

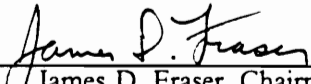
**Bald Eagle Distribution, Abundance, Roost Use and Response to Human Activity on the Northern  
Chesapeake Bay, Maryland**

by


David A. Buehler

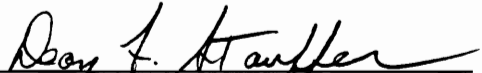
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(ABSTRACT)

I studied bald eagle (*Haliaeetus leucocephalus*) distribution, abundance, roost use and response to human activity on the northern Chesapeake Bay from 1984-89. The eagle population consisted of Chesapeake breeding eagles, Chesapeake nonbreeding eagles, northern-origin eagles and southern-origin eagles; changes in overall eagle distribution and abundance reflected the net changes in these 4 groups. Breeding territories on the northern Chesapeake increased from 12 to 28 from 1984 to 1988. Breeding eagles were resident all year, always  $\leq 7$  km from the nest. Chesapeake nonbreeding eagles moved throughout most of the bay, but rarely left it ( $\leq 5\%$  of the radio-tagged eagles were off the bay during any month). Northern eagles migrated into the bay in late fall ( $\bar{x} = 21$  December,  $n = 7$ , range = 61 days) and departed in early spring ( $\bar{x} = 27$  March,  $n = 14$ , range = 43 days). Southern eagles arrived on the northern bay throughout April-August ( $\bar{x} = 6$  June,  $n = 11$ , range = 94 days) and departed from June - October ( $\bar{x} = 3$  September,  $n = 22$ , range = 119 days). Northern Chesapeake eagle abundance peaked twice annually; in winter (261 eagles, December 1987), driven by the presence of northern eagles, and in summer (604 eagles, August 1988), driven by the presence of southern birds. Of 1,117 radio-tagged eagle locations, only 55 (4.9%) occurred in human-developed habitat, which composed 27.7% of 1,442 km<sup>2</sup> of potential eagle habitat on the northern Chesapeake Bay ( $P < 0.001$ ). During 36 aerial shoreline surveys, eagles were observed on only 111 of 700 (15.9%) 250-m shoreline segments that had development within 100 m, whereas eagles were observed on 312 of 859 (36.3%) segments when development was absent ( $P < 0.001$ ). On average, eagles were observed on 1.0 segment/survey that had coincident pedestrian use within 500 m, compared to 3.6 segments/survey expected if eagles and pedestrians were distributed along the shoreline independently ( $n = 34$  surveys,  $P < 0.001$ ). On

average, eagles also were observed on 2.7 segments/survey that had coincident boat use within 500 m, compared to 6.5 segments/survey expected if eagles and boats were distributed independently ( $P < 0.001$ ). Fewer eagles were observed during summer shoreline surveys of rivers on weekends ( $n = 9$ ) when boat activity was relatively high, than on weekdays ( $n = 4$ ) when boat activity was almost absent ( $\bar{x} = 0.44$  eagles/shoreline km and 0.04 boats/km [weekdays] vs.  $\bar{x} = 0.20$  eagles/km and 0.38 boats/km [weekends],  $P = 0.006$  [eagles] and  $P = 0.06$  [boats]). Only 360 of 2,532 segments (14.2%) had neither shoreline development or human activity during at least 1 of 34 surveys. Of 2,500 km of shoreline on the northern Chesapeake, 699 km (28.0%) was already developed beyond eagle tolerance, precluding eagle use, whereas an additional 1,190 km (47.6%) had development within 500 m, with limited potential for eagle use. Roost trees ( $n = 133$ ) were taller and more accessible and had larger diameters than random trees ( $P < 0.01$ ). Roost trees were predominantly oaks (*Quercus* spp.), beeches (*Fagus americana*), or yellow poplars (*Liriodendron tulipifera*) and had snags present more often than at random sites ( $P < 0.001$ ). Roosts were found in forested blocks  $> 40$  ha, were closer to water, including the Chesapeake Bay and ponds, were further from roads and buildings, were adjacent to nonforested corridors, and were more often publicly owned than random sites ( $P < 0.001$ ). Winter roosts were protected from prevailing winds (northwest - northeast) more often than were summer roosts (88.2% vs. 59.1% protected,  $P = 0.045$ ,  $n = 17, 22$ ). Mean winter nightly air temperature did not differ among roost, shoreline and random sites ( $\bar{x} = 2.97$  °C, 3.27 °C, 3.04 °C,  $P = 0.79$ ). Mean nightly wind speed was greater along the shoreline than at roosts or random sites ( $\bar{x} = 1.79$  m/s, 1.33 m/s, 1.23 m/s, respectively,  $P = 0.0001$ ). Winter wind speed was greatest at the summer roost, intermediate at the year-round roost, and least at the winter roost ( $\bar{x} = 1.50$  m/s, 1.38 m/s, 1.11 m/s, respectively,  $P = 0.02$ ). Net radiation was greatest along the shoreline, intermediate at roost sites, and least at random points ( $\bar{x} = -22.01$  W/m<sup>2</sup>, -20.16 W/m<sup>2</sup>, -17.42 W/m<sup>2</sup>, respectively,  $P = 0.027$ ). Eagles roosting at communal roosts were estimated to expend 201 kcal/night, compared to 202 kcal/night at shoreline perches and 199 kcal/night at random points ( $P = 0.64$ ). The estimated cost of flying from shoreline perches to inland roosts (6.19 kcal/round trip) did not significantly change the differences in nightly energy expenditure among roost and shoreline sites ( $P = 0.25$ ).

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# INTRODUCTION

The Chesapeake Bay provides extremely important habitat for the endangered bald eagle (*Haliaeetus leucocephalus*). This rich estuary may compose the most important bald eagle habitat in eastern North America. Not only do almost 200 pairs of Chesapeake eagles produce about 200 young each year (Wood et al. 1990), the Bay also provides winter and summer habitat for an unknown number of eagles from East Coast populations from Maine to Florida (Broley 1947, Cline 1986, McCollough 1986). Moreover, radio-equipped birds banded in New York, Pennsylvania and New Jersey also have been detected on the Chesapeake (Buehler et al. unpubl. data).

Bald eagles are not distributed uniformly about the Bay but tend to concentrate in certain areas that apparently have particularly favorable characteristics. Documented concentration areas include Blackwater National Wildlife Refuge, Maryland, Aberdeen Proving Ground, Maryland, Mason Neck National Wildlife Refuge, Virginia, Caledon State Park, Virginia and the James River, Virginia (Larson and Abbott 1962, Pramstaller 1981, Wood et al. 1990). The Chesapeake Bay Bald Eagle Recovery Plan (Taylor et al. 1982) has recognized the importance of these areas and the importance of locating new concentration areas. The research conducted for this dissertation was designed partly with that in mind.

In addition to locating current use areas, however, it is critical to determine why eagles use particular areas (Gavin 1989). There are several reasons for this need. First, protection of habitat

requires knowledge of the habitat characteristics that are important to eagles. Failure to understand the important components of eagle habitat could lead to inappropriate management decisions. For example, if habitat management efforts are directed at managing or protecting vegetation at roost sites when the real attractant to a particular site is the proximity of a rich food supply, resources expended on vegetation management may be wasted. The important habitat characteristic, food supply in this hypothetical case, may deteriorate unnoticed. Thus, management agencies that have a mandate to avoid activities that adversely affect this endangered species may be inappropriately monitoring their own actions. Furthermore, a thorough understanding of the factors that attract or repel eagles will allow development of predictive models that can be used to assess the expected impact of future projects and developments on Chesapeake and other North American eagle populations. Identification and protection of potential habitat will become increasingly important as the growing bald eagle and human populations compete for the remaining shoreline habitat.

Secondly, it is known that eagles shift their activities from 1 area to another, either seasonally or for longer periods. While knowing what areas are being used by eagles allows management and protection of current use areas, knowing why particular parcels are used will allow identification and protection of potential habitat as well. This approach has been used successfully for identification of eagle nesting habitat in Maryland (Taylor and Therres 1981).

Finally, understanding the requirements of nonbreeding eagles will provide the potential for creating new habitat by manipulating the operative environmental variables. Identifying potential habitat and creating new habitat may be important as eastern eagle populations increase in their post-DDT recovery. Creation of new habitat may be important in the future to mitigate habitat losses that will undoubtedly occur where shoreline development potential is great.

## OBJECTIVES

This dissertation represents the results from a portion of a larger study aimed at determining the key factors affecting northern Chesapeake bald eagle distribution and abundance. The overall study focussed primarily on the effects of prey base, vegetative habitat (diurnal and nocturnal), microclimate, human activity, social factors and migration on eagle distribution for the entire year. I, along with a succession of Master's degree students, T. J. Mersmann, D. C. DeLong, Jr., and S. K. Chandler, have collected information on all of the above factors. Because this was a team effort, the majority of the field work was jointly conducted. In the Methods sections, I identify the areas which I conducted independently.

Because of the depth and breadth of the study, I will focus on a subset of the study for this dissertation. The specific objectives I will focus on are as follows:

- 1) Determine which areas of the northern Chesapeake Bay were used by bald eagles.
- 2) Describe the seasonal patterns of bald eagle distribution.
- 3) Determine the contribution of resident and migratory populations to the overall bald eagle distribution.
- 4) Determine the impact of human activity and shoreline development on the bald eagle distribution.
- 5) Describe the patterns of bald eagle roost use on the northern Chesapeake Bay.
- 6) Determine the vegetative characteristics of bald eagle roost trees and roost sites.
- 7) Determine the microclimatic characteristics of bald eagle winter roost sites and model the energy expended by roosting eagles.

The first 3 objectives will be covered in Chapter 1, objective 4 will be covered in Chapter 2, objectives 5 and 6 will be treated in Chapter 3 and objective 7 will be discussed in Chapter 4. The Conclusions and Management Implications section of this dissertation will draw upon the results from all 4 chapters.

## STUDY AREA

The Chesapeake Bay is the largest estuary in United States, extending 290 km in length and 8-48 km in breadth. It is a relatively shallow body of water, with a mean depth of 6.5 m, including the tributaries, and a maximum depth of 53 m. The length of the Chesapeake Bay shoreline, including the tributaries, is 13,033 km (Lippson 1973). The Northern Chesapeake Study Area (NCSA) extended from the Bay Bridge at Annapolis northward throughout the bay and its tributaries, including the Susquehanna River to the Conowingo Dam, encompassing 3,512 km<sup>2</sup> (Figure 1). The area included 2500 km of bay, river and creek shoreline and extended inland to the head of all major tributaries except the Susquehanna and Chester rivers. It also included part of the Baltimore metropolitan area and the U.S. Army Aberdeen Proving Ground, a 350 km<sup>2</sup> military installation.

I divided the NCSA into 4 areas for analysis based on land ownership patterns and habitat homogeneity within each area (Figure 1). The Eastern Shore (ES) began at the Bay Bridge, included Kent Island, and extended northward up the eastern shore to the mouth of the Susquehanna River. Susquehanna River valley (SRV) extended from the mouth of the Susquehanna northwest to the Conowingo Dam. Aberdeen Proving Ground (APG) extended from the Susquehanna mouth to the western side of the mouth of the Gunpowder River, and is comprised primarily of military-owned property. Baltimore (BAL) extended from the Gunpowder



River south to the Bay Bridge on the western shore, and included part of the Baltimore metropolitan area. Shoreline lengths were 1,215 km, 699 km, 484 km and 78 km for ES, BAL, APG, and SRV, respectively. Habitat varied substantially, and included a largely urban-suburban setting near Baltimore, coastal lowland oak-gum (*Quercus* spp.-*Liquidambar styraciflua*) forest on APG, small oak-gum lowland forest sections interspersed among agricultural fields on the ES and upland and lowland oak-hickory (*Carya* spp.)-gum forests along the SRV.

# CHAPTER 1: BALD EAGLE DISTRIBUTION AND ABUNDANCE

## *INTRODUCTION*

North American bald eagle populations are continuing to expand as the effects of DDT on reproduction have been largely eliminated and man-caused mortality apparently has decreased (Grier 1982, Fraser 1984, Nickerson 1989, Wood et al. 1990). These populations include breeding birds associated with nest sites, reproductively mature birds that are summering or wintering away from their breeding areas, immature birds, and possibly mature birds without mates or breeding sites. Eagle managers must consider the needs of each of these groups to ensure maximum survival during the different bald eagle life history stages.

The Chesapeake Bay provides habitat for many eagles from the 3 major East Coast eagle populations-- Northeast, Southeast and Chesapeake (Broley 1947, McCollough 1986). Thus, the bay habitat may be important for the recovery of all U.S. East Coast bald eagle populations.

Chesapeake bald eagle distribution and abundance is influenced by migratory and local movements. Eagle monitoring on the Chesapeake must take these fluctuations into account.

Changes in migratory patterns caused by events distant from the Chesapeake may affect overall numbers of eagles seen on the bay at certain times of the year. Changes in local habitat suitability could shift eagle distribution and abundance seasonally and annually as well. Failure to adequately understand these types of effects could lead to mistakes in interpretation of monitoring results.

Chesapeake eagle managers also must consider the effects of their actions on all 3 populations of eagles using the bay. If populations behave differently, management strategies can have differential success. Managers need to target their efforts at the population of interest, and be aware of possible effects on other populations. In this chapter, I describe the dynamics of eagle distribution and abundance on the northern Chesapeake Bay and present a model describing the variables underlying the distribution and abundance.

## ***METHODS***

### **Eagle Distribution**

I determined the distribution of breeding adults using records obtained from the Maryland Department of Natural Resources (G. D. Therres, Md. Dep. Nat. Res., pers. commun.) and by conducting aerial nest searches in fixed-wing aircraft. We monitored distribution and movements of nonbreeding eagles using radio-telemetry and used aerial shoreline surveys to document changes in eagle abundance.

We trapped a sample of northern and southern migratory birds, and post-fledging bay birds using floating noose-fish (Frenzel and Anthony 1982) and padded leghold traps on sand spits (Young 1983). We also sampled the Chesapeake-hatched population by radio-tagging 8-week-old nestlings.

Eagles were equipped with 65-g radio transmitters with solar-charged nickel-cadmium batteries (Telemetry Systems, Inc., Mequon, WI). One eagle was equipped with a 170-g satellite transmitter, with solar-charged nickel-cadmium batteries, to monitor migrational movements (Strikwerda et al. 1986). We mounted radios on the middle of the eagle's back using a 1-cm wide teflon ribbon harness.

We tracked all radio-tagged eagles on NCSA 2-3 times weekly from fixed-wing aircraft. An observer and pilot homed in on radio signals using scanning receivers and H-type antennas (Telonics, Inc., Mesa, AZ) mounted on each wing strut. We recorded eagle locations on 7.5 minute U. S. Geological Survey (USGS) topographic maps. When more than 10 radio-tagged eagles were present on the study area, we randomly selected 10 eagles for relocation and obtained general geographic-area (APG, SRV, BAL, ES) locations of the rest. This kept each flight under 3 hours, minimizing pilot and observer fatigue. After each flight, we obtained the Universal Transverse Mercator (UTM) coordinates of each eagle location from the topographic maps to the nearest 25 meters and recorded data on standard forms. I used all specific and general locations to examine the relative use of APG, ES, SRV and BAL. I compared relative use based on the number of radio-tagged eagle locations per area per flight and the number of locations per flight per shoreline km for each area. I used a general linear model by ranks (Hettmansperger and McKean 1978) in a two-way analysis to test for differences in Chesapeake eagle use by area and seasons. Seasons were determined based on the dates of the spring and fall equinoxes and summer and winter solstices. Since northern and southern eagles were absent for much of the year, I used the  $\chi^2$  approximation of the Kruskal-Wallis test in a one-way analysis to test for differences in eagle use among areas in the primary season that northern eagles were present (winter) and southern eagles were present (summer). I also examined the intensity of eagle use by dividing the study area into 1-km<sup>2</sup> blocks and counted the number of radio-tagged eagle locations in each block.

Eagle movements were monitored off NCSA by using monthly relocation flights on the remainder of the Chesapeake Bay and adjacent river systems from September 1986 - August 1988. We flew south down the ES to Cape Charles, across the bay to the James River and then

northeastward about 25 km northwest of the bay shoreline. Eagle radio signals received were tracked as on the NCSA flights.

## **Eagle Abundance**

We estimated eagle numbers using monthly surveys from fixed-wing aircraft of 614 km of NCSA shoreline. We avoided surveying intensively developed BAL, because no radio-tagged eagles were ever located there. We surveyed ES on Saturdays and APG and SRV areas on the next Sunday. Surveys were flown along shoreline habitat at about 150 km/hour, 50 m above the water and 50 m offshore and began at about 30 minutes after sunrise. The pilot and a front-seat observer spotted eagles and a back-seat person recorded eagle locations on 7.5 minute USGS topographic maps. Surveys were flown only when visibility was good and winds were < 35 km/hour. After each flight, eagle locations were transcribed from topographic maps in UTM coordinates to standard data forms.

Shoreline surveys included both breeding adults and nonbreeding adults. I estimated the number of nonbreeding eagles on each survey by subtracting from the survey total any adults (up to 2) within 3 km of occupied nests; (82% of the locations of 1 radio-tagged adult were within 3 km of its nest). Nonbreeding adults may have been located within 3 km of nests, and counted as breeding birds, thus this approach underestimated the number of nonbreeding birds.

We flew preliminary shoreline surveys during 1984 and early 1985 to standardize survey route and survey protocol. We flew 12 monthly surveys per year between September 1985 and August 1988, totalling 36 surveys. I used the surveys as an index to eagle abundance on NCSA and used survey subtotals within APG, SRV and ES to interpret changes in abundance among areas.

We did not see every eagle on the NCSA during each survey primarily because 1) they were on the survey route but obscured by foliage (visibility bias) or 2) they were on the NCSA but off the survey route. I estimated the total number of eagles on the NCSA at the time of each survey

by estimating the percent of eagles missed for each month and adjusting the survey upward accordingly. I estimated visibility bias for each month of the year using data from radio-tracking birds on the shoreline survey route. I noted the percent of radio-tagged eagles spotted on the first pass along the shoreline and assumed that those spotted on the first pass would have been spotted on a single-pass shoreline survey (Table 1). I further extrapolated the monthly survey results to represent the entire NCSA by dividing by the monthly percent of radio-tagged eagle locations that occurred on the shoreline survey route (Table 1). The estimate of nonbreeding eagles was added to the number of known breeding birds on NCSA to yield the total population estimate. I used Page's (1963) nonparametric test for ordered alternatives to test the hypothesis that the eagle population was increasing each survey year. I then used Wilcoxon signed-rank tests for multiple comparisons among years.

## **Identifying Eagle Origin**

To examine differences in distribution between bay-hatched birds and migratory birds, I classified each radio-tagged eagle based on its origin. Origin was known for eagles banded as nestlings. I classified origin of the unbanded eagles we trapped as northern, bay or southern based on how their movements compared with those of eagles of known origin. Winter-trapped eagles that left the bay in February-April and returned in November-January were classed as northern birds. Summer-trapped eagles that left the bay in August-October and returned in spring-summer were classed as southern birds. Eagles trapped during any time of the year that were located on the bay throughout the year were classed as bay birds.

## **Interactions Among Breeding and Nonbreeding Eagles**

To test for distributional interactions among breeding and nonbreeding eagles, I calculated the distance from each radio-tagged nonbreeding eagle location to the nearest occupied eagle nest and assigned each location to a 250-m distance zone. I used a  $\chi^2$  test to test the hypothesis that nonbreeding eagles were located in greater distance zones from occupied nests during the breeding season (January-June), than during the nonbreeding season (July-December).

## ***RESULTS***

### **Sample of Radio-tagged Eagles**

We radio-tagged 39 eagles in NCSA nests, and trapped 10 free-flying eagles that previously had been banded as nestlings (8 from Chesapeake nests, 1 from Maine and 1 from South Carolina). We trapped 24 previously unbanded eagles and classified 12 as southern, 4 as bay birds and 8 as northern birds. We also monitored the Chesapeake for 22 eagles radio-tagged in north-central Florida nests by University of Florida personnel. From September 1984 through September 1988, we flew a total of 316 flights to relocate radio-tagged eagles, yielding a total of 1,880 specific locations and an additional 1,490 general geographic locations.

## Eagle Distribution

*Breeding Birds.*--There were 12 known breeding areas (24 adults) on NCSA in 1984 and 28 areas (56 adults) by 1988 (Figure 2, G. D. Therres, Md. Dep. Nat. Res., pers. commun.). APG and ES had similar breeding densities (8 APG breeding areas in 1988 at 1 nest/60.5 shoreline km and 19 ES breeding areas at 1 nest/63.9 shoreline km). SRV had 1 active territory (1 nest/78 shoreline km), whereas no nesting activity was observed along 699 km of BAL shoreline.

*Nonbreeding Birds.*--The number of radio-tagged eagle locations per flight and per flight per shoreline km varied among geographic areas and seasons (Table 2). For Chesapeake nonbreeders, APG and ES eagle use did not differ on a locations per flight basis for all seasons (4.17 locations/flight, 3.67 locations/flight, respectively,  $P = 0.43$ ), whereas SRV had much less use (0.65 locations/flight,  $P < 0.05$ ). APG had the greatest Chesapeake nonbreeder use on a shoreline km basis, (8.63 locations/1000 km). SRV use/km was slightly less than APG (8.35 locations/1000 km,  $P < 0.05$ ), while ES use/km was much less (3.02 locations/1000 km,  $P < 0.05$ ). Northern migrants were located most often on APG in winter, whereas use of ES and SRV did not differ on a locations/flight basis ( $\bar{x} = 2.02, 0.36, \text{ and } 0.19$  locations/flight, respectively,  $P < 0.001$ , Table 2) and also on a locations/km basis ( $\bar{x} = 4.17, 0.30, \text{ and } 2.42$  locations/1000 km, respectively,  $P < 0.001$ , Table 2). Southern migrant use of APG and SRV did not differ in summer, whereas less use of ES was observed on a locations/flight basis ( $\bar{x} = 0.83, 0.55, \text{ and } 0.17$  locations/flight, respectively,  $P < 0.001$ , Table 2). Southern migrant use of SRV was greater than use of APG and APG use was greater than use of ES on a locations/km basis ( $\bar{x} = 7.01, 1.72, \text{ and } 0.14$  locations/1000 km, respectively,  $P < 0.001$ , Table 2). No radio-tagged eagles were found in BAL, despite its 699 km of shoreline.

Relative eagle use of NCSA shifted seasonally among areas, with APG receiving the most use in winter and spring by Chesapeake nonbreeders and northern migrants ( $\bar{x} = 3.30, 5.13$  locations/flight, [Chesapeake] and  $2.02, 0.28$  locations/flight [northern], respectively). Eagle use of NCSA in summer was dispersed, because Chesapeake nonbreeder use



of APG and ES did not differ ( $\bar{x} = 6.30, 6.06$  locations/flight, respectively), and southern migrant use of APG and SRV did not differ ( $\bar{x} = 0.83, 0.55$  locations/flight, respectively). Fall eagle use was greatest on ES by Chesapeake nonbreeders ( $\bar{x} = 3.62$  locations/flight).

