC/INFO Geographic Information System (GIS) to estimate the amount of forest cover in a given shoreline area, thereby giving an indication of the potential eagle use of that area. We compared these estimates to similar estimates obtained using aerial photos and dot grids.

STUDY AREA

I studied bald eagle perching habitat on the northern Chesapeake Bay shoreline from 1985-1991. The study area extended from the Gunpowder River on the western shore to the mouth of the Susquehanna River and south on the eastern shore to the mouth of the Chester River. It included 580 km of bay, river and creek shoreline (Figure 1). The shoreline was composed of small lowland oak - sweetgum (*Quercus* Spp. - *Liquidambar styraciflua*) forests and large expanses of marsh on the western shore. Mixed species forests with large components of oak, ash (*Fraxinus* Spp.) and black cherry (*Prunus serotina*) were interspersed with small communities on the eastern shore of the study area.

METHODS

To locate shoreline areas which were used by eagles, 110 eagles were captured from 1985 to 1991. Captured eagles were fitted with solar-charged radio-transmitters containing nickel-cadmium batteries. The radios were mounted dorsally on the eagle with a back-pack type harness.

As many birds as possible were located twice weekly from 1985-1988 and twice monthly during 1989-1992. Fixed-wing aircraft and standard telemetry techniques were used. Shoreline surveys also were used to locate eagles along 547 km of the study area shoreline (Figure 1). Surveys were flown from fixed-wing aircraft once a month from August 1985 - July 1988 and September 1991 - May 1992. All perched eagles were located as accurately as possible on 1:24,000 scale U. S. Geological Survey topographic maps. The Universal Transverse Mercator (UTM) coordinates of the locations were manually entered into a computer file.

Using the ARC/INFO system, a coverage of the study area shoreline was digitized from 1:24,000 scale topographic maps. With Advanced Revelation software, the 580 km of surveyed shoreline was divided into 250 m sections. I considered a section "used" if at least one eagle had been observed perched within 50 m of that section between 1985 and 1992. If no use had been recorded then the section was considered "unused". I randomly selected samples of used and unused shoreline sections (Figure 2).

I estimated the percent of forest covering each 250m long x 50m wide section using 1:12,500 scale, color aerial photographs. Each section's boundary was estimated by hand, traced onto transparencies and overlaid on the photos. A 1 x

1mm dot grid was then used to estimate the percent of forest on each section.

To produce similar forest cover estimates using ARC/INFO, I buffered each selected 250 m shoreline length 50 m. Each buffer was edited to 250 m in length, and the ends were squared so that they became perpendicular to the shoreline (rather than rounded). I then removed any part of the buffer that fell into water (Figure 3).

A polygon coverage of forested areas was created from the aerial photos. To accomplish this, the Bay shoreline was plotted onto Mylar sheets at several scales (i.e. 1:12,500, 1:12,750 1:13,000 etc.). The forested areas within 1 km of the shoreline on each photo was traced onto the mylar sheet containing the scale the photo matched the closest. The forest areas were then digitized from the Mylar.

I used the ARC/INFO "intersect" command to overlay the coverages containing the buffered shoreline sections onto the coverage with forested areas. The resulting coverage identified the amount of forested and nonforested area within each shoreline section (Figure 4). The percent of forest cover for each section was then calculated.

RESULTS AND DISCUSSION

The estimates for percent forest from the 2 methods were significantly correlated (Spearman's rank correlation, n = 227, r= 0.85, P ≤ 0.0001; Table 1). Using the aerial photo estimates, we found the percent of forest cover on sections used by eagles was greater than that on unused sections (Wilcoxon rank sum, n = 102 and 125 sections respectively, x = 54.9 vs. 39.4 respectively, P = 0.0008; Table 2). The same comparison performed using the ARC/INFO estimates also resulted in significant difference between the used and unused sections (Wilcoxon rank sum, n = 102 and 125 sections respectively, x = 41.9 vs. 28.1 respectively, P = 0.0008; Table 2). Based on these findings, the ARC/INFO estimates appear to perform as well as the dot grid estimates for distinguishing between the amount of forest on shoreline used or unused by eagles.

Unfortunately, when the estimates from both methods were directly compared, discrepancies became apparent. The percent forest cover estimates produced by the two techniques were significantly different (Wilcoxon signed rank, n = 227, x difference = 12.1%, P ≤ 0.0001; Table 1). Estimates for 21 of 227 sections were > 40 percentage points different. Six of those 21 estimates were > 67 percentage points different. The ARC/INFO method predicted less forest than the aerial photo method for 148 of 227 sections, whereas the aerial photo method predicted less forest for 33 sections (46 estimates were less than 1.0 percentage point different).

Examination of a plot of both the study area shoreline and the forest polygons revealed errors in the alignment of the coverages of 40 m or more in some areas, principally on the northern end of the study area (Figure 5). Since the coverages were digitized from different sources (ie. aerial photographs and topographic maps) at different scales, the forest polygons and the shoreline did not match in shape.

An affine transformation using a least squares solution was attempted on ARC/INFO. Comparable locations in both coverages were located as accurately as possible. However because the same locations could not be exactly identified in both coverages, it was difficult to transform the coverages (Wolf 1983). The resulting coverages were not noticeably improved. Because the coverages were created from different data sources, they were not sufficiently compatible for the transformation to be successful.

Additionally, the positional and classification accuracies of these coverages were unknown. This was a potential problem because inaccuracies in position or classification can greatly affect the usefulness of data (Aronoff 1989). Several sources of error also were associated with digitizing the coverages. These included, but may not have been limited to, errors associated with identifying forests on the aerial photos, tracing forests onto the Mylar, human error in digitizing, and tilt and inconsistent scale in the aerial photos (Wolf 1983, Aronoff 1989, Bolstad 1993).

The aerial photo method for calculating percent forest cover also had sources of error. The configuration of the forest within the section and the contrast between vegetation types in the aerial photos affected our ability to distinguish trees through acetate overlays. Error in correctly identifying section boundaries and counting dots also may have effected accuracy. However, this method was faster and less expensive, even if the cost of obtaining the photos was included. Unfortunately, this method may not be practical when the amount of forest on large areas, such as the 580 km study area shoreline, must be estimated.

In summary, the currently available GIS coverages of the study area do not have the mutual consistency needed for this analysis. While the aerial photo method also has sources of error, it appeared to be better suited to this application and more accurate than the ARC/INFO method when the currently available coverages were used.

New coverages of the study area shoreline and forested areas could be digitized from aerial photos commercially available from the U.S.G.S. Creating the necessary coverages at a scale of 1:12,500 from the same data source and correcting each photo for tilt should allow better registration of the coverages and less resulting error (Aronoff 1989, Bolstad 1993). A sample area should be digitized and the registration and accuracy assessed to determine if both are adequate for this analysis before the time and energy are spent in creating such a database. The possibility of obtaining a commercially available coverage should also be explored.

Appendix C: Table 1. Percent forest cover on shoreline sections calculated using aerial photographs and ARC/INFO Geographic Information System, northern Chesapeake Bay, Maryland, 1990-1992.

	Forest Cover (%)			
Method	n	x	SE	Range
Aerial photo[ab]	227	34.3	2.37	0-100
ARC/INFO[ab]	227	46.4	2.20	0-100

[a] Percent of forest on sections for both methods was correlated, based on Spearman's rank correlation, H_0 :Rho = 0, R = 0.831, $P \leq 0.0001$.