Although APG, ES and SRV differed in overall use on a locations/flight and locations/flight/shoreline km basis, intensity of use (locations/km<sup>2</sup>) was similar at several key high use areas (Figure 3). APG had 4 of the most intensively used 1-km<sup>2</sup> blocks (92 locations/km<sup>2</sup> at a large creek mouth, 34 locations/km<sup>2</sup> along the bay shoreline, 31 locations/km<sup>2</sup> in the interior near a roost, and 28 locations/km<sup>2</sup> on the upper reaches of a creek), SRV had 3 (34, 33, and 27 locations/km<sup>2</sup> below Conowingo Dam), and ES had 3 (49 locations/km<sup>2</sup> on the bay across from APG and 30 locations/km<sup>2</sup> each at 2 areas on a private wildlife management area).

## Eagle Abundance

The monthly estimated number of NCSA eagles increased during the 3 survey years (Page's test statistic,  $L = 160, P = 0.001$ , Figure 4). Based on signed-rank multiple comparisons, eagle numbers increased from 9/85-8/86 to 9/87-8/88 ( $P = 0.004$ ), while 9/85-8/86 and 9/86-8/87 ( $P = 0.204$ ) and 9/86-8/87 and 9/87-8/88 ( $P = 0.056$ ) did not differ. Abundance varied in an annual cycle with winter peaks, spring lows, larger summer peaks, and fall lows (Figure 4).

Abundance on APG also increased during the 3 survey years (Page's test,  $L = 156, P = 0.01$ , Figure 4), paralleling NCSA abundance since most NCSA eagles occurred on APG. APG eagle numbers increased from 1985-86 to 1987-88 ( $P = 0.016$ ), while 1985-86 and 1986-87 eagle abundance ( $P = 0.678$ ) and 1986-87 and 1987-88 eagle abundance ( $P = 0.10$ ) did not differ. Fall and spring were low periods on APG, while winter peaks were lower than summer peaks.

Abundance on ES also increased during the 3 survey years (Page's test,  $L = 156, P = 0.01$ , Figure 4). ES eagle numbers increased from 1985-86 to 1986-87 ( $P = 0.008$ ) and from 1985-86 to 1987-88 ( $P = 0.026$ ), while 1986-87 and 1987-88 eagle abundance ( $P = 0.57$ ) did not differ.

Annual cycles, however, did not mirror APG and NCSA results. ES abundance peaked during August along with APG and NCSA abundance but ES abundance remained high through December while APG and NCSA abundance were relatively low. ES abundance dropped off in January-March while APG and NCSA abundance peaked. Eagle abundance in spring was consistently low for ES, APG and NCSA.

Abundance on SRV tended to increase for the 3 survey years (Page's test,  $L = 152$ ,  $0.05 < P < 0.10$ , Figure 4), although spring and summer surveys with no eagles (zeros) made the test less effective at detecting differences. Eagle numbers peaked in fall-early winter, then declined to almost zero by spring through summer. SRV peaks occurred during NCSA and APG lows, but coincided with ES fall peaks. SRV lows in spring coincided with NCSA, APG and ES lows. Few eagles used this area overall.

## Eagle Movements

*Chesapeake Breeding Eagles*--We monitored activity and movements of 1 breeding eagle by radio-telemetry during 2 periods from 19 April - 22 June 1984 and 19 September 1984 - 24 March 1985, visually relocating the bird 81 times. Over 81% of the relocations were  $\leq 3$  km from its nest and the adult was never located  $> 7$  km from the nest.

During shoreline surveys, we observed  $\geq 1$  adult within 3 km of each of 5 nests along the survey route more often during the breeding season (January-June) than the nonbreeding season (July-December) (79% versus 60% of surveys, respectively,  $\chi^2 = 7.13$ , 1 df,  $n = 84$ ,  $P = 0.008$ ). This probably was related to greater visibility during the breeding season for territorial defense, courtship and activity at the nest, rather than being totally absent from the area during the nonbreeding season.

*Chesapeake Nonbreeding Eagles*--Use of NCSA by Chesapeake nonbreeders differed among areas and seasons ( $F = 15.13$ , 6, 624 df,  $P < 0.01$  [areas x seasons],  $F = 79.72$ , 2, 630 df,

$P < 0.01$  [areas],  $F = 14.39$ , 3, 630 df,  $P < 0.01$  [seasons], Table 2, Figure 3A). APG appeared to have the greatest winter and spring use of all areas, whereas peak use of NCSA during the year occurred on APG and ES in summer. NCSA eagle use by Chesapeake nonbreeders did not differ between spring and fall ( $P > 0.05$ ), but fall use was concentrated on ES and SRV, whereas spring use occurred on APG.

In September-November, radio-tagged nonbreeding Chesapeake eagle use of APG declined as eagles moved up the SRV and to the lower bay (Figure 5). Relative use of ES was variable in September and October, increasing in 1987-88, stable in 1986-87 and decreasing in 1985-86, as eagles arrived on the area from APG and eventually departed enroute to the lower bay. ES eagle use started to decline in November as influx from APG slowed but departure for the lower Chesapeake Bay continued. As Chesapeake nonbreeding eagles moved down the bay, there was a net decline in NCSA eagle use during the fall. Eagle use of ES and SRV declined in December as eagles continued to move to the lower bay or further south. December use of APG remained low.

NCSA use by Chesapeake nonbreeders increased during the entire January-August period as nonbreeding eagles returned to the northern bay throughout the period and as juvenile birds, radio-tagged as nestlings in May, fledged in late June and became independent in July-August (Figure 5). Most of the eagles returning to the NCSA moved onto APG during the January-May period. June-August had continued increases in NCSA eagle use, especially on ES as some birds left APG for the ES. Eagles spent little time on SRV from April-July. NCSA use by Chesapeake nonbreeders peaked in August.

Little time was spent completely off the Chesapeake by Chesapeake nonbreeding eagles (Figure 5). About 10% of eagle use was south of the bay in winter 1986-87 but even less in winter 1987-88. Eagle use was minimal north of the Chesapeake. We located 3 Chesapeake nonbreeding eagles on Delaware Bay in April and September 1985 and March 1986 and 2 eagles in coastal Maine in August 1987 and 1988.

*Northern Eagles.*--Locations of northern eagles differed among seasons and areas, occurring most frequently during winter on APG, whereas ES and SRV use did not differ ( $\bar{x} = 2.02$ , 0.36, and 0.19 locations/flight, respectively,  $\chi^2 = 50.01$ , df 2,  $P = 0.0001$ , Table 2, Figure 3B). Arrival

of radio-tagged northern eagles ranged from 25 November to 17 January ( $\bar{x}$  = 21 December, range = 61 days,  $n$  = 7). First locations after arrival on NCSA tended to favor APG over ES and SRV (4 of 7 [57%], 2 of 7 [29%], and 1 of 7 [14%] first locations, respectively), although not as strongly as overall use, suggesting that some birds may have moved onto the NCSA via ES and SRV areas.

Departure was more synchronous than arrival, ranging from 1 March to 13 April ( $\bar{x}$  = 27 March, range = 43 days,  $n$  = 14). Northern eagles usually were last observed on APG (12 of 14 last locations, 86%), whereas 2 of 14 (14%) last locations occurred on SRV, suggesting that some birds used the SRV as a northward migration corridor in spring.

*Southern Eagles.*--Locations of southern eagles differed among seasons and areas, occurring most frequently during summer on APG and SRV, while ES was used less often ( $\bar{x}$  = 0.83, 0.55, and 0.17 locations/flight, respectively,  $\chi^2$  = 14.01, df 2,  $P$  = 0.0009, Table 2, Figure 3C). Arrival of radio-tagged southern eagles on NCSA was asynchronous compared to northern birds, ranging from 19 April to 22 July ( $\bar{x}$  = 6 June, range = 94 days,  $n$  = 11). Almost all first arrival locations occurred on APG or SRV (8 of 11 [73%], and 2 of 11 [18%], respectively), possibly from northward migration along the western shore of the bay or northward migration along the Appalachian chain and then back down the Susquehanna River to the NCSA.

Departure also was asynchronous compared to northern birds, ranging from 19 June to 17 October ( $\bar{x}$  = 3 September, range = 119 days,  $n$  = 22). Southern eagles tended to be located last on APG or SRV (13 of 22 [59.1%] and 7 of 22 [31.8%], respectively), again suggesting a southward migration along the western shore of the Chesapeake or up the Susquehanna. One southern eagle tracked via satellite in 1984 moved further north up the SRV into central Pennsylvania in August, then proceeded south along the Appalachian mountains (Strikwerda et al. 1986).

I detected 2 distinct patterns of NCSA use by southern radio-tagged eagles. Southern eagles trapped and radio-tagged on NCSA tended to stay on the NCSA for much of the summer (mean NCSA stay = 81.4 days), while eagles radio-tagged as nestlings in Florida passed through the Chesapeake region, usually without being located on the NCSA (mean Chesapeake stay = 4.5

days, Wilcoxon rank-sum = 23.0,  $n = 11, 6, P = 0.0019$ ). Mean arrival dates on the NCSA were marginally earlier for the southern trapped birds than mean arrival dates on the Chesapeake Bay for Florida nestlings (mean arrival = 6 June versus 17 July, respectively, Wilcoxon rank-sum = 73,  $n = 11, 6, P = 0.06$ ).

## **Interactions Among Breeding and Nonbreeding Eagles**

Chesapeake nonbreeding eagles were located with similar frequency near 30 NCSA nest sites during breeding (January-June) and nonbreeding (July-December) seasons: 48 of 505 locations (9.5%) and 66 of 606 locations (10.9%) were  $\leq 1000$  m from nests, respectively,  $P = 0.448$ , Table 3). Over the entire year, only 114 of 1,111 locations (10.3%) were  $\leq 1000$  m from the nearest nest.

## ***DISCUSSION***

### **Components of Eagle Distribution and Abundance**

NCSA bald eagle abundance cycled annually, with 4 distinct phases; September-November decline, December-February increase, March-May decline and June-August increase (Figure 4). Arrival and departure of migratory birds had the greatest affect on overall eagle abundance. Movements and distributional shifts of the Chesapeake nonbreeding birds tended to modify the effect of migrants. In this discussion, I refer to movements of Chesapeake nonbreeding eagles into

and out of specific areas. These distributional shifts represent the net movement of birds between areas, although some individuals moved back and forth repeatedly.

The September-November decline in eagles on the NCSA appeared to be caused by the September departure of southern birds and movement of Chesapeake nonbreeders to the lower bay. The December increase was driven by the arrival of the northern birds. Abundance in January, however, dropped after the final departure of Chesapeake nonbreeding eagles to the lower bay. Abundance peaked again in late February as the Chesapeake nonbreeders returned from the lower bay. The March-May decline was caused by the departure of northern eagles, despite the continued return of Chesapeake nonbreeders. The number of northern birds that left must have greatly exceeded the number of Chesapeake nonbreeding eagles that returned during this period because total abundance dropped markedly. The June-August increase was caused by 3 events; influx of southern birds, continued return of Chesapeake nonbreeders, and the fledging of young from NCSA nests. Breeding adults plus the annual recruitment from NCSA nests (56 adults plus 32 young, G. D. Therres, Md. Dep. Nat. Res., pers. commun.), accounted for less than 15% of the August 1988 estimate of 604 eagles.

## **Factors Affecting Distribution and Abundance**

In the absence of human intervention, food is the primary determinant of most aspects of raptor population ecology (Newton 1979:290). Dispersion of breeding territories probably is driven by the distribution of food and suitable nest sites (Newton 1979). For *Haliaeetus* eagles, nonbreeders generally are distributed in association with food abundance at any time of the year and all age classes of eagles tend to be associated with food distribution in winter (Newton 1979). For some raptors, competition or harassment from breeding birds may preclude nonbreeders from breeding territories (Newton 1979). Newton (1979:184) concurred with Lack's (1954) assessment

that movements, including migration, occurred largely in response to seasonal changes in food abundance.

I concur with Newton's (1979) and Lack's (1954) assessment of the importance of food and expect that the Chesapeake's abundant year-round prey base is the primary attractant for northern eagles in winter, southern eagles in summer, and Chesapeake breeding and nonbreeding eagles all year. The Chesapeake historically was thought to support 1 of the densest breeding populations besides Alaska, with up to 1 nest per mile of shoreline (F. C. Kirkwood pers. commun., cited in Tyrrell 1936), consistent with great prey abundance and extensive shallow-water foraging habitat. Although environmental degradation of the Chesapeake may have changed both eagle prey species composition and abundance, its overall productivity probably is still high compared to many other North American water bodies, and its extensive shallow-water areas are still very attractive to eagles.

Within the limits of Chesapeake Bay, it appeared that the eagle distribution was determined by a complex interaction of factors that defined habitat suitability, including food, distribution of human development and activity, distribution of suitable roost and diurnal perch habitat, weather, and social interactions with other eagles. Some of these factors varied seasonally, so habitat suitability of a given area may have changed seasonally as well. They also may have operated at different scales. Eagle movements, then, reshaped eagle distribution in response to the changing environmental conditions. I propose that all 4 groups of eagles identified on the Chesapeake were sensitive to a similar set of factors, but with differential tolerance or response, yielding distributional differences.

At the landscape scale, all 4 groups of eagles appeared to select habitats defined by human development intensity below some threshold. This was consistent with Newton's (1979:227) observation that "human presence has become increasingly important in rendering suitable habitat unattractive to raptors" and with other observations of eagle sensitivity to human activity and development (Stalmaster and Newman 1978, Andrew and Mosher 1982, Wallin and Byrd 1984, Fraser 1984, Fraser et al. 1985, McGarigal 1988, Smith 1988), although no one has evaluated these effects on a broad scale. Eagle avoidance of the Baltimore area may have occurred at this level,

because none of our northern, southern or Chesapeake nonbreeding radio-tagged birds or any nest sites were located there.

On a smaller scale, breeding eagle distribution was limited to areas that had suitable nest trees, < 1.5 km from open water, were isolated from human activity and development at some threshold of intensity (Andrew and Mosher 1982), and that also had an adequate prey base. Expansion of the breeding distribution would occur in areas that meet these requirements and are presently unoccupied by breeding birds. Movements of breeding birds were limited to areas near their nest sites. It appeared that breeding bird movements, therefore, did not significantly change the Chesapeake eagle distribution at the scales I examined.

The spatial distribution of nonbreeding Chesapeake eagles on a smaller scale on the NCSA may have been limited to areas with adequate food, roost and diurnal perch habitat, with low level human activity and development, and possibly lack of harassment from breeding birds. Nonbreeders, because of their lack of attachment to breeding sites, moved when suitability of local areas declined. Cooling water temperatures in fall appeared to cause a significant decline in fish availability on the northern Chesapeake (Mersmann 1989). This decline probably prompted southward movement of nonbreeders to the lower Chesapeake, where fish availability may have been temporarily greater because of warmer water temperatures and where waterfowl were abundant in winter (Lippson 1973). Nonbreeders returned as water temperatures increased, signalling the start of the spring spawning period in late February and renewed fish abundance. In severe winters, the breakup of ice cover in late winter also may have exposed an additional source of food (dead fish; Southern 1963, Southern 1964, Griffin et al. 1982). Distribution of Chesapeake nonbreeders was probably most limited in summer by the distribution of human activity and shoreline development, because that was when the 2 distributions had the greatest potential for overlap.

I did not directly quantify the effect of breeding eagle behavior on nonbreeding eagle distribution. Most of the nonbreeding eagle locations (96%, Table 3), regardless of the season, were > 500 m from nest sites. Because an experimental territorial response distance in Minnesota was 590 m (Mahaffy and Frenzel 1987), the observed distance from nests may represent nonbreeding



eagle avoidance or repulsion from nest sites by territorial behavior of the resident adults. Although Chesapeake breeding eagles were resident on their territories year-round, however, I did not detect a difference in distance nonbreeding eagles were located from nests between breeding and nonbreeding seasons. Alternatively, nonbreeders may have been located away from nest sites because their activity was centered around shoreline foraging areas whereas nest sites tended to be located more inland. Eagle nests were, on average, 637 m inland in a sample of 70 Maryland nests (Andrews and Mosher 1982).

The distribution and abundance of migratory eagles may have been based on a different model than Chesapeake breeding and nonbreeding birds. The ultimate reason for northern and southern eagle migration probably was lack of a reliable food supply on the breeding grounds (Lack 1954:243). In typical Northeast winters, ice-up of principal inland foraging areas (lakes and rivers), movement of coastal fish to deeper water or down the Atlantic coast as water temperatures drop, and the migration of waterfowl must have greatly reduced food availability, inducing eagle migration. McCollough's (1986) finding that 92% of immature eagles that located experimental feeding stations in coastal Maine during November-January did not migrate supports this conclusion.

Southern eagles also may have migrated in response to declining food availability. Fish availability in the Southeast may have declined in late spring-early summer as increasing water temperatures caused fish to abandon shallow water areas. Edwards (1988) reported declining fish abundance near the surface of inland lakes in north-central Florida during the late spring-early summer period, coincident with the movement of eagles northward. An alternative or additional explanation is that southern eagles migrated northward in late spring to avoid the physiologic consequences of extreme summer heat. Summer temperatures in the Southeast undoubtedly exceed the levels reportedly inducing thermal stress in raptors (34 °C, Hayes and Gessaman 1980).

Timing and extent of northern and southern eagle movements, then, probably were unrelated to conditions on the Chesapeake. Once they reached the bay, however, local conditions determined their distribution. Distribution of migrants was probably spatially limited by the same factors that limited Chesapeake nonbreeding eagle distribution: adequate food, roost and diurnal perches, and

low human activity and development. It appeared that northern eagle use of the NCSA food supply, however, differed from that of Chesapeake nonbreeders because northern birds wintered on the NCSA while Chesapeake nonbreeders moved south. It is possible that northern eagles out-competed Chesapeake nonbreeders at communal foraging areas in winter. Low fish availability led to increased scavenging on waterfowl and white-tailed deer (*Odocoileus virginianus*) carcasses in winter on the northern Chesapeake (Mersmann 1989), increasing the potential for competitive interactions. Northern eagles, with a distinct size advantage over their Chesapeake counterparts (Buehler et al. unpubl. data), may have excluded Chesapeake nonbreeders from communal scavenging opportunities, similar to observed competition among bald eagles in Alaska and Washington (Hansen 1986, Knight and Skagen 1988) and other avian scavengers (Wallace and Temple 1987). Most of the northern migrants stayed on APG, so most of the Chesapeake breeding pairs on the ES avoided competition with the larger birds. The adult plumage and resident experience also may have tended to offset the size advantage of the northern birds.

Southern eagle distribution may have been less affected by food distribution than eagle distributions in other seasons. Because Chesapeake nonbreeder use of NCSA was dispersed in summer, food supply probably was adequate over a broad area (Mersmann 1989). Other factors, especially human activity and shoreline development, may have had a greater effect on determining southern eagle distribution.

# CHAPTER 2: EFFECTS OF HUMAN ACTIVITY AND SHORELINE DEVELOPMENT

## *INTRODUCTION*

Recent declines in bald eagle populations largely have been attributed to effects of DDT on productivity (Hickey and Andersen 1968, Krantz et al. 1970, Wiemeyer et al. 1972, Grier 1982, Fraser 1984, Wiemeyer et al. 1984). Eagle populations began to recover throughout their range after the 1972 Environmental Protection Agency ban of DDT (Grier 1982, Fraser 1984, Wood et al. 1990). As eagle populations continue to expand, the amount of suitable habitat required to support them also will increase. However, human populations also are expanding, resulting in increased habitat destruction and disturbance to eagles. Thus, human-eagle interactions will play an increasingly important role in defining ultimate eagle population levels.

Historically, Chesapeake Bay may have had one of the densest eagle breeding populations in North America. F. C. Kirkwood, a Chesapeake-area ornithologist during the late 1800's, estimated

that there may have been 1 eagle nest per mile of Chesapeake shoreline historically (pers. commun., cited in Tyrrell 1936). Given the 13,033 km (8,080 miles) of shoreline (Lippson 1973), the Chesapeake may have had over 8,000 eagle nests and 4,000 breeding pairs, assuming each pair had two nests. Alternatively, if the Chesapeake breeding density historically equalled the densest breeding recorded in North America (1 nest/2 km of shoreline, southeastern Alaska, Hodges and Robards 1982), there would have been about 3,250 pairs, again assuming 2 nests/pair. Eagles probably declined as deforestation and human persecution began during European settlement of the bay, dropping to an estimated 600-800 pairs by the 1930's (Tyrrell 1936, Figure 6). The population continued to decline to 150 pairs in 1962 and only 80-90 pairs by 1970 (Abbot 1978). The population declined further during the early 1970's (Abbot 1978). The population began increasing during the late 1970's (Cline 1986) and continuing during the 1980's, reached 181 pairs in 1988 (Wood et al. 1990). The Chesapeake also provides habitat for many northern and southern migrants wintering and summering on the bay (Chapter 1). These birds also will require additional habitat in the future as their populations continue to expand.

The human population in the Chesapeake region increased steadily after European settlement up to about 1900 before a marked population increase during this century (Figure 6). Chesapeake shoreline habitat also has come under increasing human development pressure and human activity also has increased since the 1970's when the Chesapeake eagle population was at its all-time low. Human-developed land in Maryland increased by 16.5% from 1970 to 1980 and developed land is projected to increase by 59% from 1980 to 2020 (Breedon et al. 1988). Although the Chesapeake eagle population is presently expanding and is within the range of population recovery stated in the Chesapeake Bay Region Bald Eagle Recovery Plan (175 - 200 breeding pairs, Taylor et al. 1982), it is likely the man-caused decline in shoreline habitat will halt the recovery at or below desired levels.

There has been considerable study of eagle sensitivity to human activity. Eagles on the northern Chesapeake Bay selected roost sites away from houses, roads, and human-developed habitats (Chapter 3) and eagles showed human avoidance behavior in roost site selection elsewhere (Harmata 1984, Colorado; Hansen et al. 1980, Washington; Lish 1973, Oklahoma). Others have

noted eagle sensitivity to human activity at foraging areas (Steenhof 1976, South Dakota; Nye and Suring 1978, New York; Stalmaster and Newman 1978, Washington; Knight and Knight 1984, Washington; Wallin and Byrd 1984, Potomac River, Virginia; McGarigal 1988, Columbia River, Oregon-Washington; Smith 1988, North Carolina). A few studies also have shown that eagles selected nest sites away from human developed areas (Andrew and Mosher 1982, Chesapeake Bay; Fraser et al. 1985, Minnesota).

Given this sensitivity to human activity and development discussed above, I hypothesized that these are primary factors in determining the Chesapeake Bay eagle distribution (Chapter 1). In this chapter, I examine eagle sensitivity to human activity and shoreline development on the northern Chesapeake Bay and examine how human-eagle interactions shape eagle distribution and affect habitat suitability.

## ***METHODS***

### **Monitoring Bald Eagle Distribution and Abundance**

I used 3 approaches to document NCSA bald eagle distribution and abundance (Chapter 1). Distribution of breeding territories (adult pairs) was obtained from Maryland Department of Natural Resources records (G. D. Therres, Md. Dep. Nat. Res., pers. commun.) and by aerial searches of areas where adult eagles were observed during biweekly aerial surveys or other activities. We monitored the distribution of nonbreeding birds by using aerial radio-telemetry to monitor 95 radio-tagged eagles. We conducted aerial shoreline surveys to document changes in eagle abundance.

We randomly selected 10 eagles for visual location on each telemetry flight and obtained general geographic-area locations on the rest. We plotted visual locations on 7.5 minute USGS topographic maps. After each flight, we read the UTM coordinates of each eagle location from topographic maps to the nearest 25 meters and recorded data on standard forms. I used all visual and general locations to examine relative use of NCSA for 4 major geographic units; APG, ES, SRV and BAL (Chapter 1). I used only visual locations to determine habitat use.

We monitored eagle numbers by using monthly surveys from fixed-wing aircraft (614 km of NCSA shoreline). We avoided surveying intensively developed BAL, because radio-tagged eagles were never located there. We surveyed ES on Saturdays and APG and SRV on the next Sunday. We resurveyed eagle high use areas on weekdays 1-2 weeks after the full survey to evaluate effects of weekday versus weekend human activity on eagle use of specific stretches of shoreline. Surveys were flown along shoreline habitat at about 150 km per hour, about 50 meters above the water and about 50 meters offshore and began at about 30 minutes after sunrise, lasting about 2.5 hours. The pilot and a front-seat observer spotted eagles and a back-seat person recorded eagle locations on 7.5 minute USGS topographic maps. Surveys were flown only when there was good visibility and light winds, less than 35 km per hour. After each flight, eagle locations were transcribed from topographic maps in UTM coordinates to standard data forms.

## **Monitoring Human Activity and Shoreline Development**

We monitored human activity during our full monthly aerial shoreline surveys and our short weekday surveys and recorded locations of all boats with people on board and pedestrians on land within a visually-estimated 500 m distance of the shoreline.

I digitized the location of all buildings (houses, marinas, farms, commercial sites, industrial sites and military buildings) within 500 m of the shoreline survey route off the most recent (1970-85) 7.5 minute USGS topographic maps, updated with 1985 1:12,000 color aerial photos. I divided the shoreline survey route into 250 m segments and characterized each segment for each survey by its

human and eagle use. Segments were classified as used by eagles if  $\geq 1$  eagle on  $\geq 1$  survey was observed within 50 m of that segment. Segments were classified as human-used if  $\geq 1$  pedestrian or boat on  $\geq 1$  survey was observed within 500 m of that segment.

I used  $\chi^2$  analyses to test the hypothesis that eagle use of and developments on shoreline segments occurred independently in each season of the year and across the entire year. Seasons were determined based on the dates of the spring and fall equinoxes and the summer and winter solstices. I repeated the analyses for developments within 100 m intervals of the shoreline for distance intervals from 0 - 100 m out to 400 - 500 m, until I found the greatest distance at which a significant effect was noted.

I conducted separate  $\chi^2$  analyses of each individual survey ( $n = 34$  surveys) to determine the number of segments that would be expected to have both eagles and human activity present if eagles and humans were distributed independently, including separate analyses for pedestrian and eagles, and boats and eagles. I used a Wilcoxon signed-rank analysis to test for differences between the observed number of segments with human activity and eagles present versus the expected number of segments, with the expected value taken from the individual survey  $\chi^2$  analyses. This approach was used to control for experiment-wise (all surveys) error rates. After detecting significant differences with the Wilcoxon test, I looked at the significance level of the individual  $\chi^2$  tests to determine which individual surveys contributed to the observed differences between eagle and human distributions. I conducted Wilcoxon rank-sum analyses to test for differences between weekday versus weekend eagle densities and weekday versus weekend human activity (pedestrian and boat) in summer on 2 rivers that received substantial use by both species.

I identified cover type and land use (developed, farmland, forest, wetland, other) at each radio-tagged eagle location based on the USGS land use and land cover database (Anderson et al. 1976). I compared this to what was available on the entire NCSA using  $\chi^2$  analyses.

I used 2 separate systems to classify developed land use along the shoreline. I determined which shoreline segments were developed based on the USGS land use classification for the entire NCSA. The USGS land use system identified land uses as developed if  $\geq 4$  developments were located within a 4 ha cell. To determine the effects of development on a finer scale, I determined

which segments had developments within 500 m along the shoreline survey route from 1985 1:12,000 scale color aerial photos and USGS 7.5 minute topographic maps.

We determined eagle sensitivity to human presence by approaching perched eagles on foot and by boat until they flushed. We started at a distance > 500 m from the eagle and moved at a slow, deliberate pace (about 3 km/hr) directly toward the eagle until it flushed. We then measured the distance from the observer to where the eagle was perched with a braided nylon fishing line marked off in meters.

## ***RESULTS***

### **Human Activity and Development**

Of the 1,442 km<sup>2</sup> of nonaquatic habitat on the NCSA, 400 km<sup>2</sup> (27.7%) was identified as developed in the USGS land use and land cover database. This included 201 km<sup>2</sup> (14.0%) residential, 86 km<sup>2</sup> (6.0%) commercial, 43 km<sup>2</sup> (3.0%) industrial, 36 km<sup>2</sup> (2.5%) transportation, communication and utilities and 34 km<sup>2</sup> (2.4%) in mixed and miscellaneous developed categories (Table 4, Figure 7). Of the 2,500 km of NCSA shoreline, 703 km (28.1%) was developed in the USGS classification.

The number of human developments/shoreline km differed by geographic area. Of the 5,120 human development sites within 500 m of the survey route shoreline, APG had the lowest development intensity ( $n = 924$ ,  $\bar{x} = 3.58$  sites/shoreline km), while ES and SRV were similar ( $n = 3,857$ ,  $\bar{x} = 11.91$  sites/shoreline km and  $n = 339$ ,  $\bar{x} = 10.60$  sites/shoreline km, respectively, Table 5).



Of the 2,532 survey route segments, 1,673 (66.1%) had development within 500 m. Of the developed segments, 50% had  $\geq 3$  development sites, a minimum density of 0.74 sites/ha. The sites within 500 m of the shoreline were located, on average, 169 m inland (Figure 8).

The USGS developed land use classification only identified intensively developed areas. Of the 700 shoreline segments along the shoreline survey route that had developments within 100 m, as determined by aerial photo analysis, only 232 (33.2%) were classified as developed in the USGS land use system. All segments classified as developed in the USGS land use system, in contrast, had developments within 100 m in the aerial photo analysis.

The number of pedestrians/shoreline km differed among seasons ( $P < 0.01$ , Friedman's test). Pedestrian activity was greatest in summer and least in winter ( $P < 0.05$ ); pedestrian activity did not differ between spring and fall, and between spring and summer ( $P > 0.05$ ; pair-wise Friedman's tests, Table 6, Figure 9). Pedestrians/shoreline km also differed by geographic area ( $P < 0.01$ , Friedman's test). Pedestrian activity was greatest on the SRV, intermediate on ES and least on APG ( $P < 0.05$ , pair-wise Friedman's tests, Table 6, Figure 9). Boats/shoreline km differed seasonally ( $P < 0.01$ ). Boat activity was greatest in summer and least in winter ( $P < 0.05$ ), whereas spring and fall did not differ ( $P > 0.05$ , pair-wise Friedman's tests, Table 6, Figure 10). Boats/shoreline km also differed geographically ( $P < 0.01$ ). Boat activity was greatest on the SRV ( $P < 0.05$ ), whereas ES and APG did not differ ( $P > 0.05$ ; pair-wise Friedman's tests, Table 6, Figure 10).

Human activity was observed over much of the shoreline. Pedestrians were observed within 500 m of 1,425 of 2,532 (56.3%) shoreline segments and boats were observed within 500 m of 1,748 of 2,532 (69.0%) segments. Human activity, however, was inconsistent with respect to which segments were used. Of the human-used segments, pedestrians were observed on 76.3% of the segments on  $\leq 5$  of 34 surveys and boats were observed on 59.9% of the segments on  $\leq 5$  surveys. Pedestrians were observed close to the shoreline ( $\bar{x} = 32.4$  m) whereas boat use occurred farther from shore ( $\bar{x} = 163.5$  m, Figure 8).

Human activity (pedestrian and boat) occurred on developed segments more often than would be expected if human activities were distributed independently of development ( $P < 0.001$ ).

During each season and over the entire year, pedestrians were observed more often within 500 m of developed segments than expected if pedestrians were distributed independently of development ( $P = 0.001$ , Table 7). During each season and over the entire year, boats were observed within 500 m of developed segments more often than expected if boats and development were distributed independently ( $P = 0.001$ , Table 8). Human activity (pedestrians and boats) and development were totally absent from only 360 of 2,532 segments (14.2%) monitored, while pedestrians, boats and development were observed on 983 segments (38.8%).

## Human-Eagle Interactions

Based on the USGS land use database, only 55 of 1,117 (4.9%) radio-tagged eagle locations occurred in human-developed habitat blocks, although 27.7% of the NCSA was developed ( $P < 0.001$ , Table 6, Figure 7). Most of the eagle locations in human-developed habitat (80.4%) occurred on APG, where habitat was designated as developed because of military operations despite low human use in these areas and very few physical structures present. Thus, only 11 of 1,117 eagle locations (0.9%) occurred in nonmilitary developed areas.

During all shoreline surveys, eagles were observed less often on developed segments than would be expected if eagles selected shoreline segments independent of development ( $P < 0.001$ , Table 9). Eagles appeared to avoid segments during all seasons for all 100-m distance zones with developments ( $P < 0.05$ ), except in fall, when eagle use was not consistent with avoidance of segments with developments in the 200-300 m, 300-400 m and 400-500 m zones ( $P > 0.05$ ).

Eagles were located less often than expected on shoreline segments that had human activity (pedestrians and boats) within 500 m ( $P < 0.001$ , Tables 10 and 11). Based on individual survey analyses, eagle avoidance of pedestrian-used segments was significant ( $P < 0.05$ ) in May-September, 1987 and August 1986; periods when pedestrian activity was greatest. Eagle avoidance of segments with boat activity was significant ( $P < 0.05$ ) in July-August 1986,

April-September 1987 and May 1988 surveys, periods when boat activity was greatest. For both pedestrians and boats, the number of segments in which eagles and human activity occurred was very low per survey (range of 0 to 6, pedestrians; 0 to 17, boats).

Boat use of the Bush River on APG and the Sassafra River on the ES in summer tended to be greater on weekends ( $\bar{x} = 0.38$  boats/km,  $n = 9$ ) than weekdays ( $\bar{x} = 0.04$  boats/km,  $n = 4$ ,  $P = 0.06$ ). Pedestrian use was low and did not differ during the 2 periods ( $P = 0.385$ , Table 12), primarily because of the greatly restricted access to military property on APG, and limited shoreline development on the stretch of the Sassafra river surveyed for this analysis. During these periods, more eagles were located on the Bush River on APG and the Sassafra River on the ES on weekdays when human activity was low, than on weekends when human activity was high ( $\bar{x} = 0.44$  eagles/km vs.  $0.20$  eagles/km, respectively,  $P = 0.006$ ).

## Eagle Flush Distances

Eagle boat flush distances averaged 215 m, with a range of 40 - 475 m, (Figure 11). Eagle boat flush distances in winter were greater than those measured in summer ( $\bar{x} = 265$  m and  $175$  m, respectively,  $P = 0.0013$ , Wilcoxon rank-sum test) whereas flush distances were similar between adults and immatures ( $P = 0.38$ , Wilcoxon rank-sum test, Table 13). ES flush distances were less than APG flush distances ( $\bar{x} = 163$  m and  $223$  m, respectively,  $P = 0.049$ , Table 13). It also appeared that pedestrian and boat flush distances did not differ ( $\bar{x} = 209$  m and  $215$  m, respectively,  $P = 0.77$ , Table 13) although the pedestrian sample was very limited ( $n = 4$ ).

## *DISCUSSION*

NCSA bald eagle distribution appears to be shaped both geographically and seasonally by human activity (pedestrians and boats) and shoreline development. On a large scale, I observed no eagle use of the BAL area, despite its 699 km of shoreline. I suspect avoidance of this area is attributable to avoidance of the intensely developed areas that composed nearly 70% of the BAL shoreline. BAL was much more developed than SRV, APG and ES areas, all of which had significant eagle use.

On a smaller scale, it appears that eagles avoided large portions of the shoreline in the other 3 areas because of development and human activity. I observed significant eagle avoidance of shoreline which had developments within 500 m in all seasons but fall. Eagles also appeared to avoid shoreline segments with human activity within 500 m, primarily in summer, when human activity was greatest. Assuming the survey route is representative of the NCSA shoreline, excluding BAL, 66.1% (1,190 km) of the shoreline had developments within 500 m. This shoreline, in addition to the 699 km in BAL, totalling 1,889 km (75.6% of NCSA shoreline) may be largely lost as eagle habitat. Additional shoreline with human activity but not development (10.2% of the survey route for pedestrian use and 19.4% for boat use), also appeared to be unsuitable for eagle use, at least while the human activity was present.

Human activity cycled seasonally, weekly and daily, with corresponding effects on eagles. Human activity was greatest in May - September, on weekends. In summer, human weekend activity (Figures 9 and 10) also varied depending upon whether it was a holiday weekend. The peak boat survey (Figure 10) occurred on Labor Day weekend, 1 September 1986. Weather conditions also probably contributed to the variance in human activity among surveys during a given season and among years. I documented effects on eagle distribution in morning, when human activity was generally low, and eagle foraging activity was high (Mersmann 1989). I do not know for certain what happened when human activity was greatest during the midday period. I suspect eagles still avoided human activity, similar to their response to human activity in the morning.

The mechanism causing eagles to avoid areas inhabited by people remains unknown. I hypothesize that human activity may be the most important mechanism causing eagle avoidance of developed shoreline. People could have either directly flushed eagles from developed shoreline, thus minimizing eagle use of these areas or eagles simply could have avoided shoreline which had people or developments present. Direct response (flushing) to disturbance occurred very infrequently in 1 study on the Columbia River, Oregon-Washington (McGarigal 1988). In that study, eagles apparently actively avoided flying into areas where boats were present. Eagles on the northern Chesapeake also avoided developed shoreline in winter, when human activity was largely absent, suggesting that eagles also must be sensitive to the development structure, regardless of whether human activity is present.

Eagles appeared to be more tolerant of developed shoreline in fall than in other seasons. This suggests that other factors, such as food supply, may effect eagle tolerance to human disturbance. Food supply appeared to be most limited in fall on the northern Chesapeake (Mersmann 1989), and eagles moved up to the SRV (Chapter 1), apparently to take advantage of an abundance of gizzard shad (*Dorosoma cepedianum*) available below Conowingo Dam. Eagle use of the key foraging area along the SRV occurred in spite of the presence of developments within 500 m and apparently accounted for the increased tolerance of developments observed in fall. Other potential effects of development, such as vegetative habitat alteration and prey base disruption, need to be studied to isolate the most detrimental effects of human development on eagles.

Eagle sensitivity to human activity, as measured by flush distances, appeared to be within the range of values reported elsewhere. Our summer boat flush distances ( $\bar{x} = 175$  m) were similar to distances reported elsewhere (Wallin and Byrd 1984, 154 m, Virginia; Smith 1988, 137 m, North Carolina; McGarigal 1988, 197 m, Columbia River, Oregon-Washington). Our winter boat flush distances ( $\bar{x} = 265$  m) were much greater than that reported by Knight and Knight (1984), 152 m, (canoe) in Washington. Our limited-sample pedestrian flush distance ( $\bar{x} = 209$  m) was similar to that reported in North Carolina, 220 m (Smith 1988), but greater than that reported in Washington, 131 m (Stalmaster and Newman 1978). I detected no difference in response by age,

similar to Knight and Knight (1984), Wallin and Byrd (1984) and Smith (1988), but unlike Stalmaster and Newman (1978).

The greater flush distance reported in winter may be attributed to seasonal changes in individual tolerance, related to eagles becoming accustomed to and more tolerant of human disturbance in summer, when human activity is common and less avoidable. Eagles in winter may be more sensitive because of the lack of frequent exposure. The greater flush distances observed on APG, where human activity was less common than ES, is consistent with this interpretation. An alternative explanation is that there were differences in response among the predominantly northern migrants inhabiting the northern Chesapeake in winter, compared to the southern migrants and Chesapeake eagles present in summer (Chapter 1). I was unable to test these 2 hypotheses in this study.

# CHAPTER 3: BALD EAGLE ROOST USE AND VEGETATIVE CHARACTERISTICS

## *INTRODUCTION*

Chesapeake Bay provides habitat for 181 pairs of breeding bald eagles and wintering and summering habitat for hundreds of nonbreeding birds (Wood et al. 1990). It provides a critical link in the life history of not only resident breeding and immature eagles but also migratory eagles from the Northeast in winter and from the Southeast in summer (Chapter 1). As such, the Chesapeake Bay may play a particularly important role in the recovery of eastern bald eagle populations.

Availability of roost sites with suitable thermal and vegetative characteristics could be an important determinant of bald eagle distribution and abundance, and also may affect eagle ability to use otherwise suitable foraging areas. Roost use and roost site characteristics have been studied extensively in middle and western United States (Southern 1963, Swisher 1964, Edwards 1969, Jonen 1973, Lish 1973, Shea 1973, Servheen 1975, Griffin 1978, Stalmaster et al. 1979, Hansen et al. 1980, Steenhof et al. 1980, Anthony et al. 1982, Keister and Anthony 1983, Harmata 1984, Sabine and Klimstra 1985, Keister et al. 1987). Very little study has been done on roost use and

site characteristics for eastern populations. Nye (1977) briefly described features of 2 winter roosts located in association with hydro-electric dams on rivers in New York and Chester et al. (1990) described use and characteristics of 2 summer roosts at man-made reservoirs in North Carolina. Eastern bald eagle roost sites may differ from many western sites in topography, microclimate, vegetation and the distribution and abundance of associated prey species. These geographic differences could result in corresponding geographic differences in eagle distribution and abundance and have far-reaching consequences when roost management options are considered. For these reasons, I studied bald eagle roost use in an eastern estuarine setting and determined vegetative characteristics of roost trees and roost sites from 1984-89. I also characterized random trees and sites to test the hypothesis that eagles selected roosting habitat in proportion to what was available.

## ***METHODS***

### **Identifying Bald Eagle Roost Sites**

We located most roost sites by tracking radio-tagged eagles until they roosted in the evening. Three communal roosts were located during a previous study on APG (Millsap et al. 1983). Twice weekly, we randomly selected 1 of 20 to 36 radio-tagged eagles present on the NCSA and tracked it during the evening by foot, vehicle or boat in August 1986 and June 1988 - May 1989.



## **Monitoring Roost Use**

Once a roost was located, I classified each site as communal or solitary. Communal roosts were those in which more >1 eagle roosted. Solitary roosts were those in which a radio-tagged eagle was located alone. I also classified roosts as winter roosts (used November - April) or summer roosts (used May - October). These use periods coincided with leaf-off and leaf-on periods on the study area.

We conducted evening eagle counts at roost sites from parked vehicles or blinds. Counts were conducted by 1-2 observers, depending upon the size and visibility of the area. Counts usually began 2 hours before dark and ended when it was too dark to see eagles. Observers then could leave without flushing the birds. We recorded the time, age based on plumage characteristics (adult, subadult, immature or juvenile, Southern 1964), and roost tree used for each eagle entering the roost. Roost counts were conducted twice monthly at sites in use, but only monthly after use stopped during a season. We also conducted weekly counts in the most frequently-used year-round roost (APG-1).

## **Identifying Roost Trees**

We identified roost trees by marking trees on enlarged panoramic photos of the roost and by rough sketches in field notebooks. Using the sketches or photos as a guide, we relocated and marked the trees for later measurement. While marking known-use trees, we also marked adjacent trees that had pellets underneath.

## Characterizing Roost and Random Trees and Sites

We recorded roost tree species, diameter at breast height (dbh) and height (measured by clinometer). Tree accessibility was the estimated total arc (0-360°) that was unobstructed by other trees for a distance of 10 m from the trunk and 3 m from the tree's crown. We measured percent canopy cover with a densiometer at 4 randomly selected points 5.6 m from the roost tree trunk. We averaged these 4 readings to get percent canopy coverage for the entire tree. We classed roost trees as totally alive, totally dead or dead topped and measured the distance from the tree to nearest habitat edge.

I defined a roost site as the area enclosed by a convex polygon connecting all identified perimeter roost trees. I measured the enclosed area using 1:12,000 color aerial photos for large areas or calculated the area based on angles and distances between perimeter trees measured at the site for small areas. For solitary roosts with only 1 identified roost tree, I arbitrarily assigned roost size at 400 m<sup>2</sup>. Habitat type at each site was classified as developed, forested, or agricultural and size of the habitat blocks were determined from the USGS land use and land cover database (Anderson et al. 1976). We sampled tree density at the site by counting all trees  $\geq 10$  cm diameter at breast height (dbh) in 11.3 m radius plots (400 m<sup>2</sup>) centered on individual roost trees. I averaged tree density across all roost tree plots for each roost. I measured on aerial photos the largest canopy opening contiguous to each roost site and noted the exposure direction at this opening. I did not make comparable measurements at random sites because comparable aerial photos were unavailable. I measured on USGS 7.5 minute topographic maps the distance to aquatic features including Chesapeake Bay, rivers (> 1 km wide at the narrowest point), creeks (250 m - 1 km wide), rills (< 250 m wide) and ponds. I similarly measured the distance to the nearest paved road and to the nearest human development (houses, barns, marinas, public buildings and commercial and industrial sites). I measured canopy height with a clinometer at each individual tree plot and averaged these values to generate canopy height of the entire site. I randomly selected 127 points

from all non-aquatic habitat on the NCSA and took measurements similar to those taken for roost trees and sites on the closest tree to that point that was  $\geq 20$  cm dbh.

## Statistical Analyses

To meet the assumption of independence of observations for roost tree analyses, I considered each roost a sampling unit. For each continuous roost tree variable measured, I calculated the average value from all roost trees in the site. This average was the sample value for that roost. I used Wilcoxon rank-sum tests to compare location parameters of continuous variables, because variables were non-normally distributed (Shapiro-Wilk test,  $P < 0.05$ ).

# RESULTS

## Eagle Roost Use

*Communal roosts.*--We located 33 roost sites on the NCSA from 1984-89; 17 were communal and 16 were solitary. Communal roosts were clumped in 3 general locations: APG (8 sites), ES (6 sites) and SRV below Conowingo Dam (3 sites, Figure 12). Two communal roosts were used year-round, 11 roosts were used primarily in winter and 4 roosts primarily in summer. Almost all (14 of 17) communal sites were used consistently and in the same seasons each year. Exceptions were APG-6, used only during winter 1983, ES-2, used only in January 1987 and SRV-1, used every fall except 1987.