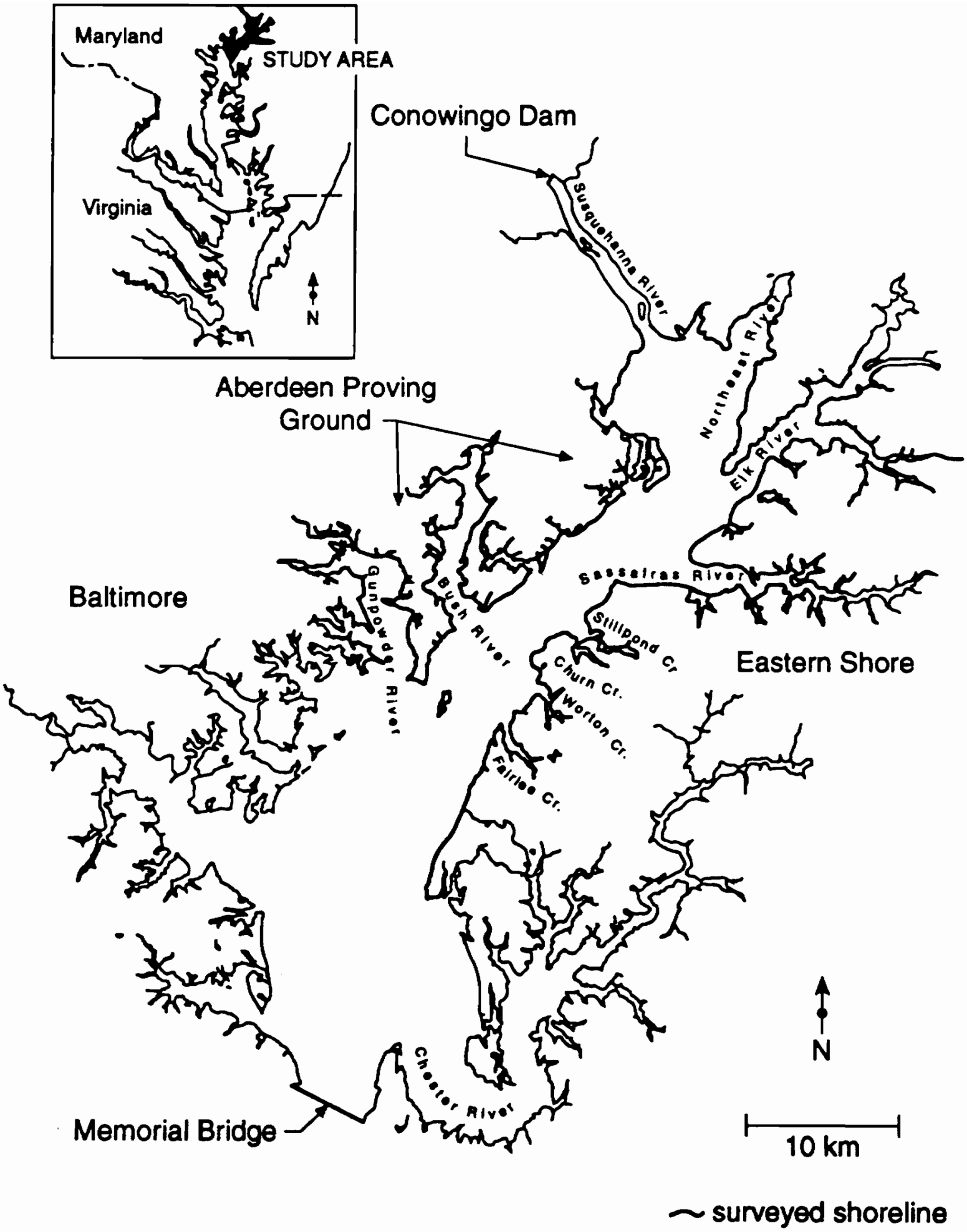
[b] Percent of forest on sections differed between methods, based on Wilcoxon signed rank, x difference = 12.1%, $P \leq 0.0001$.

Appendix C. Table 2. Comparison of the percent of forest on shoreline sections by bald eagle use, for aerial photograph and ACR/INFO methods, northern Chesapeake Bay, Maryland, 1990-1992.