The total count of eagles roosting at the 17 communal sites was 3,481, during 444 roost observations, averaging 7.84 eagles per evening count. We determined age for 3,149 of 3,481 eagles observed, of which 843 (26.8%) were adults, 144 (4.6%) were subadults, and 2,162 (68.7%) were immatures and juveniles.

APG-1 had the greatest use of any roost ( $\bar{x}$  = 12.3 eagles/evening count,  $n$  = 132, range = 0 - 30) and was used all year. ES-1 also had comparable winter and summer use, although at much lower levels than APG-1. Eight roosts (APG-3, -4, -6, -7, -8, ES-2, -4, -5) were used primarily during winter and 4 roosts (APG-2, APG-5, ES-3, ES-6) were used primarily in summer. All 3 SRV roosts were used in fall and early winter (Figure 13).

Roost use peaked in winter coincident with presence of northern migrants and concentration of some resident eagles and again in summer coincident with presence of southern migrants and most NCSA resident eagles (Figure 13, Chapter 1). Roost use along the SRV showed little consistency with 3 alternate sites being used in 5 consecutive winters but coincided with peaks in eagle use below Conowingo Dam in the late fall and early winter (Figure 13, Chapter 1).

*Solitary roost use*--Radio-tagged eagles roosted alone 60% of the time during summer, compared to 50% of the time in spring, 39% in winter and only 21% in fall ( $n$  = 86,  $\chi^2$  = 7.86, 3 df,  $P$  = 0.049). In general, solitary sites were more widely dispersed than communal sites, especially on the ES (Figure 12).

## **Vegetative Characteristics-Trees**

We identified 117 roost trees at 14 communal sites, including 44 trees used strictly in summer, 57 trees used strictly in winter, and 16 trees used during both seasons. We identified 16 solitary roost trees, including 11 trees in summer, 1 tree in fall, and 4 trees in winter.

Roost trees were much larger (dbh and height) than random trees and occurred in stands with greater canopy height than did random trees ( $P$  < 0.0001, Table 14). The average roost tree crown

extended 4.5 m above the canopy, compared to 1.2 m for random trees ( $P = 0.0001$ ). Roost trees were more accessible than random trees ( $P = 0.01$ ), but had greater canopy cover ( $P < 0.0001$ ). Distance to edge was comparably small for both roost and random trees ( $P = 0.35$ ) and stand density also did not differ ( $P = 0.83$ ).

Beeches, oaks and yellow poplars were used most frequently at roosts (73.3%) but occurred most frequently at only 17.7% of random sites ( $P < 0.001$ , Table 15). In most cases, it appeared that eagles selected roost tree species that typically grow very large with accessible branches, at least in mature trees. Random tree species, in contrast, included other species, such as red maple (*Acer rubrum*) (9.8% of random trees) which do not grow as large (Brown and Brown 1972) or younger stands of species with similar growth potential. Snags were used at 46.7% of roost sites while they occurred at only 14.5% of random sites ( $P < 0.001$ , Table 15).

Summer communal roost trees, on average, extended farther above the canopy, occurred in stands with lower canopies, and were more accessible than winter trees ( $P = 0.009, 0.01, 0.05$ , respectively). I detected no differences in tree diameter or height, canopy cover, distance to edge, stand density, dominant species used or snags present for summer versus winter communal roost trees ( $P > 0.05$ , Tables 14 and 15).

Solitary roost trees were shorter, occurred in stands with lower canopies and greater stand density than communal roost trees ( $P = 0.039, 0.018, 0.019$ , respectively, Table 14). I detected no differences between solitary and communal roost trees for tree diameter, tree - canopy height, access, canopy cover, distance to edge, dominant species used or snags present ( $P > 0.05$ , Tables 14 and 15).

Summer and winter solitary roost trees did not differ for all variables measured ( $P > 0.05$ , Tables 14 and 15) although ability to discriminate between differences was limited by the small winter solitary roost sample size ( $n = 4$ ).

## Vegetative Characteristics-Sites

More than 75% (25 of 33) of roost sites were within 300 m of some type of water (range = 0 - 790 m) while only 37% (47/127) of random sites were equally close ( $P < 0.0001$ , Table 16, Figure 14). Roosts were closer to Chesapeake Bay ( $P = 0.0004$ ) and to ponds ( $P = 0.0007$ ) than were random points. Roosts and random points were equidistant from rivers, creeks and rills ( $P > 0.05$ , Table 16). Eagles selected roost sites farther from paved roads and buildings than were random points ( $P < 0.0001$ , Table 16). Building density was > 10 times greater within 500 m of random sites than for roosts ( $P < 0.0001$ , Table 16).

Of 33 roost sites, 19 (57.6%) were on public land whereas only 25 of 127 (19.7%) random sites were on public land ( $\chi^2 = 18.86$ , 1 df,  $P < 0.001$ , Table 17). Seven of 14 remaining roosts (50%) occurred on private land on 2 large corporate farms, 1 of which was managed specifically for wildlife. Eagles selected > 10 ha forested blocks for roosts far more often than expected based on availability ( $\chi^2 = 23.96$ , df = 2,  $P < 0.0001$ , Table 17). The smallest forested block in which a roost occurred had an area of 43 ha, whereas 48% of all forested blocks on NCSA had areas <43 ha (Figure 15). All 8 APG roosts occurred in a 5,068 ha forested block; the second largest forest on the NCSA.

I found almost no differences in site characteristics among roost classes except that communal sites were farther from creeks than were solitary sites ( $P = 0.008$ , Table 16) and winter communal roosts tended to be more protected from prevailing winter winds than were summer sites (85% vs. 50% protected from northwest-northeast winds,  $\chi^2 = 3.199$ ,  $P = 0.074$ , Table 17). Eagles selected forested sites for roosting in almost all cases, although solitary sites tended to occur in smaller forest blocks (Figure 15). Eagles never selected roost sites associated with human developed habitats (Table 17).

# *DISCUSSION*

## **Roost Characteristics**

Eagles on the northern Chesapeake selected large, super-canopy trees that were open and accessible for roosting, consistent with results reported elsewhere (Hansen et al. 1980, Steenhof 1980, Anthony et al. 1982, Keister and Anthony 1983, Chester et al. 1990). Roost trees used were all deciduous similar to midwestern roosts (Southern 1963, Lish 1973, Griffin 1978, Steenhof 1980), but unlike western roosts where conifers predominate (Swisher 1964, Edwards 1969, Hansen et al. 1980, Anthony et al. 1982, Keister and Anthony 1983), except in some riparian zones (Shea 1973, Servheen 1975). Nye (1977) reported use of white pine (*Pinus strobus*) in New York roosts and Chester et al. (1990) reported use of loblolly pine (*Pinus taeda*) in 1 North Carolina roost but dead hardwoods at another. Relative use of snags or decadent trees (22.6% of all roost trees) fell in about the middle of the range of values reported elsewhere: 9%, Klamath Basin, Keister and Anthony (1983); 18%, Colorado, Harmata (1984); 34%, Missouri River, Griffin (1978); 42% dead or dead branches, Oklahoma, Lish (1973).

Differences between summer versus winter communal roost tree height, canopy height, access and protection for prevailing winds suggest eagles selected more protected trees in winter, possibly for heat conservation (Chapter 4). Summer trees, in contrast, were super-canopy and more accessible (exposed), possibly for cooling from summer heat. Eagle perch heights were consistent with this hypothesis, with perch height 2.7 m above canopy height in summer versus 3.3 m below canopy height in winter ( $n = 3, 8, P = 0.024$ ).

The tendency for roosts to be located close to water reflected eagle use of aquatic areas for foraging. Selection of sites relatively close to the bay reflected eagle focus on the bay as their primary unit of habitat, supplemented by other more limited aquatic areas. Roosts were more closely associated with ponds apparently because they offered alternative foraging opportunities

(waterfowl and fish). Both roost and random sites were, on average, close (< 6 km) to all types of aquatic habitat, compared to distances > 10 km often travelled in western states from roosts to foraging areas (Swisher 1964, Edwards 1969, Hansen et al. 1980, Harmata 1984, Keister and Anthony 1987). Most of these aquatic habitats could be considered potential eagle foraging areas for most of the year.

NCSA eagles selected roost sites away from houses and roads, consistent with human avoidance behavior associated with roosts reported elsewhere (Harmata 1984, Hansen et al. 1980, Lish 1973). Others have noted eagle sensitivity to human activity and development at nest sites and foraging areas (Stalmaster and Newman 1978, Andrew and Mosher 1982, Wallin and Byrd 1984, Fraser 1984, Knight and Knight 1984, Fraser et al. 1985, McGarigal 1988, Smith 1988, Chapter 2). Strong selection for roosts on public land, excluding municipal areas, also may be related to human avoidance. Military reserves and state parks have protected mature coastal forests and limited human development (roads and buildings). Private land was more often in more intensive cultivation or human development.

Eagles selected sites in relatively large forested blocks but adjacent to large open corridors, similar to Stalmaster et al.'s (1979) observation that roosts in western Washington were adjacent to clearings. These corridors may be important for providing access to roost sites given the eagles' limited flight agility.

## **Relationship among Eagle Roost Site Selection, Roosting Behavior and Food**

It is unclear what the underlying basis was for roost site selection. Stalmaster and Gessaman (1984) reported that Washington eagles saved energy by selecting conifer sites within 3.88 km of foraging areas, rather than roosting in closer deciduous stands, suggesting that minimizing nightly energy expenditure was driving roost site selection. Keister et al. (1985), however, reported that Klamath basin eagles selected distant, coniferous roost sites that were more protected than the



exposed foraging areas, but the overall energy savings at these sites did not offset the cost of flying there. This suggests that protection from rare, unpredictable, catastrophic (survival-reducing), winter weather may be more important than minimizing nightly energy expense on most nights. The long distances eagles travelled in western states to reach conifer roost sites in Utah, 28.7 km one-way, Edwards (1969); Colorado, 9.6 km and 20.0 km, Harmata (1984); Klamath basin, > 10 km, Keister et al. (1985) tend to support this hypothesis. In ideal sites, such as Washington, both energy conservation and protection from catastrophic weather may be obtained from the same site.

Very limited stands of small Virginia pine (*Pinus virginiana*) and larger loblolly pine occurred on NCSA. Opportunities to roost in conifers would, in most cases, require energy costly flights. In Chapter 4, I examine roost microclimate and determine whether energetic relationships demonstrated for western roosts apply on the Chesapeake.

Hansen et al. (1980), McClelland et al. (1981), and Knight and Knight (1983) have proposed that communal roosting behavior by bald eagles in winter occurs to facilitate information exchange in response to a scarce, clumped food supply, following Ward and Zahavi's (1973) information-food center hypothesis. I observed seasonal changes in the frequency of communal roosting that were consistent with this hypothesis. In summer, eagles roosted alone most often (60% of tracked eagles). Summer roosts (primarily solitary) were more dispersed across NCSA than winter sites (primarily communal) (Figure 12). In fall, eagles roosted solitarily least often (21% of tracked eagles), consistent with Mersmann's (1989) finding that the fall had the lowest food availability of the year. I hypothesize, then, that a more abundant, dispersed prey base in summer encouraged eagles to use a larger portion of NCSA than in other seasons and negated the need for information gained in communal settings. Thermo-energetic pressure in summer probably favors exposed sites, (Chapter 4), which also may have contributed to the more dispersed roosting pattern. In other seasons, eagles typically roosted communally, in more protected sites, apparently in association with a more limited and clumped prey base.

Roost behavior on northern Chesapeake was different than that described for eagles roosting in middle and western United States because solitary roosting was so prevalent, although primarily

in summer. Except for Southern (1964), there are no reports elsewhere of extensive solitary roosting. This may be largely explained by the fact that most studies were conducted in winter, when communal roosting may be most common and because most studies focused on known roost sites rather than on tracking eagles to roosts.

# CHAPTER 4: MICROCLIMATE OF BALD EAGLE WINTER ROOSTS

## *INTRODUCTION*

Bald eagles select communal roost sites that have unique vegetative characteristics (Chapter 3, Southern 1963, Swisher 1964, Edwards 1969, Jonen 1973, Lish 1973, Shea 1973, Servheen 1975, Nye 1977, Griffin 1978, Hansen et al. 1980, Steenhof et al. 1980, Anthony et al. 1982, Keister and Anthony 1983, Harmata 1984, Sabine and Klimstra 1985, Keister et al. 1987, Chester et al. 1990). In winter, protected roost sites could contribute positively to an eagle's energy balance if they occurred close to foraging areas. Two previous studies of roost energetics in the northwest United States have produced different results. In Washington, eagles roosted in protected inland coniferous sites rather than at deciduous sites located adjacent to foraging areas which appeared to yield energy savings that exceeded the flight costs to the conifer roosts (Stalmaster and Gessaman 1984). In the Klamath basin, Oregon-California, energy savings at communal roost sites apparently did not offset the cost of flying to the site from foraging areas (Keister et al. 1985). In both cases, however, coniferous roost sites yielded lower eagle nightly heat budgets than at more exposed foraging areas.

Eagle roosting habits on the northern Chesapeake Bay were different from those reported above because eagles used only deciduous trees for roosting, and roosted close ( $\bar{x} = 0.18$  km) to foraging areas (Chapter 3). Northern Chesapeake eagle roost behavior was similar to that reported elsewhere, in that eagles selected protected winter roost trees and sites, compared to those used in summer. Roost energetics may differ from those studied at western sites, however, because of the lack of conifers and the lack of substantial topographic relief which could provide great microclimatic variability. Eagle management strategies also may differ because the importance of roost sites in an eagle's energy balance on the Chesapeake may differ from that reported in the West. For these reasons, I studied northern Chesapeake bald eagle roost microclimate to determine whether roost sites in winter were energetically more favorable for bald eagles than eagle shoreline perch sites and randomly-selected inland forested sites.

## ***METHODS***

*Roost, Shoreline Perch and Random Sites*--We located roost sites during 1984-89 by tracking radio-tagged eagles until they roosted in the evening (Chapter 3). I selected for microclimate study 3 communal roosts on APG that were used by birds foraging on the Chesapeake Bay and Romney Creek; 1 site (APG-1) was a year-round roost, another (APG-2) was a summer roost and the third (APG-4) was a winter roost. They were located 1.76 km, 0.82 km and 1.59 km from their closest access to Romney Creek, respectively, and 2.89 km, 2.24 km and 1.00 km from the Chesapeake Bay. At each site, I selected for monitoring 4 regularly-used roost trees that were dispersed throughout the site to ensure that a representative array of microclimate conditions would be present in the roost sample. I randomly selected for microclimate monitoring 2 of 8 Chesapeake Bay shoreline perch trees identified within 3 km of all 3 roosts and 2 of 12 Romney Creek shoreline perch trees identified from tracking radio-tagged eagles in the foraging areas. For comparison, we

monitored the microclimate at 4 randomly-selected continuous-canopy forested sites within 3 km of the foraging areas that had trees within the range of roost tree heights (15.5 m - 46.6 m).

*Microclimate Monitoring*--To monitor wind speed, we used 3-cup anemometers with  $\pm 1.5\%$  accuracy and minimum wind speed detection of 0.22 m/s (Campbell Scientific, Inc., Logan, UT). To monitor temperature, we used thermistor probes,  $\pm 0.4$  °C accuracy (Campbell Scientific, Inc., Logan, UT). To monitor net long-wave radiation, we used net radiometers,  $\pm 10\%$  accuracy (Radiation Energy Measurement Systems, Seattle, WA). We mounted all sensors on a custom frame, and suspended the frame from a tree limb 20-25 m above the ground, within the range of heights eagles roosted at on the northern Chesapeake (Chapter 3). We used Campbell Scientific CR10 modules to record sensor output every 6 seconds, to compute averages for input variables every 2 minutes, and to output the average values to a storage module. Data were recorded for 7-day intervals, then uploaded to a computer for statistical analysis. I used only data collected between sunset and sunrise for analysis because this was the primary time eagles spent in the roost (Buehler et al. unpubl. data).

I monitored the microclimate at a perch and random tree pair for 21 days while sampling 1 tree at each of the 3 communal roosts for 7 days each. At the end of the 21 day period, I randomized the monitoring instruments and placed them in a new set of roost, perch and random trees for another 21 day sample.

*Eagle Nightly Energy Requirements*--I used Keister et al.'s (1985:150-153) heat budget model as detailed in Keister (1981), to estimate metabolic heat production rates and total energy that could have been expended by an eagle for each sampling night spent in a roost, a shoreline perch and a randomly-selected forested site. (See Table 18 for definitions of variables used in the model). The Keister et al. (1985) model was similar to earlier models developed for mammals and birds (Monteith 1973, Calder and King 1974, Robinson et al. 1976, Hayes and Gessaman 1980, Walsberg and King 1980).

Keister et al. (1985) started with the underlying assumption that eagles existed in a state of equilibrium in which their body temperature was 40°C and did not fluctuate significantly, such that heat gained by an eagle equalled heat lost. Primary sources of heat were metabolic production (M)

and stored heat (J). Heat losses occurred through 4 avenues: net radiation ( $R_n$ ), which equalled radiation absorbed from the environment minus radiation emitted, convection (C) from free and forced air (wind) processes, conductance ( $G_2$ ) through the feet to the perch, and evaporative heat loss (HE):

$$J + M = R_n + C + G_2 + HE. \quad \text{Eq. 1}$$

Because body temperature was assumed to be constant,  $J = 0$ . Keister et al. (1985) further assumed that  $HE = 0.10 M$ , from Robinson et al. (1976) and arbitrarily assumed that  $G_2 = 0.02M$ , because conductance was thought to be an insignificant but positive ( $> 0$ ) source of heat loss. This reduced Eq. 1 to

$$0.88M = R_n + C. \quad \text{Eq. 2}$$

To estimate radiation lost by the bird, Keister et al. (1985) derived a radiation balance relationship, such that

$$R_n = -R_m + eS(T_s^4 - T_a^4), \quad \text{Eq. 3}$$

where  $-R_m$  = net radiation measured by the radiometer,  $e$  = Stephen-Boltzmann constant ( $5.67 \times 10^{-8} \text{W/m}^2\text{°K}$ ),  $S$  = surface area of eagle,  $T_s$  = temperature at surface of eagle and  $T_a$  = ambient temperature. This relationship was substituted back into Eq. 2 to yield

$$0.88M = -R_m + eS(T_s^4 - T_a^4) + C. \quad \text{Eq. 4}$$

To derive convective heat loss relationships, Keister et al. (1985) used electric circuit analogues, as suggested by Bakken (1976) and Robinson et al. (1976). In this derivation, heat transfer resistances

were used instead of thermal conductances. The basic relationship used, from Monteith (1973), was

$$C = dC_p (T_s - T_a)/r_h, \quad \text{Eq. 5}$$

where  $d$  = density of air,  $C_p$  = specific heat of air (1010 J/Kg-K), and  $r_h$  equalled resistance to convective heat loss.

The radiative heat loss also was put in resistance terms, Monteith (1973), such that

$$eS(T_s^4 - T_a^4) = dC_p(T_s - T_a)/r_r, \quad \text{Eq. 6}$$

where  $r_r$  equalled the resistance to radiative heat loss. Substituting Eqs. 5 and 6 back into Eq. 4 led to

$$0.88M = -R_m + dC_p(T_s - T_a)/r_{hr}, \quad \text{Eq. 7}$$

where the resistances are in parallel such that  $1/r_{hr} = 1/r_r + 1/r_h$ . Keister et al. (1985) simplified Eq. 7 by introducing a new term, defined as the effective temperature the eagle was exposed to

$$T_e = T_a + R_m(r_{hr})/dC_p, \quad \text{Eq. 8}$$

solved for  $T_a$ , and substituted Eq. 8 into Eq. 7, which resulted in

$$0.88M = dC_p(T_s - T_e)/r_{hr}. \quad \text{Eq. 9}$$

Because  $T_s$  was difficult to measure in the wild, it was replaced by another relationship derived by Monteith (1973)

$$G_1 = dC_p(T_b - T_s)/r_b \quad \text{Eq. 10}$$

where  $G_1$  = conductance of heat from the body of the bird to the surface layer,  $T_b$  = the core temperature of the bird and  $r_b$  = resistance to heat loss through the skin-feather layer. Because the heat loss through the feathers at the surface must equal the heat loss from the body to the feathers

$$G_1 = 0.88M \quad \text{Eq. 11}$$

which when substituted into Eq. 10 and solved for  $T_s$  led to

$$T_s = T_b - r_b(0.88M)/dC_p \quad \text{Eq. 12}$$

Eq. 12 was then substituted into Eq. 9 and terms were rearranged.

$$0.88M = dC_p(T_b - T_e)/(r_{hr} + r_b) \quad \text{Eq. 13}$$

Keister et al. (1985) converted Eq. 13 from  $W/m^2$  to kcal/hr by multiplying by the eagle surface area ( $A$ ) and by the units conversion factor of 1.163 W/kcal/hr, which resulted in

$$M = 0.977AdC_p(T_b - T_e)/(r_{hr} + r_b) \quad \text{Eq. 14}$$

Eq. 14 was the basic relationship used for calculating metabolic heat production rates. The resistance terms ( $r_b$ ,  $r_r$ , and  $r_s$ ) were estimated from relationships developed in Monteith (1973). The resistance to heat loss through skin and feathers ( $r_b$ ) was the most important of the resistance terms (Robinson et al. 1976) and was comprised of resistance of the feathers ( $r_f$ ) plus resistance of the vaso-constricted skin ( $r_s$ ). Keister et al. (1985) estimated  $r_f = 836 \text{ s/m}$ , assuming that Monteith's (1973) value of  $r_f$  for red fox (*Vulpes vulpes*) fur was similar to that for eagle feathers.



Keister et al. (1985) estimated  $r_t = 80$  s/m, assuming that the value for eagles was less than that reported by Monteith (1973) for several larger mammals. Based on this

$$r_b = r_f + r_t = 836 + 80 = 916 \text{ s/m.} \quad \text{Eq. 15}$$

Because Robinson et al. (1976) determined that  $r_b$  varied with wind speed, Keister modified Robinson et al.'s (1976) regression equation developed for the white-crowned sparrow (*Zonotrichia leucophrys gambelii*) to

$$r_b = 916 - 32U^{0.5}, \quad \text{Eq. 16}$$

correcting the slope of the equation for the difference in feather thickness between eagles (2.54 cm) and sparrows (1 cm). Density of air was estimated from Monteith (1973),  $(d) = 1.2924 - 0.00466(T_a - 273.16)$ . The key components driving the heat budget model, then, were eagle surface area, the difference between the eagle's body temperature and the effective environmental temperature, and the eagle's resistance to heat transfer (loss), related to the insulative properties of its skin and feathers.

I calculated the mean metabolic heat production rate (M) (kcal/hr) over every 2 minute period of each night. Energy expended per 2 minute period was calculated by multiplying M by the time period (2/60 of an hour). I calculated the total energy (TE) expended per night by summing all 2-minute energy increments.