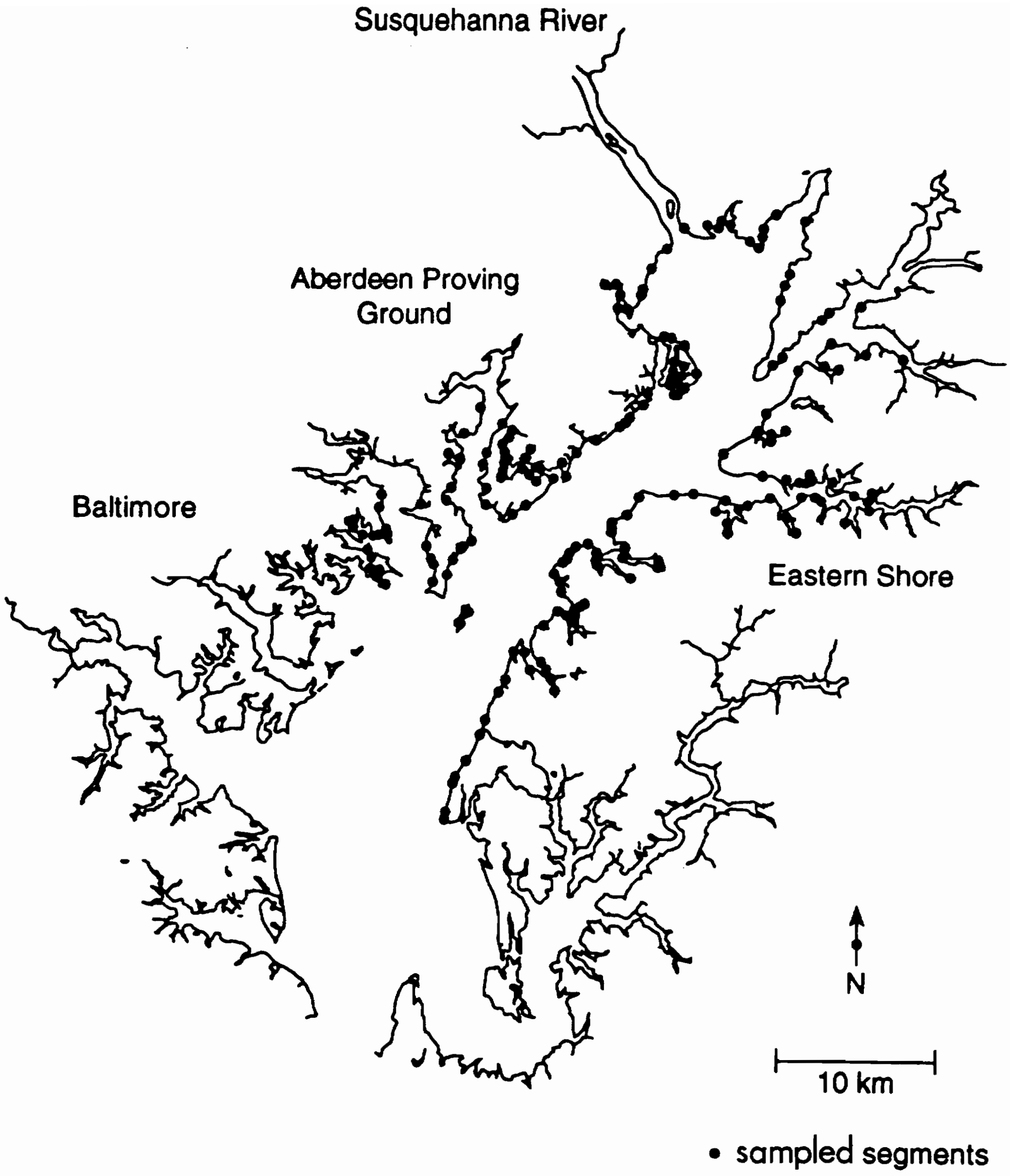
		Forest Cover (%)			
Method	Eagle use	*n*	*x*	SE	Range
Aerial photo[a]	used	102	54.9	3.39	0-100
	unused	125	39.4	3.18	0-100
ARC/INFO[b]	used	102	41.9	3.34	0-100
	unused	125	28.1	2.81	0-100

[a] Percent forest estimated from aerial phototgraphs differed between eagle use categories, based on Wilcoxon rank-sum, *P* = 0.0008.