*Statistical Analyses*-- I used  $\chi^2$  approximations to the Kruskal-Wallis test to test for differences in microclimate and heat budget parameters among roost, shoreline and random sites on  $n = 126$  nights, because most of the variables were non-normally distributed (Kolomogorov test,  $P < 0.05$ ). I tested the nightly mean temperature (average of all 2 minute mean temperatures per night), the nightly mean wind speed (average of all 2 minute mean wind speeds per night), the nightly mean net radiation (average of all 2 minute mean net radiations per night), the nightly mean metabolic rate (average of all 2 minute mean metabolic rates), and the total nightly energy (nightly

sum of the 2 minute mean metabolic production rates multiplied by the time interval). I tested the the nightly minimum 2 minute mean temperature, the nightly maximum 2 minute mean wind speed, the nightly minimum 2 minute mean net radiation, and the nightly maximum 2 minute mean metabolic production rate for differences among sites for microclimate and heat budget extremes. If the Kruskal-Wallis test was significant ( $P < 0.05$ ), I used Wilcoxon rank-sum analyses for pair-wise comparisons. I conducted similar analyses for each individual roost and for the shoreline and random sites that were monitored simultaneously ( $n = 42$  nights); and compared the 3 roost sites against each other. Because the roosts weren't monitored simultaneously, I also compared shoreline and random points as controls for these sample periods.

To test for effects of extreme weather, I tested for differences among roost, shoreline and random sites for the 10 lowest mean shoreline temperature nights of winter, the 10 greatest mean shoreline wind nights, the 10 lowest mean net radiation nights and the 10 nights with the greatest mean shoreline metabolic heat production rates.

I used assumptions about flight cost similar to Stalmaster and Gessaman (1984) (flight speed = 45 km/hr, energy for flapping flight =  $12.5 \times$  basal metabolic rate (BMR), energy for soaring flight =  $3.5 \times$  BMR, BMR = 12.47 kcal/hr and flight to and from roosts is 50% flapping and 50% soaring flight) to estimate how much energy an eagle would expend to fly back to the roost sites rather than roosting on the shoreline. I added these values into total nightly energy expended and compared total nightly energy for roosts versus shoreline perches again using a Wilcoxon rank-sum test.

To test the sensitivity of the heat budget model to changes in input parameters, I used the average nightly roost values for temperature, wind speed and net radiation to calculate an average nightly metabolic heat production rate. I then varied temperature by  $\pm 25\%$  and recalculated the heat production rate to determine how it changed relative to the original value, and repeated this analysis for wind speed and net radiation. I also varied eagle body temperature, surface area and body resistance by  $\pm 5\%$  separately, while holding all other variables constant to determine the effects of these model inputs on the heat production rate.

Some of the relationships used in the heat budget model have been tested for other species (Robinson et al. 1976) and have been shown to agree fairly well with laboratory-measured values. No direct field verification, however, has been done on the predicted value for the metabolic heat production rate. Therefore, results from the model should be interpreted with caution.

## ***RESULTS***

### **All Roost, Shoreline and Random Microclimate**

*Roost versus shoreline versus random*--Nightly temperature over the winter ranged from -8.31 °C to 20.00 °C (Figure 16). Most nights (118/126 of roost nights, 93.7%) had mean temperatures below the lower limit of the thermal neutral zone for bald eagles of 10.6 °C (Stalmaster and Gessaman 1984). Nightly mean and minimum roost, shoreline and random site temperatures did not differ, ( $P = 0.79, 0.64$ , respectively, Table 19). Mean nightly winds ranged from 0.22 m/s - 7.54 m/s (Figure 17). Mean wind speed varied among sites ( $\chi^2 = 19.76, 2$  df,  $P = 0.0001$ , Kruskal-Wallis test, Table 19). Shoreline winds were greatest, whereas roost and random sites did not differ ( $\bar{x} = 1.79$  m/s, 1.33 m/s and 1.23 m/s, respectively, Table 19), based on Wilcoxon paired rank-sum tests. Maximum wind speed also varied among sites ( $\chi^2 = 32.05, 2$  df,  $P = 0.0001$ ), and was greatest along the shoreline; roost and random sites again did not differ ( $\bar{x} = 4.15$  m/s, 3.19 m/s and 2.89 m/s, respectively). Mean nightly net radiation ranged from -53.03 W/m<sup>2</sup> to 3.00 W/m<sup>2</sup> (Figure 18). Mean net radiation varied among sites ( $\chi^2 = 7.23, 2$  df,  $P = 0.027$ , Table 19). Random site mean net radiation was greater than net radiation at shoreline sites ( $\bar{x} = -17.42$  W/m<sup>2</sup>, -22.01 W/m<sup>2</sup>, respectively, Table 19). Minimum net radiation differed among sites ( $\chi^2 = 21.00, 2$  df,  $P = 0.0001$ , Table 19). Roost and shoreline minimum net radiation

were less than net radiation at random sites ( $\bar{x} = -32.00 \text{ W/m}^2, -33.42 \text{ W/m}^2, -27.21 \text{ W/m}^2$ , respectively, Table 19).

*Individual roost versus shoreline versus random sites*--Mean and minimum nightly temperatures did not differ among individual roosts and the simultaneously-monitored shoreline and random sites ( $P = 0.78, 0.64$ , mean and minimum temperature, respectively, year-round roost,  $P = 0.95, 0.91$ , summer roost, and  $P = 0.89, 0.82$ , winter roost, Table 19).

Mean nightly winds were different among the year-round roost, shoreline and random sites ( $\chi^2 = 6.98, 2 \text{ df}, P = 0.03$ , Table 19). Shoreline mean winds were greater than year-round roost and random sites ( $\bar{x} = 1.98 \text{ m/s}, 1.38 \text{ m/s}, 1.34 \text{ m/s}$ , respectively, Table 19). Maximum nightly winds differed among the year-round roost, shoreline and random sites ( $\chi^2 = 10.86, 2 \text{ df}, P = 0.004$ , Table 19). Shoreline maximum winds were greater than year-round roost and random site maximum winds ( $\bar{x} = 4.51 \text{ m/s}, 3.27 \text{ m/s}, 3.07 \text{ m/s}$ , respectively, Table 19).

Mean nightly winds differed among the summer roost, shoreline and random sites ( $\chi^2 = 9.07, 2 \text{ df}, P = 0.011$ , Table 19). Shoreline mean winds were greater than random site mean winds but shoreline mean winds did not differ from summer roost mean winds. Summer roost mean winds did not differ from random site winds ( $\bar{x} = 1.75 \text{ m/s}$  [shore],  $1.50 \text{ m/s}$  [roost],  $1.15 \text{ m/s}$  [random], Table 19). Similarly, maximum nightly winds differed among the summer roost, shoreline and random sites ( $\chi^2 = 11.01, 2 \text{ df}, P = 0.004$ , Table 19). Shoreline maximum winds were greater than random site maximum winds, but shoreline maximum winds did not differ from summer roost maximum winds and summer roost maximum winds did not differ from random site maximum winds ( $\bar{x} = 4.10 \text{ m/s}, 3.49 \text{ m/s}$  [roost],  $2.87 \text{ m/s}$ , respectively, Table 19).

Mean nightly winds differed among the winter roost, shoreline and random sites ( $\chi^2 = 8.15, 2 \text{ df}, P = 0.017$ , Table 19). Shoreline mean winds were greater than winter roost and random site mean winds ( $\bar{x} = 1.62 \text{ m/s}, 1.11 \text{ m/s}, 1.20 \text{ m/s}$ , respectively, Table 19). Maximum nightly winds differed among the winter roost, shoreline and random sites ( $\chi^2 = 13.26, 2 \text{ df}, P = 0.001$ , Table 19). Shoreline maximum winds were greater than winter roost and random site maximum winds ( $\bar{x} = 3.84 \text{ m/s}, 2.83 \text{ m/s}, 2.72 \text{ m/s}$ , respectively, Table 19).

Mean nightly net radiation did not differ among any individual roosts and the shoreline and random sites ( $P = 0.49$ , year-round roost,  $P = 0.14$ , summer roost,  $P = 0.15$ , winter roost, Table 19). Minimum nightly net radiation did not differ among the year-round roost, shoreline and random sites ( $P = 0.20$ , Table 19). Minimum nightly net radiation differed among the summer roost, shoreline and random sites ( $\chi^2 = 11.58$ , 2 df,  $P = 0.003$ , Table 19). Random site minimum net radiation was greater (smaller negative value) than summer roost and shoreline site radiation ( $\bar{x} = -26.39 \text{ W/m}^2$ ,  $-34.39 \text{ W/m}^2$ ,  $-33.66 \text{ W/m}^2$ , respectively, Table 19). Minimum nightly net radiation differed also for the winter roost, shoreline and random sites ( $\chi^2 = 10.82$ , 2 df,  $P = 0.005$ , Table 19). Random site minimum net radiation was greater than summer roost and shoreline site radiation ( $\bar{x} = -30.05 \text{ W/m}^2$ ,  $-33.12 \text{ W/m}^2$ ,  $-36.09 \text{ W/m}^2$ , respectively, Table 19).

*Comparisons among roosts*--Mean and maximum nightly temperature did not differ among the 3 roosts ( $P = 0.29$ ,  $0.34$ , Table 19). Mean winds differed among roosts ( $\chi^2 = 7.83$ , 2 df,  $P = 0.02$ , Table 19). The summer roost mean winds were greater than winter roost winds, but did not differ from year-round roost winds ( $\bar{x} = 1.50 \text{ m/s}$ ,  $1.11 \text{ m/s}$ ,  $1.38 \text{ m/s}$ , respectively, Table 19). Maximum nightly winds also differed among roosts ( $\chi^2 = 8.69$ , 2 df,  $P = 0.013$ , Table 19). The summer roost maximum winds were greater than winter roost winds, but did not differ from year-round roost winds ( $\bar{x} = 3.49 \text{ m/s}$ ,  $2.83 \text{ m/s}$ ,  $3.27 \text{ m/s}$ , respectively, Table 19). Nightly mean net radiation differed among roosts ( $\chi^2 = 8.69$ , 2 df,  $P = 0.013$ , Table 19). The year-round roost mean net radiation was greater than summer and winter roost net radiation ( $\bar{x} = -15.52 \text{ W/m}^2$ ,  $-21.94 \text{ W/m}^2$ ,  $-23.01 \text{ W/m}^2$ , respectively, Table 19). Nightly minimum net radiation also differed among roosts ( $\chi^2 = 7.27$ , 2 df,  $P = 0.026$ , Table 19). The year-round roost mean net radiation was greater than summer roost net radiation, whereas winter roost net radiation did not differ from either year-round or summer roosts ( $\bar{x} = -28.49 \text{ W/m}^2$ ,  $-34.39 \text{ W/m}^2$ ,  $-33.12 \text{ W/m}^2$ , respectively, Table 19).

Similar separate analyses of shoreline and random sites showed no differences for the 3 sampling periods for mean and minimum temperature, mean and maximum wind and mean and minimum net radiation variables ( $P > 0.05$ ) with the exception that mean net radiation differed among the random sites ( $P = 0.029$ ).

## Eagle Heat Budgets

*All roosts versus shoreline versus random sites*--Considering all sites, there was no evidence of differences in mean metabolic heat production rates among roost, shoreline and random sites ( $P = 0.64$ , Table 20, Figure 19). Maximum metabolic rates also were not different among sites ( $P = 0.55$ , Table 20, Figure 19). Similarly, total nightly energy expended did not differ ( $P = 0.68$ , Table 20, Figure 20) among roost, shoreline and random sites.

*Individual roost versus shoreline versus random sites*--On an individual roost basis, mean metabolic production rates did not differ for the year-round roost, and the shoreline and random sites ( $P = 0.87$ , Table 20). Maximum metabolic rates also were not different among sites ( $P = 0.82$ , Table 19), and total nightly energy did not differ ( $P = 0.91$ , Table 20).

There was no evidence of differences among the summer roost, shoreline and random sites for mean metabolic production rates ( $P = 0.77$ , Table 20). Maximum metabolic rates and total nightly energy also did not differ among sites ( $P = 0.83, 0.76$ , respectively, Table 20). Mean and maximum metabolic production rates, and total nightly energy expended did not differ for the winter roost, shoreline and random sites ( $P = 0.82, 0.69, 0.87$ , respectively, Table 20).

*Comparisons among roosts*--There was no evidence of differences in mean and maximum metabolic production rates, and total nightly energy expended among year-round, summer and winter roosts ( $P = 0.23, 0.25, 0.23$ , respectively, Table 20). Mean and maximum metabolic rates, and total energy were not different for shoreline sites during the 3 sampling periods ( $P > 0.05$ ), and mean and maximum metabolic rates and total energy did not differ for random sites during the 3 sampling periods for random sites ( $P > 0.05$ ).

*Extreme Nights*--Mean and maximum metabolic rates and total energy expended among all roost, shoreline and random sites on the 10 coldest temperature nights of winter did not differ ( $P = 0.57, 0.64, \text{ and } 0.57$ , respectively, Table 21). Mean and maximum metabolic rates and total energy expended were not different for roost, shoreline and random sites on the 10 windiest nights ( $P = 0.76, 0.86, \text{ and } 0.79$ , respectively, Table 21). Mean and maximum metabolic rates and total

energy expended were not different for roost, shoreline and random sites on the 10 lowest net radiation nights ( $P = 0.63, 0.78, \text{ and } 0.77$ , respectively, Table 21). Mean and maximum metabolic rates and total energy expended were not different for roost, shoreline and random sites on the 10 nights with the highest metabolic rates ( $P = 0.56, 0.65, \text{ and } 0.68$ , respectively, Table 21).

*Flight Cost Effects*--At 2.22 kcal/km of flight to roost, eagles expended 7.96 kcal to reach the year-round roost (round-trip) from the closest foraging area (Romney Creek), 3.61 kcal to reach the summer roost from Romney Creek, and 4.44 kcal to reach the winter roost from the bay shoreline. When these values were added into the total nightly energy expended, mean nightly energy for the year-round roost still did not differ from total energy at shoreline sites ( $\bar{x} = 202.70 \text{ kcal}, 195.96 \text{ kcal}$ , respectively,  $P = 0.25$ ). Similarly, summer roost nightly energy increased to 212.55 kcal, but not significantly over the 208.55 kcal expended at the shoreline site ( $P = 0.63$ ). Winter roost nightly energy increased to 204.74 kcal, still not different from the 202.15 kcal expended at the shoreline site ( $P = 0.69$ ).

*Sensitivity Analysis*--Changes in the ambient temperature, wind speed and net radiation had relatively little effect on the metabolic heat production rates; 25% changes in input parameters led to  $\bar{x} = 2.17\%, 0.76\% \text{ and } 0.91\%$  changes in metabolic heat production rates, respectively (Table 22). Other key input variables in the model (body temperature, surface area and body resistance) had a more linear and proportional effect on metabolic heat production; 5% changes in input parameters led to  $\bar{x} = 5.22\%, 5.00\% \text{ and } 4.55\%$  changes in metabolic heat production rates, respectively (Table 22).

## ***DISCUSSION***

Northern Chesapeake mean roost temperature, wind speed and net radiation appeared to be slightly greater than comparable values for a deciduous roost site in western Washington (2.97°C,

1.33 m/s, -20.16 W/m<sup>2</sup>, this study vs. 0.1°C, 0.60 m/s, -22.0 W/m<sup>2</sup>, Stalmaster and Gessaman 1984). Keister et al. (1985) reported minimum nightly temperature ranged from -14.9 to 8.0 °C in the Klamath Basin, colder than the northern Chesapeake range of minimum roost temperatures (-12.42 to 17.23 °C), whereas Klamath maximum nightly winds were less severe; 0.73 - 2.5 m/s at 2 conifer roosts, and 0.73 - 6.9 m/s at 2 other conifer roosts versus 1.03 - 9.35 m/s at northern Chesapeake roosts. Keister et al. (1985) did not report mean temperatures, mean wind speeds or any net radiation to allow comparison with northern Chesapeake results. Almost all of the northern Chesapeake nights (93.7%) had mean temperatures below 10.6 °C, the lower limit of the thermal neutral zone for bald eagles (Stalmaster and Gessaman 1984). Mean temperatures, however, usually were above the threshold level reported for cold stress in the cold-sensitive American kestrel (*Falco sparverius*) (-5°C and 4.47 m/s winds) and well above the conditions reported to have no effect on red-tailed hawks (*Buteo jamaicensis*) and golden eagles (*Aquila chrysaetos*) (-17 °C, 13.47 m/s wind and 0.0 W/m<sup>2</sup> net radiation, Hayes and Gessaman 1980).

Wind speeds were greater on the shoreline than at roosts or random sites. Wind speeds also were greater in the summer roost site than in the winter roost site and intermediate in the year-round site. This is consistent with the finding (Chapter 3) that northern Chesapeake winter roost sites were protected from prevailing (northwest - northeast) winter winds, whereas summer sites were not. This also is consistent with wind speed moderation in winter roost sites reported by Hansen et al. 1980, Stalmaster and Gessaman (1984) and Keister et al. (1985) and with general observations made by others for winter roost sites (Edwards 1969, Jonen 1973, Steenhof 1976, Nye 1977, Griffin 1978, Harmata 1984, Sabine and Klimstra 1985).

Differential wind speeds may explain why eagles abandoned use of the summer sites in winter (selection for wind protection) and possibly why they abandoned winter sites in summer (selection for wind exposure for cooling). Ambient temperatures 28°C to 30 °C with no wind induced panting in American kestrels, red-tailed hawks and golden eagles, whereas 34 °C with no wind induced thermal stress in all 3 species, including mortality of 1 bird (Hayes and Gessaman 1980). Maximum summer night-time roost temperatures on the northern Chesapeake were within the 28 °C to 30°C



range on 26% of the nights and exceeded 30°C on about 14% of the nights with a summer peak night-time temperature of 32.76 °C, approaching the level reportedly inducing thermal stress. I observed behavioral responses to summer night-time temperatures, including eagles panting and holding wings out-stretched, apparently to aid evaporative, convective and radiative heat transfer.

Assuming the heat budget model accurately predicted metabolic heat production rates, bald eagle winter roost-site selection on the northern Chesapeake did not appear to be a mechanism to conserve thermal energy because nightly heat budgets at the 3 roost sites monitored were not different from those monitored at eagle foraging-area perch sites. Because roosts were close ( $\leq 1.76$  km) to foraging areas, the additional energy expense of flying to and from the roost did not significantly increase the eagle nightly energy budgets, compared to those measured at shoreline perches. The relatively close distances also minimized the potential effects of any error in modeling flight energy costs, compared to error potential for eagles flying to the much more distant western roosts. Stalmaster and Gessaman (1984) also detected no significant difference between foraging area nightly heat budgets, measured along a western Washington river and heat budgets measured at nearby deciduous roost sites during winter. Stalmaster and Gessaman (1984) did report significant energy reduction at more distant conifer roosts. Keister et al. (1985) similarly found reduced energy expenditures at conifer roosts in the Klamath Basin on the Oregon-California border in winter, but not enough to offset the energy cost associated with flying to and from the roosts, partly because the roosts were  $> 10$  km from the foraging areas. Eagles on the northern Chesapeake did not have alternative conifer sites within maximum reported distances between eagle roost and foraging areas (28.7 km, Edwards 1969), and used deciduous sites exclusively (Chapter 3).

The mean metabolic rates in northern Chesapeake roosts (14.68 kcal/hr) appeared to be lower than the mean rate reported for the mildest roost in the Klamath basin (18.13 kcal/hr, Keister et al. 1985), consistent with the milder temperatures but counter to the greater observed wind speeds and greater net radiative losses observed on the northern Chesapeake. The northern Chesapeake mean metabolic rates appeared to be closer to the mean metabolic rate from western Washington, 15.74 kcal/hr, calculated using Stalmaster and Gessaman's (1984) deciduous roost microclimate data

but Keister et al.'s (1985) heat budget model to ensure comparable results. Northern Chesapeake shoreline microclimate was moderated by open water, which was usually warmer than ambient temperatures. Effects of the warmer shoreline ambient temperatures, however, were partly offset by the effects of greater wind speeds and greater net radiative losses, which increased metabolic heat production requirements and tended to equilibrate shoreline and roost metabolic rates.

It appeared that even on extreme nights (coldest temperature, windiest, lowest net radiation or greatest metabolic rate), roost sites did not provide energy savings compared to shoreline or random sites. It is possible that the heat budget model inaccurately predicted eagle nightly energy expenses if it was biased toward underestimating the effect of wind speeds or radiative energy losses on energy expended, because these were the 2 microclimate inputs that varied among shoreline and roost sites.

In general, winter 1988-89 was relatively mild with ice cover of the bay within the areas monitored limited to only a few days. Although I did not detect a difference in total energy expended on the most extreme nights, it is possible that even more extreme weather could have led to significant total energy differences. Furthermore, my results do not account for any possible survival value of microclimate protection at roost sites in the event of catastrophic winter weather, such as severe blizzards.

Although bald eagle roost sites did not appear to play a critical role in eagle thermal energy conservation in winter, roosts did provide eagles the opportunity to get out of the wind, were close to foraging areas and were undeveloped with little human disturbance (Chapter 3). My results did not consider potential energetic benefits accrued via information-transfer about winter foraging opportunities. It is possible that roost sites were better suited for social interactions toward this end because of a more clumped configuration of trees, compared to possibly a more linear and dispersed distribution of suitable perches along shoreline areas.

My results point to the need to examine summer roost microclimate and bald eagle thermal regulation under summer conditions. It is possible there is more selective pressure on bald eagle roosting behavior in summer, when microclimatic conditions have greater potential for inducing thermo-regulatory stress and affecting survival, than in winter, at least for the Chesapeake and more

southerly regions of the bald eagle's range. This information may be critical to the understanding of bald eagle summer roosting habitat requirements.

# CONCLUSIONS AND MANAGEMENT IMPLICATIONS

## Migratory Effects

Northern Chesapeake bald eagle distribution was seasonally and geographically dynamic, as migratory and resident eagles moved about the Chesapeake in response to changing environmental conditions. Influxes of migratory eagles from northern and southern populations had a marked effect on Chesapeake eagle distribution and abundance (Chapter 1). The movement of migrants into the Chesapeake region and the timing of their departure appeared to be largely independent of Chesapeake regional conditions. Changes in this portion of overall Chesapeake eagle distribution and abundance could occur without any changes in Chesapeake suitability. Most North American eagle populations have similar overlap of resident breeding and nonbreeding and migratory populations, although not perhaps to the extent observed on the Chesapeake. Eagle managers need to target their management efforts for individual groups of eagles using their area, with management priorities set for the group of birds in most need of management action.