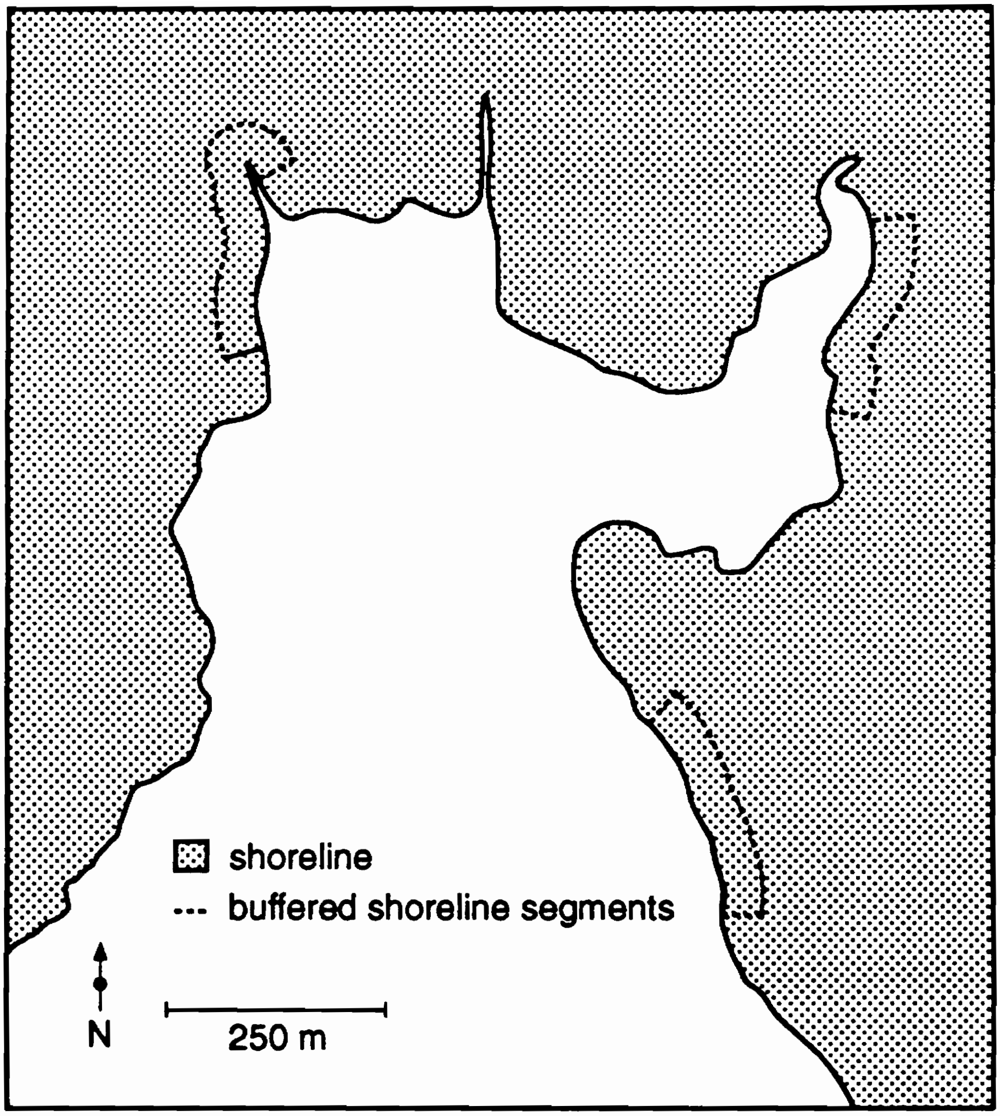
[b] Percent forest estimated from ARC/INFO GIS differed between eagle use categories, based on Wilcoxon rank-sum, *P* = 0.0008.