## Roost Management

Based on my results, it is possible to develop a roost management prescription, applicable at least to the Chesapeake region. I have identified the minimum and mean habitat requirements for roost trees and sites (Chapter 3) and the microclimatic characteristics (Chapter 4), but it remains unclear what the optimal roost tree and site configuration would be. By managing for conditions in excess of the minimum roost tree and site characteristics used by eagles in communal roosts, it is likely that suitable roost habitat will be created. Given this approach, shoreline zone habitat should be managed for relatively large (> 100 ha) forested blocks, with mature (> 50-cm dbh) oaks, beeches or yellow poplars for the northern Chesapeake. Roost managers elsewhere should select tree species that have maximum growth potential for their region and an open-branching form that allows for eagle access to the tree. Roost sites need to be relatively close to foraging areas and water (< 800 m). Corridors need to be provided into these forested blocks on the leeward side (southeast - southwest) to provide eagle access to protected roost trees for winter roosts. Access also is needed to summer roosts, but, given the potential for thermal stress in summer (Chapter 4), corridors exposing the roost to prevailing summer winds may be optimal. Human development for both winter and summer sites needs to be excluded within 500 m of the site. Human activity also should be either excluded altogether or at least limited to time periods when eagles are not present, generally between 2 hours after sunrise to 2 hours before sunset. Bald eagle roost sites on the northern Chesapeake do not appear to have unique microclimatic characteristics, other than wind protection, that play a critical thermal energy saving role for wintering eagles (Chapter 4). Roost sites in the Chesapeake region, or at similar latitudes elsewhere, then, with adequate vegetative characteristics, also should have suitable microclimatic conditions as long as wind direction is considered. Given this information, proper management of existing sites and possible creation of new sites is possible.

## Shoreline Management

I examined only the impacts of migratory eagle movements, and human activity and shoreline development on eagle distribution specifically in this dissertation. This information, however, in conjunction with foraging ecology data simultaneously collected (Mersmann 1989), indicate that these 3 factors are important determinants of Chesapeake eagle distribution and abundance. Two possible options, from a management perspective, would be to manage for optimal prey distribution and abundance and/or manage the shoreline habitat. Because the Chesapeake is a very rich estuary, food may not be limiting eagle distribution and abundance, except in fall and late winter (Mersmann 1989) and may not be limiting survival significantly. Water quality improvement associated with the Chesapeake clean-up efforts could improve the fish prey base, although increasing populations of predatory fishes, such as striped bass (*Morone saxatilis*), could actually increase competition for prey species in size classes used in common by predatory fishes and eagles. For these reasons, and given the difficulty of prey base management, prey base management may not be fruitful at this time. Managing shoreline habitat, in contrast, may be the single most critical goal for ensuring the future of Chesapeake eagle populations. The present and projected extent of shoreline development and associated human activity on the Chesapeake (Chapter 2) indicate that the current eagle population expansion will in the future be seriously limited by habitat availability. The ultimate eagle population level will be determined by how much habitat is left undeveloped, the eagle carrying capacity of these habitat islands, and how eagle tolerance of marginal, human-disturbed habitat changes in the future as eagle--habitat limitations become more pronounced.

Shoreline habitat needs to be protected to ensure that adequate undisturbed perching areas are preserved in conjunction with good aquatic foraging habitat. My results highlight the need to maintain shoreline habitat for protection of nocturnal roosting areas, because northern Chesapeake roost sites were very close to water. Shoreline protection also is needed adjacent to nest sites to maintain foraging habitat for breeding pairs. Comprehensive effort is needed, then, to maintain a

forested shoreline strip wide enough to include the perch and roost sites and provide a visual barrier from inland human activity and disturbance.

The Maryland Critical Areas Commission developed criteria (Code of Maryland 14.15.02-1986) for limiting human development within a 305 m shoreline management zone, creating resource conservation areas where shoreline development was <1 house/2 ha. New development within these areas cannot exceed 1 house/8 ha. This is the first comprehensive shoreline management legislation, with built-in provisions for wildlife habitat protection and enhancement, applied over a large area in the United States. Virginia also has passed regulations aimed at water quality improvement through shoreline protection (Code of Virginia 10.1-2100-1988), that prohibits new development within 30.5 m of the shoreline in designated resource protection areas. I found significant avoidance of shoreline segments with development within 500 m in all seasons except fall. The Maryland and Virginia shoreline protection zones would provide inadequate protection of shoreline habitat for diurnal eagle activity on this basis.

Maryland's 305 m zone would encompass 76% of northern Chesapeake roosts if they occurred in designated resource conservation areas. The zone would allow development, however, far in excess of the development density observed within 500 m of northern Chesapeake roost sites ( $\bar{x}$  = 1.67 houses/78 ha, Chapter 3), does not protect roosts from development outside the zone and does not limit human activity. For these reasons, the 305 m zone provides inadequate protection for eagle nocturnal roost habitat.

Because the Maryland Critical Areas Law is being used as a model for other states, it is important to note that a much larger management zone is needed to protect bald eagle perching, roosting and nesting habitat. A 1000 m management zone, for example, would encompass all roost sites identified on the northern Chesapeake and provide a  $\geq 500$  m buffer from inland human activity for 85% of those sites. This zone would provide a 1000 m buffer for eagles on the shoreline during daytime periods, that also is adequate, given the maximum effect distances reported at foraging areas (800 m, McGarigal 1988). A 1000 m zone would encompass most of the nest sites, but would only provide a 363 m buffer from inland human activity, on average (Andrew and

Mosher 1982), suggesting that site-specific management zones around nest sites would be more effective.

## **Population Recovery Status**

Because of a recent U. S. Fish and Wildlife Service proposal to review the status of bald eagles in the lower 48 United States (D. L. James, U. S. Fish and Wild. Serv., pers. commun.), and in light of my results, it is important to examine the recovery status of bald eagle populations using the Chesapeake Bay at this time. All 3 populations using the Chesapeake Bay (Chesapeake resident, northern and southern migrants, Chapter 1) appear to be increasing (Wood et al. 1990, Nickerson 1989). The Chesapeake and southeastern breeding populations are within the range for recovery stated in the respective recovery plans (175 - 200 breeding pairs, Chesapeake, Taylor et al. 1982; 400 breeding pairs, Florida, 40 breeding pairs, South Carolina, Murphy et al. 1984), although the Maine population (91 breeding pairs in 1987, Nickerson 1989) is still well below the recovery goal (150 breeding pairs, Grier et al. 1983).

If we knew for certain that these populations trends would continue, the justification for down-listing the bald eagle from endangered to threatened status would have merit. Given the effect of shoreline development on limiting habitat suitability on the Chesapeake (Chapter 2), urbanization impacts on eagle habitat in Florida (Bohall Wood et al. 1989) and human encroachment on eagle habitat in coastal Maine (Todd 1979), the future of bald eagles in eastern United States is at best tenuous. The expected development pressure in the future in these areas, including 59% increase in developed lands to year 2020 on the Chesapeake (Breedon et al. 1988), implies that without adequate protection of eagle habitat on private land, eagles may be restricted in the future to only public lands.

In most of the eastern United States, eagle habitat occurs primarily on private land. On the Chesapeake, 15.5% of the nests occurred on public land (Cline 1986). In a Florida survey of 106 of 400 eagle nests, 27.6% were on public lands, whereas human development was posing a serious



threat to nests on private lands (Bohall Wood et al. 1989). In South Carolina, 13 of 52 nests (25%) occurred on public lands (T. M. Murphy, S. C. Wild. and Mar. Res. Dep.). In Maine, less than 10% of the nests occur on public lands or on private lands protected from development, such as Nature Conservancy lands (C. S. Young, Me. Dep. Inland Fish. and Wild., pers. commun.). If steps are not taken to protect eagle habitat from destruction on private lands, eagles may be confined in the future largely to islands of publicly-owned habitat. The carrying capacity of these habitat islands is presently unknown. Down-listing, however, also may reduce the management emphasis on habitat protection on public lands, that could further decrease the overall carrying capacity. Given the amount of habitat currently protected, the carrying capacity of publicly-held habitat may, in the future, be below recovery goals.

For these reasons, it appears to be premature to down-list the bald eagle in eastern United States. Until estimates of the amount of protected eagle habitat and, more importantly, the carrying capacity of these habitat islands in the East can be made, we can not know for certain whether eastern United States bald eagle populations have truly recovered.

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# TABLES

**Table 1.** Monthly values of visibility bias (1/percent of eagles seen on surveys) and survey route coverage (1/percent of eagles on survey route) coefficients and the product of these coefficients used to extrapolate aerial shoreline survey data to total eagle abundance on the northern Chesapeake Bay, Maryland, 1985-88.

	Visibility Bias			Survey Coverage			Total
		%	Correction		% on	Correction	Correction
	n	Seen	Factor	n	Route	Factor	
January	8	75.0	1.33	82	54.9	1.82	2.42
February	32	71.9	1.39	105	66.7	1.50	2.09
March	51	66.7	1.50	159	57.1	1.75	2.63
April	22	45.5	2.20	89	55.2	1.81	3.96
May	31	45.2	2.21	116	69.0	1.45	3.20
June	20	35.0	2.86	120	64.9	1.54	4.40
July	28	42.9	2.33	214	51.0	1.96	4.57
August	29	31.1	3.22	210	58.1	1.72	5.54
September	13	46.1	2.17	121	61.3	1.63	3.54
October	44	52.4	1.91	167	63.7	1.57	3.00
November	32	53.2	1.88	106	64.1	1.56	2.93
December	31	65.8	1.52	52	55.9	1.79	2.72

**Table 2.** Mean number of radio-tagged eagle locations per flight and number/1000 shoreline km by season and geographic area of the northern Chesapeake Bay, Maryland, 1984-88 by eagle origin.

Season/Origin	Flights	Geographic Area								
		Aberdeen		Eastern		Susquehanna		Total		
		Proving Ground		Shore		River Valley		$\sum \bar{x}^d$	$\sum \bar{x}/\text{km}^d$	
		$\bar{x}$	$\bar{x}/\text{km}$	$\bar{x}$	$\bar{x}/\text{km}$	$\bar{x}$	$\bar{x}/\text{km}$			
<b>Winter</b>										
Chesapeake <sup>a</sup>	53	3.30	6.82	2.21	1.82	0.26	3.39	5.77A	12.03A	
Northern <sup>b</sup>	53	2.02A	4.17X	0.36B	0.30Y	0.19B	2.42Y	2.57	6.90	
Southern	53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<b>Spring</b>										
Chesapeake <sup>a</sup>	53	5.13	10.60	2.79	2.30	0.06	0.73	7.98B	13.62B	
Northern	53	0.28	0.58	0.00	0.00	0.04	0.48	0.33	1.08	
Southern	53	0.68	1.40	0.00	0.00	0.17	2.18	0.84	3.57	
<b>Summer</b>										
Chesapeake <sup>a</sup>	53	6.30	13.02	6.06	4.98	0.70	8.95	13.05C	26.94C	
Northern	53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Southern <sup>c</sup>	53	0.83A	1.72X	0.17B	0.14Y	0.55A	7.01Z	1.56	8.88	
<b>Fall</b>										
Chesapeake <sup>a</sup>	53	1.96	4.05	3.62	2.98	1.58	20.32	7.17B	27.36C	
Northern	53	0.02	0.04	0.08	0.06	0.00	0.00	0.09	0.09	
Southern	53	0.08	0.16	0.00	0.00	0.06	0.73	0.12	0.87	

Table 2. continued.

		Geographic Area							
		Aberdeen		Eastern		Susquehanna		Total	
		Proving Ground		Shore		River Valley			
Season/Origin	Flights	$\bar{x}$	$\bar{x}/\text{km}$	$\bar{x}$	$\bar{x}/\text{km}$	$\bar{x}$	$\bar{x}/\text{km}$	$\sum \bar{x}$ <sup>d</sup>	$\sum \bar{x}/\text{km}$ <sup>d</sup>
All Seasons									
Chesapeake <sup>a</sup>	212	4.17A	8.63X	3.67A	3.02Y	0.65B	8.35Z	8.49	20.00
Northern	212	0.58	1.20	0.11	0.09	0.06	0.73	0.75	2.00
Southern	212	0.40	0.82	0.04	0.03	0.19	2.48	0.62	3.33

<sup>a</sup> Numbers of locations of Chesapeake nonbreeding eagles by area and season differed, ( $P < 0.001$ ), based on a general linear models analysis by ranks.

<sup>b</sup> Numbers of locations of northern eagles by area in winter differed, ( $P < 0.001$ ), based on the  $\chi^2$  approximation of the Kruskal-Wallis test. Within row comparisons for northern origin with the same letter did not differ ( $P > 0.05$ ), based on Wilcoxon rank-sum pair-wise tests.

<sup>c</sup> Numbers of locations of southern eagles by area in summer differed, ( $P < 0.001$ ), based on the  $\chi^2$  approximation of the Kruskal-Wallis test. Within row comparisons for southern origin with the same letter did not differ ( $P > 0.05$ ), based on Wilcoxon rank-sum pair-wise tests.

<sup>d</sup> Within column comparisons for Chesapeake origin with the same letter did not differ ( $P > 0.05$ ), in Wilcoxon rank-sum pair-wise tests.

<sup>e</sup> Within row comparisons for Chesapeake origin with the same letter did not differ ( $P > 0.05$ ), in Wilcoxon rank-sum pair-wise tests.

**Table 3.** Number ( $n$ ) and percent of radio-tagged nonbreeding Chesapeake eagle locations within different distance zones of eagle nests during breeding (January-June) and nonbreeding (July-December) periods, northern Chesapeake Bay, 1984-88.

Season	Distance from Nest									
	0 - 250 m		251 - 500 m		501 - 750 m		751 - 1000 m		> 1000 m	
	$n$	%	$n$	%	$n$	%	$n$	%	$n$	%
Breeding <sup>a</sup>	10	2.0	8	0.7	10	2.0	20	4.0	457	90.5
Nonbreeding <sup>a</sup>	12	2.0	14	2.3	20	3.3	20	3.3	540	89.1
All Year	22	2.0	22	2.0	30	2.7	40	3.6	997	89.7

<sup>a</sup> Numbers of locations per distance zone did not differ for breeding and nonbreeding seasons ( $P = 0.574$ ), based on  $\chi^2$  test of equal proportions.

**Table 4.** Habitat at radio-tagged bald eagle locations and available overall, northern Chesapeake Bay, Maryland, 1985-88.

	Habitat Type										
	Developed		Farmland		Forested		Wetland		Other		Total
	n	%	n	%	n	%	n	%	n	%	n
Eagle Locations <sup>a</sup>	55	4.9	338	30.3	562	50.3	161	14.4	1	0.1	1117
Northern Chesapeake <sup>a</sup> (km <sup>2</sup> )	400	27.7	331	23.0	634	44.0	52	3.6	25	1.7	1442

<sup>a</sup> Habitat at eagle locations differed from habitat available on the northern Chesapeake Bay, based on  $\chi^2$  test of equal proportions,  $\chi^2 = 729.91$ ,  $df = 4$ ,  $P < 0.001$ ).

**Table 5.** Number of radio-tagged eagle locations per shoreline kilometer, average number of development sites and percent of area developed by geographic area of the northern Chesapeake Bay, Maryland, 1985-88.

	Susquehanna River Valley	Aberdeen Proving Ground	Eastern Shore	Baltimore	Total
	Number/km	Number/km	Number/km	Number/km	Number/km
Eagles	11.56	10.65	3.14	0.00	25.35
Development	10.60	3.58	11.91	*** a	8.39
% Developed	9.4	25.1	3.5	59.5	27.8

a Number of development sites along Baltimore shoreline was not quantified.



**Table 6.** Mean number of pedestrians and boats per shoreline survey kilometer by season and geographic sub-unit on the northern Chesapeake Bay, Maryland, November 1985- August 1988.

	n	Susquehanna River Valley		Aberdeen Proving Ground		Eastern Shore		Total	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
<b>Pedestrians <sup>b,c</sup></b>									
Fall	7	0.23	0.07	0.05	0.02	0.18	0.04	0.13D	0.02
Winter	9	0.04	0.02	0.01	0.00	0.07	0.03	0.04E	0.02
Spring	9	1.16	0.32	0.08	0.02	0.14	0.04	0.17DF	0.04
Summer	9	0.96	0.18	0.10	0.02	0.29	0.08	0.24F	0.06
Total	34	0.62A	0.13	0.06B	0.01	0.17C	0.03	0.15	0.02
<b>Boats <sup>a,c</sup></b>									
Fall	7	0.28	0.10	0.11	0.04	0.12	0.04	0.12J	0.04
Winter	9	0.00	0.00	0.00	0.00	0.01	0.00	0.00K	0.00
Spring	9	0.57	0.18	0.07	0.02	0.08	0.03	0.12J	0.03
Summer	9	0.76	0.13	0.21	0.06	0.46	0.13	0.38L	0.09
Total	34	0.41G	0.08	0.10H	0.02	0.17H	0.05	0.15	0.04

<sup>a</sup> Mean number of pedestrians per shoreline survey kilometer differed by geographic sub-unit and season, based on  $\chi^2$  approximations of Friedman's test,  $\chi^2 = 34.28$ ,  $df = 2$ ,  $P < 0.01$ ,  $\chi^2 = 32.32$ ,  $df = 3$ ,  $P < 0.01$ , respectively.

<sup>b</sup> Mean number of boats per shoreline survey kilometer differed by geographic sub-unit and season, based on  $\chi^2$  approximations of Friedman's test,  $\chi^2 = 15.49$ ,  $df = 2$ ,  $P < 0.01$ ,  $\chi^2 = 46.11$ ,  $df = 3$ ,  $P < 0.01$ , respectively.

<sup>c</sup> Multiple comparisons were made for each human activity by season and geographic area separately, using pair-wise Friedman's tests. No season by geographic area cross comparisons were made. Values followed by the same letter are not significantly different ( $P > 0.05$ ).

**Table 7.** Number of developed and undeveloped 250 m shoreline segments that had pedestrians observed within 500 m of during 34 aerial shoreline surveys on the northern Chesapeake Bay, Maryland, November 1985 - August 1988.

	Season									
	Fall		Winter		Spring		Summer		All Year	
	n	%	n	%	n	%	n	%	n	%
<b>Pedestrians Absent *</b>										
Undeveloped	723	84.2	765	89.1	749	87.2	767	89.3	602	70.1
Developed	967	57.8	1213	72.5	1063	63.5	878	52.5	505	30.2
<b>Pedestrians Present *</b>										
Undeveloped	136	15.8	94	10.9	110	12.8	92	10.7	257	29.9
Developed	706	42.2	460	27.5	610	36.5	795	47.5	1168	69.8

\* Proportions of segments with people present versus absent differed for developed versus undeveloped segments over all seasons and the entire year, based on  $\chi^2$  tests of equal proportions,  $P < 0.001$ .

**Table 8.** Number of developed and undeveloped 250 m shoreline segments that had boats observed within 500 m of during 34 aerial shoreline surveys on the northern Chesapeake Bay, Maryland, November 1985 - August 1988.

	Season									
	Fall		Winter		Spring		Summer		All Year	
	n	%	n	%	n	%	n	%	n	%
<b>Boats Absent <sup>a</sup></b>										
Undeveloped	566	65.9	852	99.2	528	61.5	450	52.4	367	42.7
Developed	985	58.9	1615	96.5	893	53.4	595	35.6	417	24.9
<b>Boats Present <sup>a</sup></b>										
Undeveloped	293	34.1	7	0.8	331	38.5	409	47.6	492	57.3
Developed	688	41.1	58	3.5	780	46.6	1078	64.4	1256	75.1

<sup>a</sup> Proportions of segments with boats present versus absent differed for developed versus undeveloped segments over all seasons and the entire year, based on  $\chi^2$  tests of equal proportions,  $P < 0.001$ .

**Table 9.** Number of 250-m shoreline segments on which eagles were observed during 36 shoreline surveys that also had developments within specified distance zones on the northern Chesapeake Bay, Maryland, 1985-88.

	Segments with Developments within Specified Distance from Shoreline												Total
	0-100 m		100-200 m		200-300m		300-400 m		400-500 m		> 500 m		
	n	%	n	%	n	%	n	%	n	%	n	%	
<b>Fall *</b>													
Eagles Absent	666	95.1	260	91.9	232	89.9	214	86.6	170	91.9	753	87.7	2295
Eagles Present	34	4.9	23	8.1	26	10.1	33	13.4	15	8.1	106	12.3	237
<b>Winter *</b>													
Eagles Absent	654	93.4	253	89.4	226	87.6	214	86.6	161	87.0	679	79.1	2187
Eagles Present	46	6.6	30	10.6	32	12.4	33	13.4	24	13.0	180	20.9	345
<b>Spring *</b>													
Eagles Absent	676	96.6	266	94.0	245	95.0	231	93.5	176	95.1	749	87.2	2343
Eagles Present	24	3.4	17	6.0	13	5.0	16	6.5	9	4.9	110	12.8	189
<b>Summer *</b>													
Eagles Absent	660	94.3	243	85.9	225	87.2	216	87.4	166	89.7	666	77.5	2176
Eagles Present	40	5.7	40	17.2	33	12.8	31	12.6	19	10.3	193	22.5	356
<b>All Year *</b>													
Eagles Absent	589	84.1	212	74.9	192	74.4	175	70.9	141	76.2	547	63.7	1856
Eagles Present	111	15.9	71	25.1	66	25.6	72	29.1	44	23.8	312	36.3	676

\* Proportion of segments with eagles present versus absent differed for segments with development in different distance-from-shoreline zones in fall, winter, spring, summer, and all year ( $P < 0.001$ ), based on  $\chi^2$  analyses.

**Table 10.** Observed and expected number of shoreline segments in which both bald eagles and pedestrians occurred during aerial shoreline surveys, northern Chesapeake Bay, Maryland, 1985-88. <sup>a</sup>

Month	1985-86		1986-87		1987-88	
	Observed	Expected	Observed	Expected	Observed	Expected
Sep	*** <sup>c</sup>	***	0.0	3.0	2.0 <sup>b</sup>	6.8 <sup>b</sup>
Oct	***	***	0.0	1.8	1.0	4.9
Nov	1.0	0.6	3.0	7.6	1.0	2.2
Dec	0.0	0.0	0.0 <sup>b</sup>	5.9 <sup>b</sup>	5.0	6.2
Jan	0.0	0.7	0.0	0.5	0.0	0.3
Feb	0.0	0.4	0.0	0.6	4.0 <sup>b</sup>	1.5 <sup>b</sup>
Mar	0.0	1.5	0.0	1.3	1.0	2.7
Apr	0.0	0.8	2.0	2.8	0.0	0.8
May	0.0	2.1	0.0 <sup>b</sup>	3.5 <sup>b</sup>	0.0	2.1
Jun	2.0	4.3	0.0 <sup>b</sup>	13.6 <sup>b</sup>	0.0	1.8
Jul	6.0	9.7	1.0 <sup>b</sup>	6.6 <sup>b</sup>	1.0	2.4
Aug	3.0 <sup>b</sup>	10.3 <sup>b</sup>	0.0 <sup>b</sup>	6.7 <sup>b</sup>	0.0	3.0

<sup>a</sup> Observed number of segments with eagles and pedestrians present was significantly less than expected, based on Wilcoxon signed-rank tests,  $P < 0.001$ .