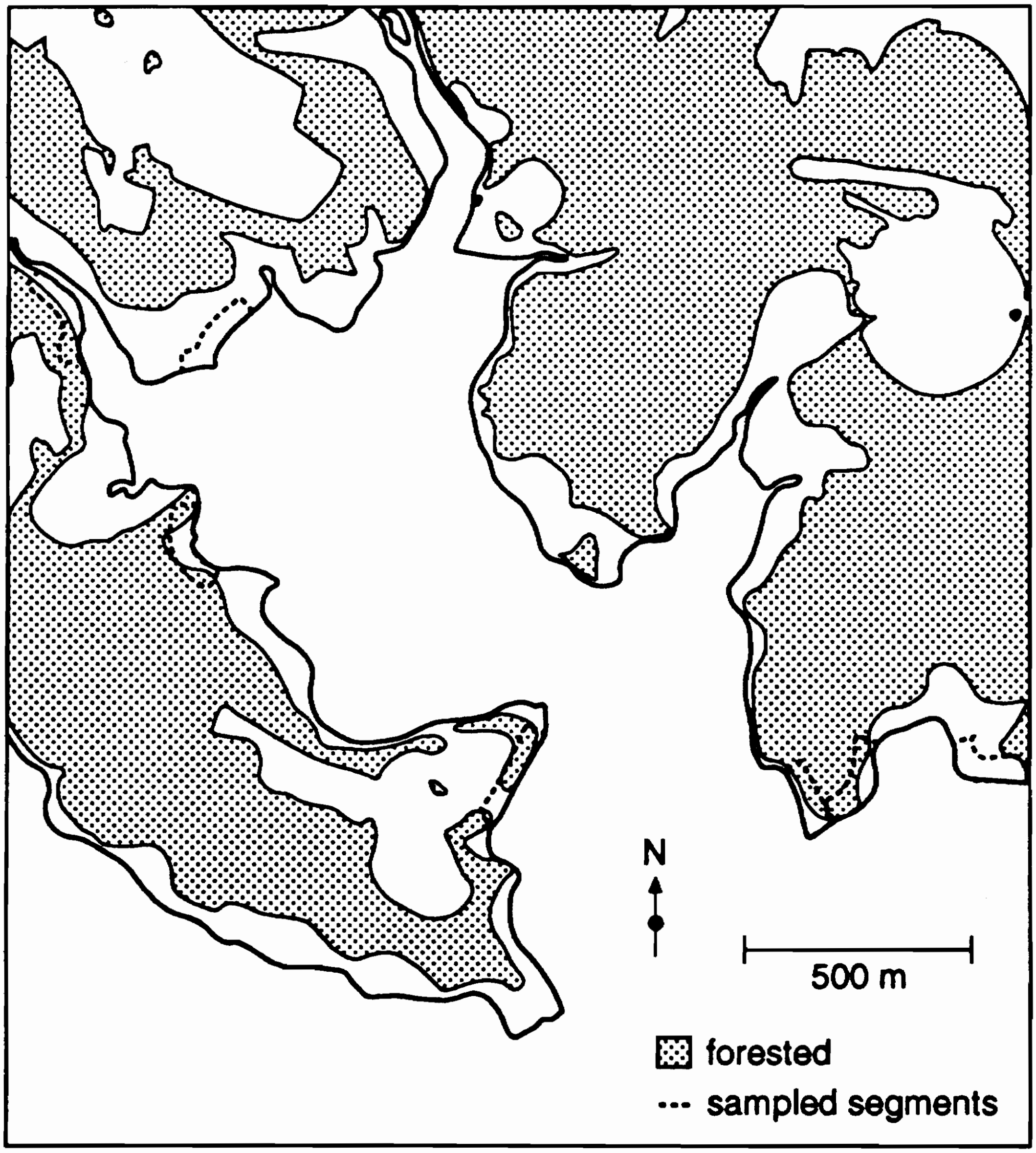
Appendix C: Figure 1. Location of the study area on the northern Chesapeake Bay, Maryland, 1990-1991. The 580 km of shoreline surveyed for eagles is delineated by a bold line.