<sup>b</sup> Segments with eagles present versus absent and segments with pedestrians present versus absent were not independent, based on  $\chi^2$  tests of independence,  $P < 0.05$ .

<sup>c</sup> Human activity was not recorded during September and October, 1985 surveys.

**Table 11.** Observed and expected number of shoreline segments in which both bald eagles and boats occurred during aerial shoreline surveys, northern Chesapeake Bay, Maryland, 1985-88. <sup>a</sup>

Month	1985-86		1986-87		1987-88	
	Observed	Expected	Observed	Expected	Observed	Expected
Sep	*** c	***	6.0	9.0	6.0 <sup>b</sup>	14.0 <sup>b</sup>
Oct	***	***	0.0	3.2	0.0	0.4
Nov	0.0	0.6	0.0	3.2	0.0	0.4
Dec	0.0	0.0	0.0	1.0	0.0	0.3
Jan	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.1	0.0	0.0	0.0	0.6
Mar	0.0	0.9	0.0	0.6	0.0	0.4
Apr	0.0	1.7	0.0 <sup>b</sup>	6.9 <sup>b</sup>	0.0	3.2
May	1.0	3.9	0.0 <sup>b</sup>	6.9 <sup>b</sup>	0.0 <sup>b</sup>	3.2 <sup>b</sup>
Jun	5.0	9.4	10.0 <sup>b</sup>	18.1 <sup>b</sup>	1.0	5.1
Jul	17.0 <sup>b</sup>	27.2 <sup>b</sup>	5.0 <sup>b</sup>	12.4 <sup>b</sup>	3.0	4.4
Aug	8.0 <sup>b</sup>	25.7 <sup>b</sup>	8.0 <sup>b</sup>	15.6 <sup>b</sup>	9.0	9.7

<sup>a</sup> Observed number of segments with eagles and boats present was significantly less than expected, based on Wilcoxon signed-rank tests,  $P < 0.001$ .

<sup>b</sup> Segments with eagles present versus absent and segments with boats present versus absent were not independent, based on  $\chi^2$  tests of independence,  $P \leq 0.05$ .

<sup>c</sup> Human activity was not recorded during September and October, 1985 surveys.

**Table 12.** Number of bald eagles, pedestrians and boats observed per shoreline kilometer during aerial shoreline surveys on weekdays and weekends in summer of the northern Chesapeake Bay, Maryland, 1985-88.

	n	Eagles <sup>a</sup>		Pedestrians <sup>b</sup>		Boats <sup>c</sup>	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Weekdays	4	0.44	0.04	0.03	0.03	0.04	0.03
Weekends	9	0.20	0.02	0.06	0.03	0.38	0.15

<sup>a</sup> Observed number of eagles/shoreline km was greater on weekdays than weekends, based on Wilcoxon rank-sum test,  $P = 0.006$ .

<sup>b</sup> Observed number of pedestrians/shoreline km did not differ on weekdays and weekends, based on Wilcoxon rank-sum test,  $P = 0.598$ .

<sup>c</sup> Observed number of boats/shoreline km was marginally greater on weekends than weekdays, based on Wilcoxon rank-sum test,  $P = 0.06$ .

**Table 13.** Differences in eagle flush distances (m) by eagle age, season, and geographic area of northern Chesapeake Bay, Maryland, 1984-88, in response to boats and pedestrians.

	Flush Distance (m)		
	n	$\bar{x}$	SE
Boat			
Adult <sup>a</sup>	40	203.67	16.14
Immature <sup>a</sup>	36	228.61	19.12
Summer <sup>b</sup>	42	175.48	12.08
Winter <sup>b</sup>	34	264.91	20.63
Eastern Shore <sup>c</sup>	10	163.00	36.78
Aberdeen Proving Ground <sup>c</sup>	66	223.44	13.01
Boat <sup>d</sup>	76	215.49	12.42
Pedestrian <sup>d</sup>	4	208.50	70.50

<sup>a</sup> Flush distances of adult and immature eagles did not differ ( $P = 0.385$ ), based on Wilcoxon rank-sum tests.

<sup>b</sup> Eagle flush distances in summer and winter differed ( $P = 0.001$ ), based on Wilcoxon rank-sum tests.

<sup>c</sup> Eagle flush distances on Eastern Shore and Aberdeen Proving Ground differed ( $P = 0.049$ ), based on Wilcoxon rank-sum tests.

<sup>d</sup> Eagle flush distances from boats and pedestrians did not differ ( $P = 0.774$ ), based on Wilcoxon rank-sum tests.



**Table 14.** Mean values of vegetative characteristics of bald eagle roost and random trees and sites, northern Chesapeake Bay, Maryland, 1984-89. (Tr - Can = tree - canopy height).

		Vegetative Characteristic																	
		Tree		Canopy		Tr - Can		Access		Canopy		Distance		Trees		Roost			
		Dbh (cm)		Ht (m)		Ht (m)		(degrees)		Cover %		Edge (m)		/Ha		Area (ha)			
n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	
<b>Roosts</b>																			
Communal-Summer	9	65.1	3.7	27.8	1.2	22.2 <sup>a</sup>	2.1	5.7 <sup>a</sup>	1.0	294 <sup>a</sup>	17.7	63.8	6.8	31	16	182	25.7	0.92	0.41
Communal-Winter	10	71.5	3.5	29.8	1.7	29.3 <sup>a</sup>	1.4	0.5 <sup>a</sup>	1.3	232 <sup>a</sup>	22.4	71.1	5.7	13	6	232	31.2	0.35	0.10
All Communal	14	68.5	3.0	28.3 <sup>b</sup>	1.3	25.6 <sup>b</sup>	1.7	2.6	1.2	259	19.0	67.1	4.8	26	11	219 <sup>b</sup>	25.3	0.61	0.20
Solitary-Summer <sup>c</sup>	12	83.1	12.6	26.8	1.7	19.7	1.6	7.1	2.2	298	20.5	72.1	9.3	22	10	313	34.9	0.04	0.00
Solitary-Winter <sup>c</sup>	4	74.8	12.4	22.0	2.5	18.7	3.9	3.3	1.5	258	50.7	76.8	9.3	13	5	306	27.7	0.04	0.00
All Solitary	16	81.0	9.8	25.6 <sup>b</sup>	1.5	19.4 <sup>b</sup>	1.5	6.1	1.7	288	19.5	73.3	7.2	20	8	311 <sup>b</sup>	25.3	0.04	0.00
All Roosts	30	75.2 <sup>d</sup>	5.5	26.8 <sup>d</sup>	1.0	22.3 <sup>d</sup>	1.2	4.5 <sup>d</sup>	1.1	274 <sup>d</sup>	13.7	70.4 <sup>d</sup>	4.4	23	6	268	20.0	*	*
Random	123	39.2 <sup>d</sup>	1.6	16.6 <sup>d</sup>	0.5	15.4 <sup>d</sup>	0.7	1.2 <sup>d</sup>	0.5	195 <sup>d</sup>	12.1	39.0 <sup>d</sup>	3.1	33	7	281	18.1	*	*

<sup>a</sup> Characteristics of summer and winter communal roosts were different ( $P < 0.05$ ), based on Wilcoxon rank-sum tests.

<sup>b</sup> Characteristics of all communal and solitary roosts were different ( $P < 0.05$ ), based on Wilcoxon rank-sum tests.

<sup>c</sup> Characteristics of summer and winter solitary roosts did not differ ( $P > 0.05$ ), based on Wilcoxon rank-sum tests.

<sup>d</sup> Characteristics of all roosts and random sites were different ( $P < 0.01$ ), based on Wilcoxon rank-sum tests.

**Table 15.** Percent of bald eagle roost and random sites with given tree species predominant and percent of sites with snags present, northern Chesapeake Bay, Maryland, 1984-89.

Roosts	n	Dominant Species								Snags Present
		American Beech		Oak Species		Yellow Poplar		Other Species		
		%	%	%	%	%	%	%	%	
Communal-Summer <sup>a</sup>	9	11.1	33.3	22.2	33.3	77.8				
Communal-Winter <sup>a</sup>	10	20.0	30.0	30.0	20.0	50.0				
All Communal <sup>b</sup>	14	21.4	28.6	21.4	28.6	64.3				
Solitary-Summer <sup>c</sup>	12	0.0	58.3	16.7	25.0	33.3				
Solitary-Winter <sup>c</sup>	4	0.0	75.0	0.0	25.0	25.0				
All Solitary <sup>b</sup>	16	0.0	62.5	12.5	25.0	31.3				
All Roosts <sup>d</sup>	30	10.0	46.7	16.7	26.7	46.7				
Random <sup>d</sup>	123	2.4	12.9	2.4	92.7	14.5				

<sup>a</sup> Dominant species and snags present at summer and winter communal roosts did not differ ( $P > 0.05$ ), based on  $\chi^2$  tests.

<sup>b</sup> Dominant species and snags present at all communal and solitary roosts did not differ ( $P > 0.05$ ), based on  $\chi^2$  tests.

<sup>c</sup> Dominant species and snags present at summer and winter solitary roosts did not differ ( $P > 0.05$ ), based on  $\chi^2$  tests.

<sup>d</sup> Dominant species and snags present at all roost and random sites were different,  $\chi^2 = 37.59, 15.17$ , respectively,

df = 3, 1,  $P < 0.001$ .

**Table 16.** Mean values of distances (km) from bald eagle roost and random sites to key aquatic and human features, northern Chesapeake Bay, Maryland, 1984-89.

	Site Characteristic																		
	Distance to Water		Distance to Bay		Distance to River		Distance to Creek		Distance to Rill		Distance to Pond		Distance to Road		Distance to Blding		Buildings w/i 500 m		
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	
<b>Roosts</b>																			
Communal-Summer <sup>a</sup>	10	0.30	0.09	1.97	0.31	7.11	1.15	2.77	0.44	1.38	0.36	0.61	0.12	0.80	0.17	1.21	0.17	0.00	0.00
Communal-Winter <sup>a</sup>	13	0.14	0.05	4.71	1.33	5.54	1.04	5.38	1.38	1.28	0.31	0.53	0.11	0.74	0.16	0.87	0.15	0.85	0.54
All Communal	17	0.20	0.06	4.02	1.06	5.82	0.93	4.76 <sup>b</sup>	1.10	1.32	0.27	0.51	0.09	0.70	0.13	0.96	0.14	0.65	0.42
Solitary-Summer <sup>c</sup>	12	0.19	0.08	5.30	1.31	6.25	1.36	2.00	0.50	1.19	0.36	0.86	0.20	0.64	0.14	0.70	0.20	3.50	2.07
Solitary-Winter <sup>c</sup>	4	0.04	0.04	3.98	1.82	1.22	0.22	1.18	0.62	0.63	0.37	0.53	0.27	0.60	0.13	0.55	0.12	0.50	0.50
All Solitary	16	0.15	0.06	4.97	1.06	4.99	1.15	1.79 <sup>b</sup>	0.41	1.05	0.28	0.77	0.16	0.63	0.11	0.66	0.15	2.75	1.57
All Roosts	33	0.18 <sup>d</sup>	0.04	4.48 <sup>d</sup>	0.74	5.42	0.73	3.32	0.65	1.19	0.19	0.64 <sup>d</sup>	0.09	0.67 <sup>d</sup>	0.08	0.82 <sup>d</sup>	0.11	1.67 <sup>d</sup>	0.80
Random	127	0.58 <sup>d</sup>	0.06	8.09 <sup>d</sup>	0.50	4.72	0.40	2.77	0.19	1.35	0.11	1.34 <sup>d</sup>	0.10	0.27 <sup>d</sup>	0.02	0.34 <sup>d</sup>	0.04	20.44 <sup>d</sup>	3.11

<sup>a</sup> Characteristics of summer and winter communal roosts did not differ ( $P > 0.05$ ), based on Wilcoxon rank-sum tests.

<sup>b</sup> Characteristics of all communal and solitary roosts differed ( $P < 0.05$ ), based on Wilcoxon rank-sum tests.

<sup>c</sup> Characteristics of summer and winter solitary roosts did not differ ( $P > 0.05$ ), based on Wilcoxon rank-sum tests.

<sup>d</sup> Characteristics of all roosts and random sites differed ( $P < 0.001$ ), based on Wilcoxon rank-sum tests.

**Table 17.** Frequency of occurrence of different habitat types, size of openings, wind protection, and ownership of bald eagle roosts and random sites, northern Chesapeake Bay, Maryland, 1984-89.

	n	Habitat Type			Maximum		Protected		Public	
		Developed		Forested	Opening (m)		from Wind		Ownership	
		%	%	%	$\bar{x}$	SE	%	%	%	%
<b>Roosts</b>										
Communal-Summer <sup>a</sup>	10	0.0	10.0	90.0	656	163	50.0	50.0	50.0	50.0
Communal-Winter <sup>a</sup>	13	0.0	0.0	100.0	754	245	85.0	85.0	69.2	69.2
All Communal <sup>b</sup>	17	0.0	5.9	94.1	712	153	69.6	69.6	64.7	64.7
Solitary-Summer <sup>c</sup>	12	0.0	16.7	83.3	3509	998	66.7	66.7	50.0	50.0
Solitary-Winter <sup>c</sup>	4	0.0	0.0	100.0	4758	2007	100.0	100.0	50.0	50.0
All Solitary <sup>b</sup>	16	0.0	12.5	87.5	3821	877	75.0	75.0	50.0	50.0
All Roosts <sup>d</sup>	33	0.0	9.1	90.9	1987	441	71.8	71.8	57.6	57.6
Random <sup>d</sup>	127	8.7	48.0	43.3	*	*	*	*	19.7	19.7

<sup>a</sup> Winter and summer communal roosts did not differ ( $P > 0.05$ ), for any of the variables.

<sup>b</sup> Communal and solitary roosts did not differ ( $P > 0.05$ ), for any of the variables.

<sup>c</sup> Winter and summer solitary roosts did not differ ( $P > 0.05$ ), for any of the variables.

<sup>d</sup> Habitat and ownership of roost and random sites differed ( $P < 0.001$ ), based on  $\chi^2$  tests of equal proportions.

**Table 18.** Symbols used in the bald eagle heat budget model.

Symbol	Definition
A	Surface area of the bald eagle ( $m^2$ )
$C_p$	Specific heat of air ( $1010 J/kg^\circ K$ )
D	Diameter of a bald eagle (m)
d	Density of air ( $kg/m^3$ )
e	Thermal emmissivity
$G_1$	Conductive heat loss from eagle body to skin and feathers ( $W/m^2$ )
$G_2$	Conductive heat loss to the perch ( $W/m^2$ )
J	Stored Heat
HE	Evaporative heat loss ( $W/m^2$ )
M	Metabolic heat production rate (kcal/hr)
$r_b$	Resistance to conductive heat loss through skin and feathers (sec/m)
$r_f$	Resistance to conductive heat loss through feathers (sec/m)
$r_h$	Resistance to convective heat loss at eagle surface (sec/m)
$r_r$	Resistance to radiative heat loss at eagle surface (sec/m)
$r_t$	Resistance to conductive heat loss through skin (sec/m)
$r_{hr}$	Resistance to radiative and convective heat losses together (sec/m)
$R_m$	Net radiation measured by net radiometer ( $W/m^2$ )
$R_n$	Net radiation exchange between eagle and environment ( $W/m^2$ )
S	Stefan-Boltzmann constant ( $5.67 \times 10^{-8} W/m^2 \circ K^4$ )
$T_a$	Ambient temperature ( $^\circ K$ )
$T_b$	Eagle body temperature ( $^\circ K$ )
$T_e$	Effective environmental temperature ( $^\circ K$ )
$T_s$	Temperature at the eagle's surface ( $^\circ K$ )
TE	Total energy expended nightly (kcal)
U	Wind speed (m/s)

**Table 19.** Mean and minimum values of temperature and net radiation, and mean and maximum values of wind speed at 3 roost sites, shoreline perches, and randomly-selected inland forested sites on northern Chesapeake Bay, Maryland, November 1988 - March 1989.

	n	Mean Temperature (°C)			Minimum Temperature (°C)			Mean Wind (m/s)			Maximum Wind (m/s)			Mean Net Radiation (W/m <sup>2</sup> )			Minimum Net Radiation (W/m <sup>2</sup> )		
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Year-round Roost <sup>a,d</sup>	42	3.70A	0.65	1.10A	0.67	1.38A	0.14	3.27A	0.20	-15.52A	1.76	-28.49A	2.07						
Shoreline <sup>a</sup>	42	4.12A	0.60	1.88A	0.60	1.98B	0.25	4.51B	0.37	-18.81A	2.26	-30.53A	2.33						
Random <sup>a</sup>	42	3.87A	0.59	1.62A	0.60	1.34A	0.12	3.07A	0.16	-14.80A	1.71	-25.17A	1.91						
Summer Roost <sup>b,d</sup>	42	2.36A	0.83	-0.13A	0.80	1.50AB	0.13	3.49AB	0.21	-21.94A	2.30	-34.39A	2.44						
Shoreline <sup>b</sup>	42	2.58A	0.82	0.02A	0.78	1.75A	0.15	4.10A	0.26	-22.01A	2.29	-33.66A	2.36						
Random <sup>b</sup>	42	2.31A	0.82	-0.25A	0.79	1.15B	0.10	2.87B	0.16	-16.59A	1.79	-26.39B	1.94						
Winter Roost <sup>c,d</sup>	42	2.86A	0.80	0.24A	0.79	1.11A	0.12	2.83A	0.25	-23.02A	1.83	-33.12A	2.01						
Shoreline <sup>c</sup>	42	3.10A	0.75	0.69A	0.73	1.62B	0.16	3.84B	0.29	-25.21A	1.96	-36.09A	2.12						
Random <sup>c</sup>	42	2.92A	0.72	0.43A	0.73	1.20A	0.12	2.72A	0.17	-20.88A	1.58	-30.05B	1.75						
All Roosts <sup>e</sup>	126	2.97A	0.44	0.40A	0.44	1.33A	0.08	3.19A	0.13	-20.16AB	1.17	-32.00A	1.27						
All Shoreline <sup>e</sup>	126	3.27A	0.42	0.87A	0.41	1.79B	0.11	4.15B	0.18	-22.01A	1.27	-33.42A	1.32						
All Random <sup>e</sup>	126	3.04A	0.41	0.60A	0.41	1.23A	0.07	2.89A	0.10	-17.42B	1.00	-27.21B	1.09						

Table 19. (Cont.)

- Mean and maximum wind speed differed ( $P = 0.030, 0.004, 0.004$ , respectively) among the year-round roost, shoreline and random sites, based on Kruskal-Wallis tests. Shoreline mean and maximum winds were greater than the year-round roost and the random sites, ( $P < 0.05$ ).
- Mean and maximum wind speed and minimum radiation differed ( $P = 0.011, 0.004, 0.003$ , respectively), among the summer roost, shoreline and random sites, based on Kruskal-Wallis tests. Shoreline mean and maximum winds were greater than the summer roost and the random sites and random minimum net radiation was greater than summer roost and shoreline sites, ( $P < 0.05$ ).
- Mean and maximum wind speed and minimum radiation differed ( $P = 0.017, 0.001, 0.005$ , respectively), among the winter roost, shoreline and random sites, based on Kruskal-Wallis tests. Shoreline mean and maximum winds were greater than the winter roost and the random sites and random minimum net radiation was greater than winter roost and shoreline sites, ( $P < 0.05$ ).
- Mean and maximum wind speed and mean and minimum radiation differed ( $P = 0.020, 0.013, 0.013, 0.026$ , respectively), among the year-round, summer and winter roost sites, based on Kruskal-Wallis tests. Winter roost mean and maximum winds were less than at the year-round and summer roosts; year-round roost mean radiation was greater than at summer and winter roosts; and year-round roost minimum net radiation was greater than at the summer roost, ( $P < 0.05$ ).
- Mean and maximum wind speed and mean and minimum radiation differed ( $P = 0.0001, 0.0001, 0.027, 0.0001$ , respectively), among roost, shoreline and random sites, based on Kruskal-Wallis tests. Shoreline mean and maximum winds were greater than at the roost and random sites; random mean radiation was greater than at shoreline sites; and random minimum radiation was greater than at roost and shoreline sites, ( $P < 0.05$ ).

Within column section comparisons with similar letters were not different, based on pair-wise Wilcoxon rank-sum tests ( $P > 0.05$ ).

**Table 20.** Mean and maximum values of metabolic heat production rate and total nightly energy expended for 3 roost sites, shoreline perches, and randomly-selected inland forested sites, northern Chesapeake Bay, Maryland, November 1988 - March 1989.

	n	Mean Metabolic Rate (kcal/hr)		Maximum Metabolic Rate (kcal/hr)		Total Nightly Energy (kcal/night)	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
All-year Roost <sup>a,d</sup>	42	14.26	0.31	15.54	0.33	194.74	4.46
Shoreline <sup>a</sup>	42	14.35	0.30	15.58	0.31	195.96	4.31
Random <sup>a</sup>	42	14.17	0.28	15.39	0.30	193.47	4.10
Summer Roost <sup>b,d</sup>	42	15.07	0.40	16.39	0.40	208.94	6.65
Shoreline <sup>b</sup>	42	15.04	0.38	16.41	0.38	208.55	6.38
Random <sup>b</sup>	42	14.77	0.38	16.13	0.38	204.69	6.31
Winter Roost <sup>c,d</sup>	42	14.72	0.35	15.99	0.36	200.30	5.77
Shoreline <sup>c</sup>	42	14.87	0.33	16.15	0.33	202.15	5.77
Random <sup>c</sup>	42	14.67	0.31	15.88	0.32	199.49	5.59
All Roosts <sup>a</sup>	126	14.68	0.20	15.98	0.21	201.33	3.34
All Shoreline <sup>a</sup>	126	14.75	0.19	16.05	0.20	202.22	3.34
All Random <sup>a</sup>	126	14.54	0.19	15.80	0.19	199.22	3.13



**Table 20. (cont.)**

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- <sup>a</sup> Mean and maximum metabolic rates and total energy did not differ among year-round roost, shoreline and random sites, based on Kruskal-Wallis tests ( $P = 0.870, 0.820, 0.912$ , respectively).
- <sup>b</sup> Mean and maximum metabolic rates and total energy did not differ among summer roost, shoreline and random sites, based on Kruskal-Wallis tests ( $P = 0.767, 0.829, 0.762$ , respectively).
- <sup>c</sup> Mean and maximum metabolic rates and total energy did not differ among winter roost, shoreline and random sites, based on Kruskal-Wallis tests ( $P = 0.818, 0.690, 0.872$ , respectively).
- <sup>d</sup> Mean and maximum metabolic rates and total energy did not differ among year-round, summer, and winter roosts, based on Kruskal-Wallis tests ( $P = 0.230, 0.252, 0.230$ , respectively).
- <sup>e</sup> Mean and maximum metabolic rates and total energy did not differ among roost, shoreline and random sites, based on Kruskal-Wallis tests ( $P = 0.639, 0.550, 0.676$ , respectively).