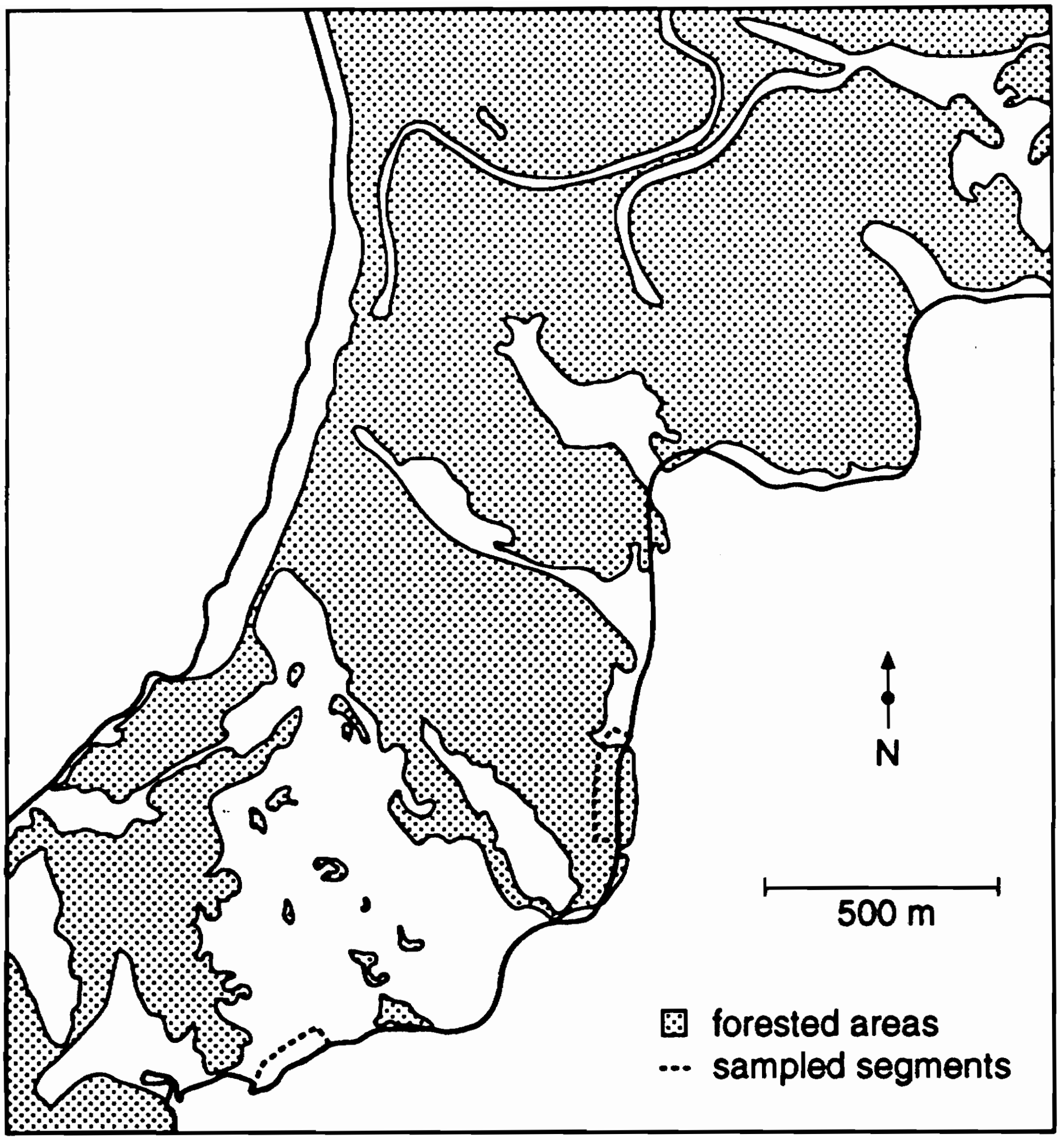
Appendix C: Figure 2. Locations of sampled shoreline segments on the shoreline on the northern Chesapeake Bay 1990-1991.



Appendix C: Figure 3. Sample of buffered shoreline segments after editing (n = 229). Northern Chesapeake Bay, Maryland, 1990-1991.



Appendix C: Figure 4. Example of forest polygons (shaded) with shoreline segment polygons (bold outline) overlaid. Percent of forest was calculated for each segment (n = 229). Northern Chesapeake Bay, Maryland (1990-1991) shoreline.



Appendix C: Figure 5. Shoreline of Chesapeake Bay, Maryland, with sampled segments (bold outline) and forested areas (shaded). The shoreline and forested areas are poorly aligned. The forest should meet the shoreline on the west and is overlapping approximately 50 m on the eastern shore of the peninsula.

Vita

Sheri Kay Chandler was born on March 13, in Indianapolis, Indiana. She entered Purdue University located in West Lafayette, Indiana in the fall of 1984. While attending Purdue, Sheri participated in the Co-operative Education Program, sponsored by the Purdue Department of Forestry and Natural Resources and the Indiana Department of Natural Resources, Division of Fish and Wildlife. While in this program Sheri worked alternate semesters for the Indiana Division of Fish and Wildlife as a Wildlife Technician from 1986 to 1989. She received a Bachelor of Science in Forestry degree with a Wildlife Specialization and graduated with Highest Distinction in Spring, 1989.

Sheri began a Master's degree at Virginia Polytechnic Institute and State University in the Wildlife Sciences program in the fall of 1989. She has been accepted into the Doctorate program at Virginia Tech and after completion of her M.S., intends to obtain her Ph.D. in Wildlife Sciences.

Sheri Kay Chandler