**Table 21.** Mean and maximum values of metabolic heat production rate and total nightly energy expended for 3 roost sites, shoreline perches, and randomly-selected inland forested sites on the ten coldest temperature, ten windiest, ten lowest net radiation and ten greatest metabolic rate nights on northern Chesapeake Bay, Maryland, November 1988 - March 1989.

	n	Mean		Maximum		Total Nightly	
		Metabolic Rate		Metabolic Rate		Energy	
		(kcal/hr)		(kcal/hr)		(kcal/night)	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
<b>Coldest temperature <sup>a</sup></b>							
Roosts	10	16.91	0.54	18.40	0.60	228.62	9.66
Shoreline	10	17.09	0.54	18.49	0.60	231.09	9.93
Random	10	16.66	0.51	18.16	0.58	225.21	9.39
<b>Windiest <sup>b</sup></b>							
Roosts	10	14.96	1.16	16.75	1.20	195.87	18.48
Shoreline	10	15.25	1.10	17.03	1.12	199.49	17.89
Random	10	14.85	1.01	16.63	1.05	194.14	16.65
<b>Lowest Net Radiation <sup>c</sup></b>							
Roosts	10	19.08	0.34	20.27	0.50	272.05	5.74
Shoreline	10	18.81	0.34	20.00	0.48	268.14	5.08
Random	10	18.65	0.31	19.79	0.48	265.99	5.26
<b>Greatest Metabolic Rates <sup>d</sup></b>							
Roosts	10	19.05	0.35	20.41	0.49	269.87	6.44
Shoreline	10	18.89	0.32	20.19	0.45	267.47	5.32
Random	10	18.63	0.32	19.93	0.48	263.84	5.90

Table 21. (cont.)

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- <sup>a</sup> Mean and maximum metabolic rates and total energy did not differ on the ten coldest temperature nights among roost, shoreline and random sites, based on Kruskal-Wallis test, ( $P = 0.567, 0.642, 0.568$ , respectively).
- <sup>b</sup> Mean and maximum metabolic rates and total energy did not differ on the ten windiest nights among roost, shoreline and random sites, based on Kruskal-Wallis test, ( $P = 0.761, 0.855, 0.791$ , respectively).
- <sup>c</sup> Mean and maximum metabolic rates and total energy did not differ on the ten lowest net radiation nights among roost, shoreline and random sites, based on Kruskal-Wallis test, ( $P = 0.625, 0.783, 0.774$ , respectively).
- <sup>d</sup> Mean and maximum metabolic rates and total energy did not differ on the ten greatest metabolic rate nights among roost, shoreline and random sites, based on Kruskal-Wallis test, ( $P = 0.558, 0.647, 0.678$ , respectively).

**Table 22.** Estimated changes in metabolic heat production rates for bald eagles in nighttime roosts on the northern Chesapeake Bay, Maryland, when input variables were changed by specified amounts.

Input Variable	% Change Input	% Change Metabolic Rate	$\Delta$ Input/ $\Delta$ MR
Temperature (°C)	25.0%	2.17%	0.09
Wind (m/s)	25.0%	0.76%	0.03
Net Radiation (W/m <sup>2</sup> )	25.0%	0.91%	0.04
Body Temperature (°C)	5.0%	5.22%	1.04
Surface Area (m <sup>2</sup> )	5.0%	5.00%	1.00
Body Resistance (s/m)	5.0%	4.55%	0.91

# FIGURES

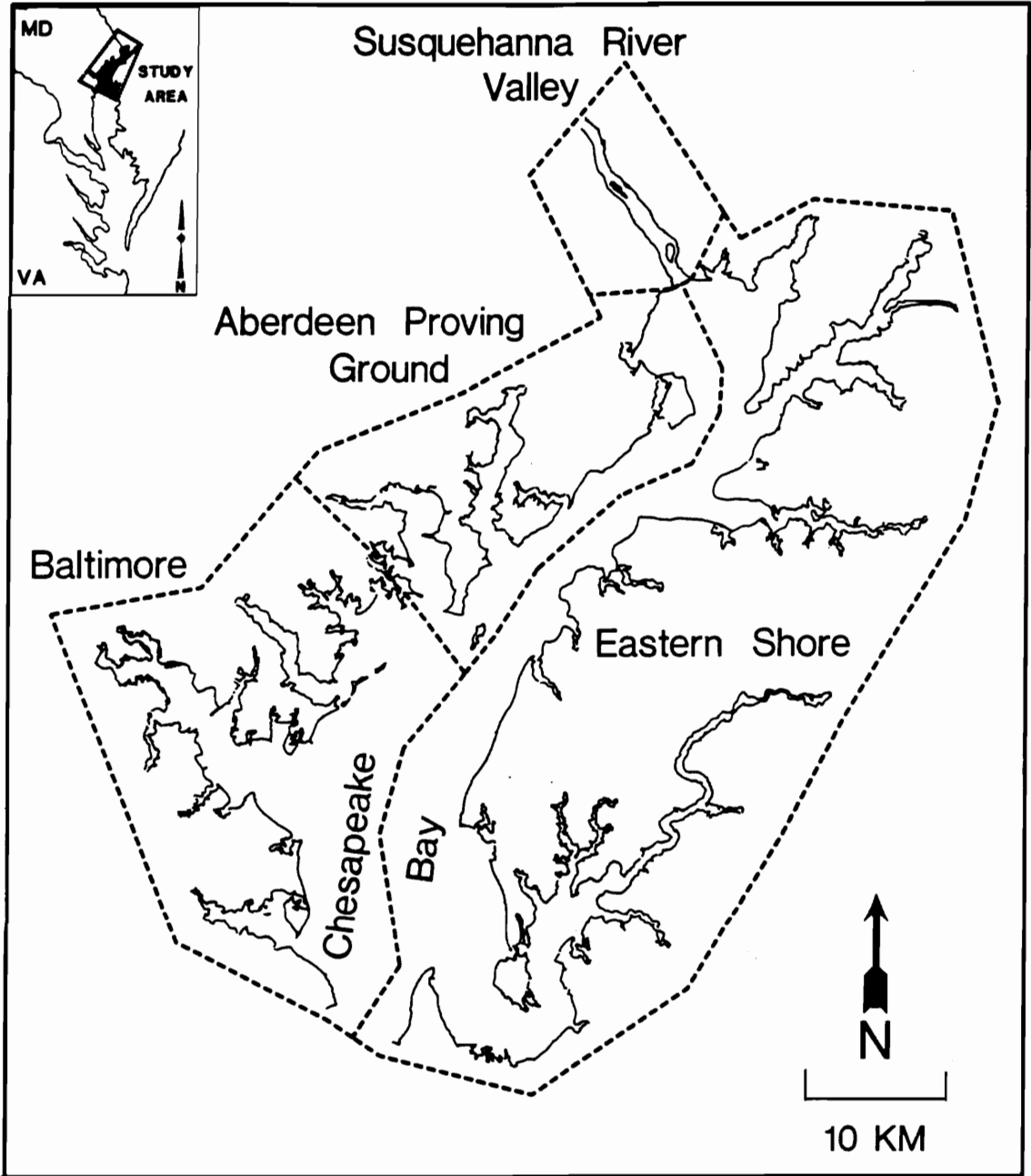


Fig. 1. The four major geographic sub-units of the Northern Chesapeake Study Area, Maryland used in bald eagle distribution analyses (Aberdeen Proving Ground, Eastern Shore, Baltimore, and Susquehanna River Valley).

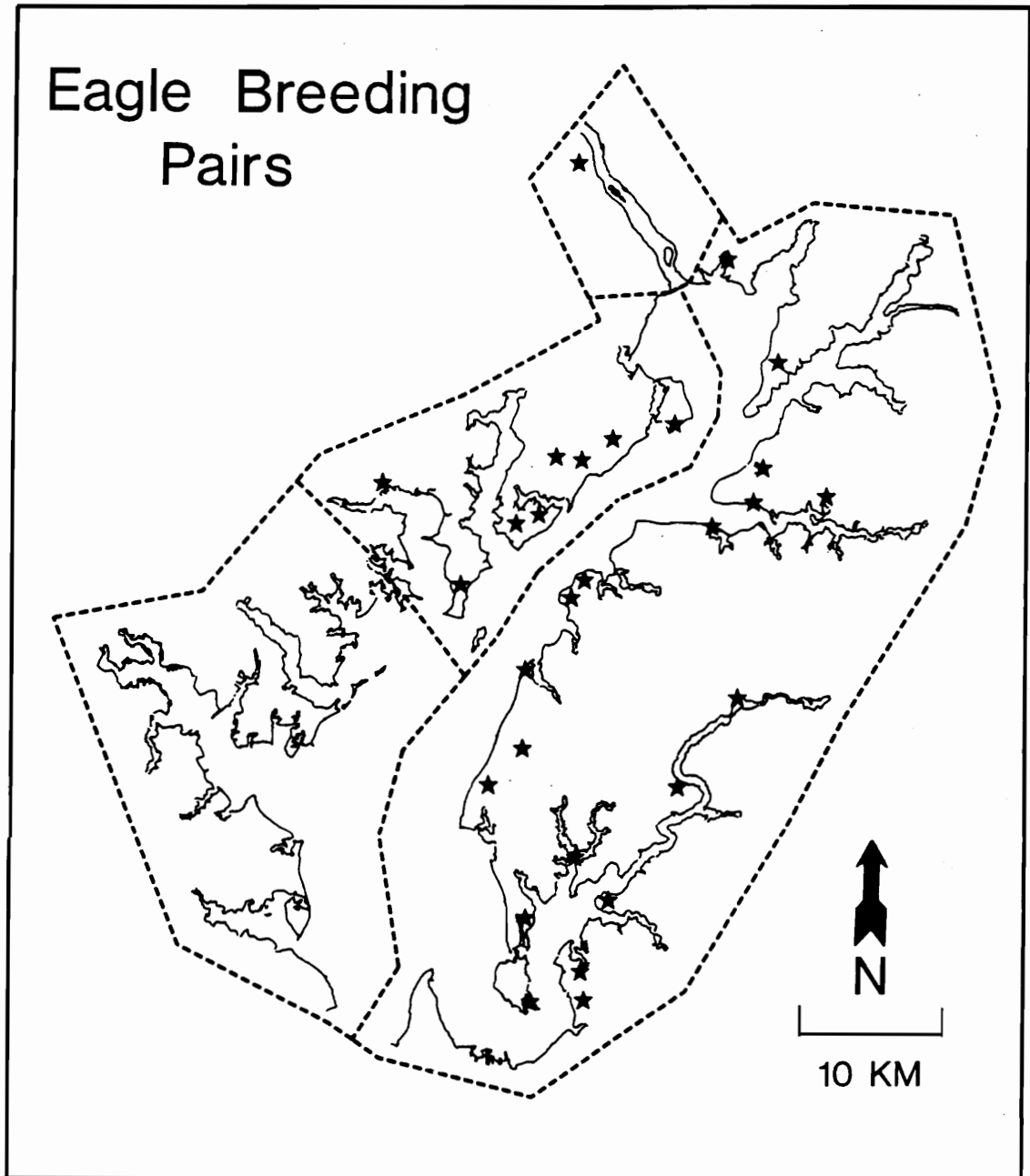


Fig. 2. Distribution of bald eagle breeding territories on northern Chesapeake Bay, Maryland, 1988.

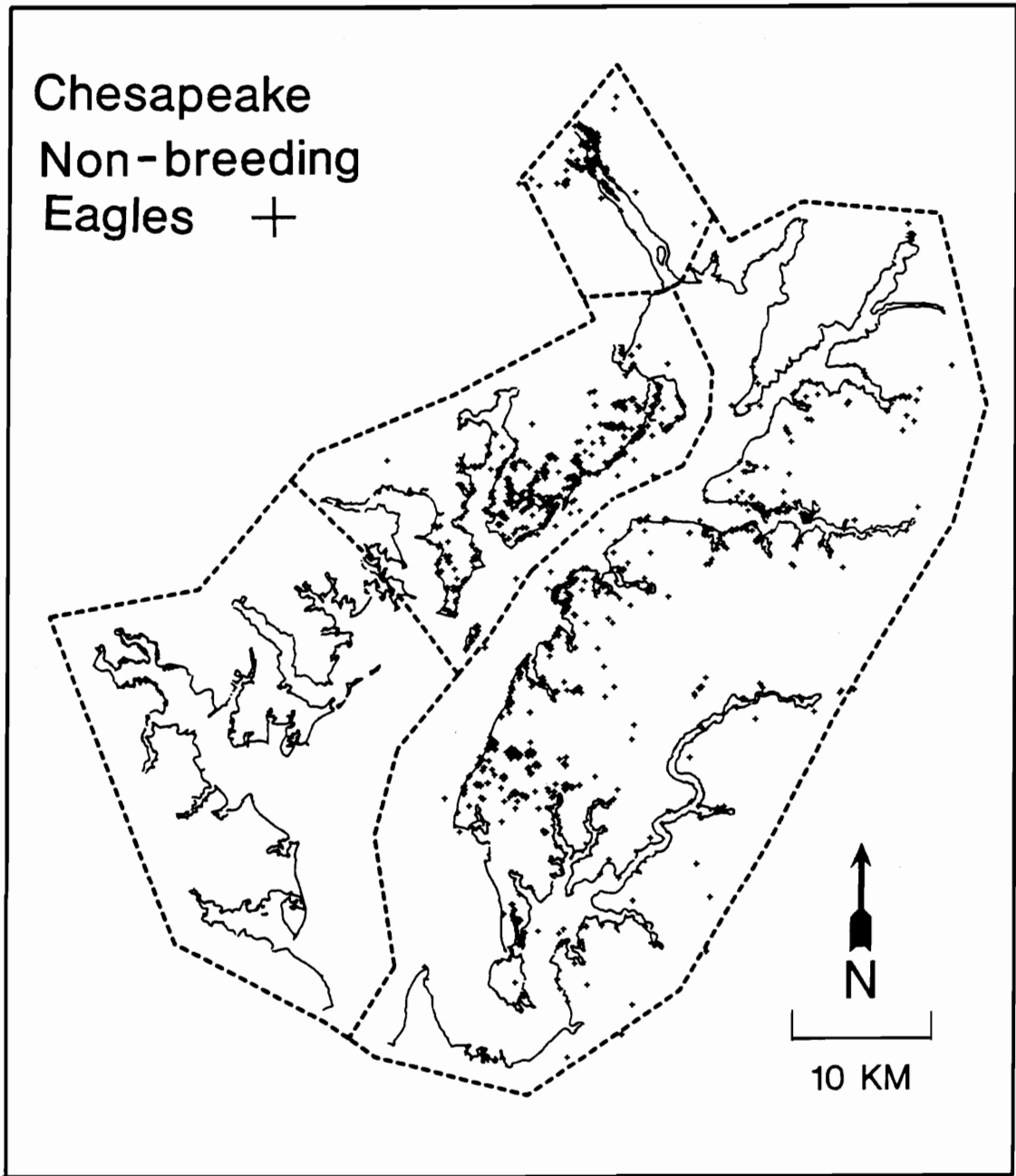


Fig. 3A. Radio-tagged bald eagle locations on northern Chesapeake Bay, Maryland during 1984-88 for Chesapeake non-breeding eagles.



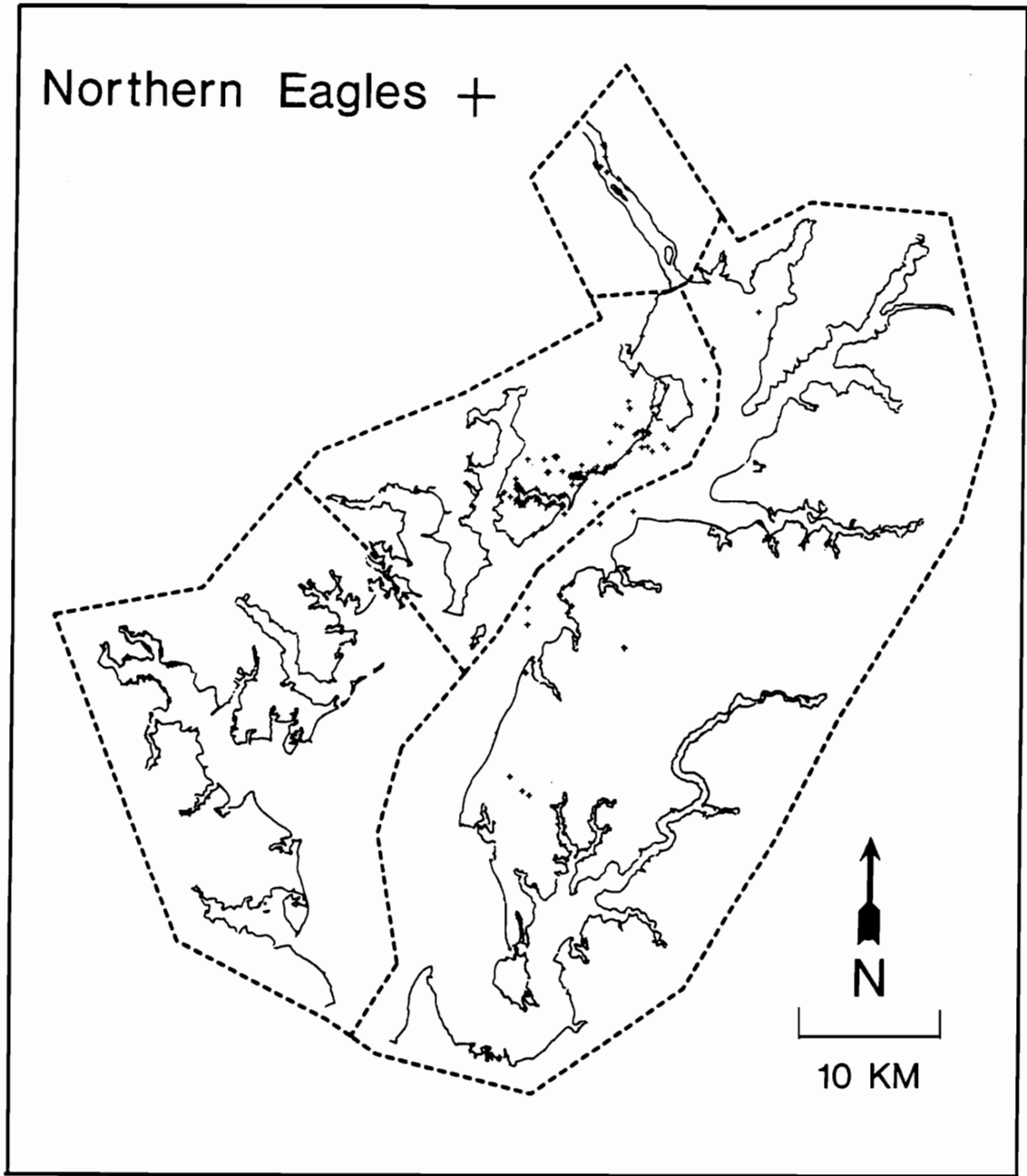


Fig. 3B. Radio-tagged bald eagle locations on northern Chesapeake Bay, Maryland during 1984-88 for northern-origin eagles.

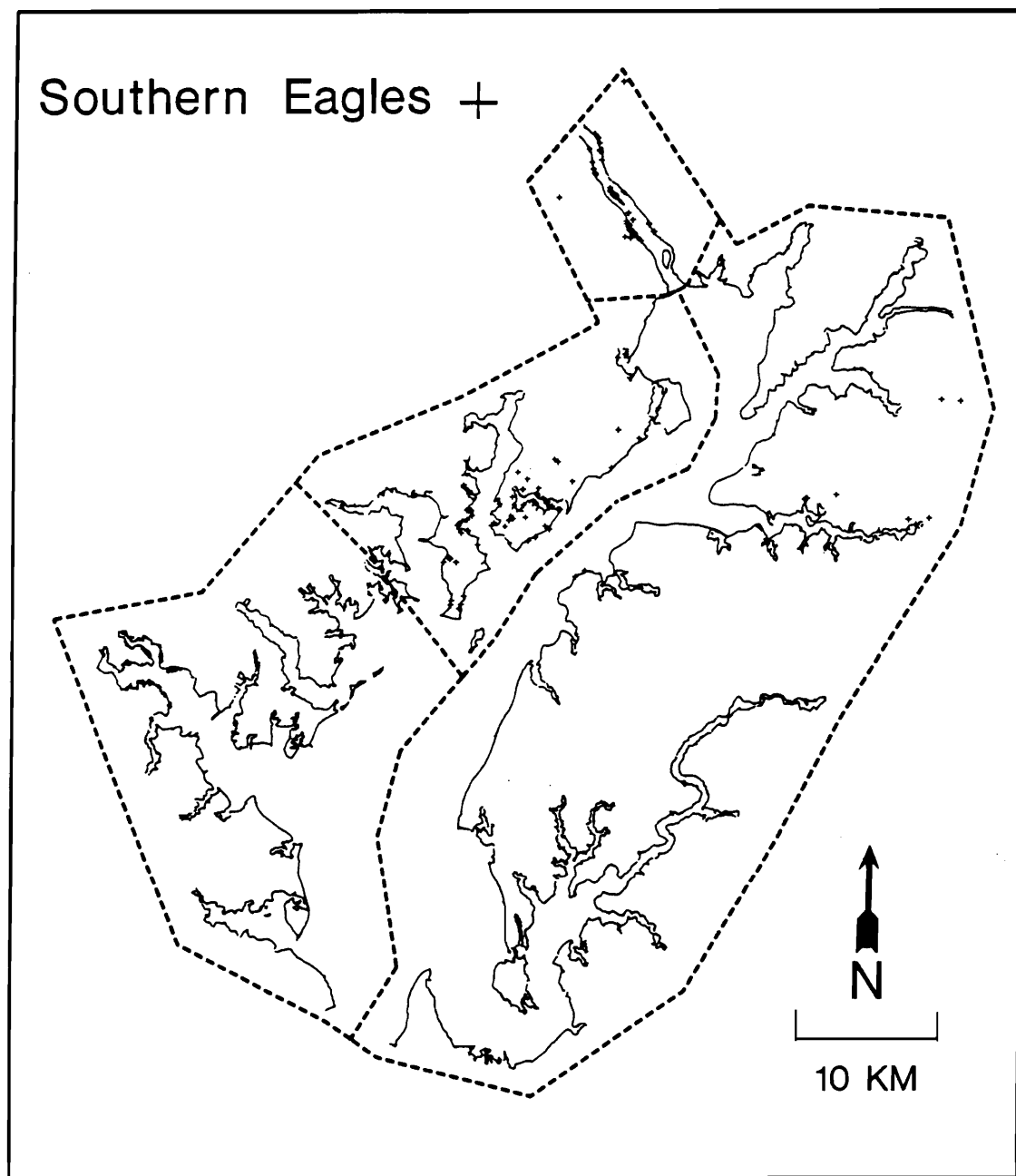


Fig. 3C. Radio-tagged bald eagle locations on northern Chesapeake Bay, Maryland during 1984-88 for southern-origin eagles.

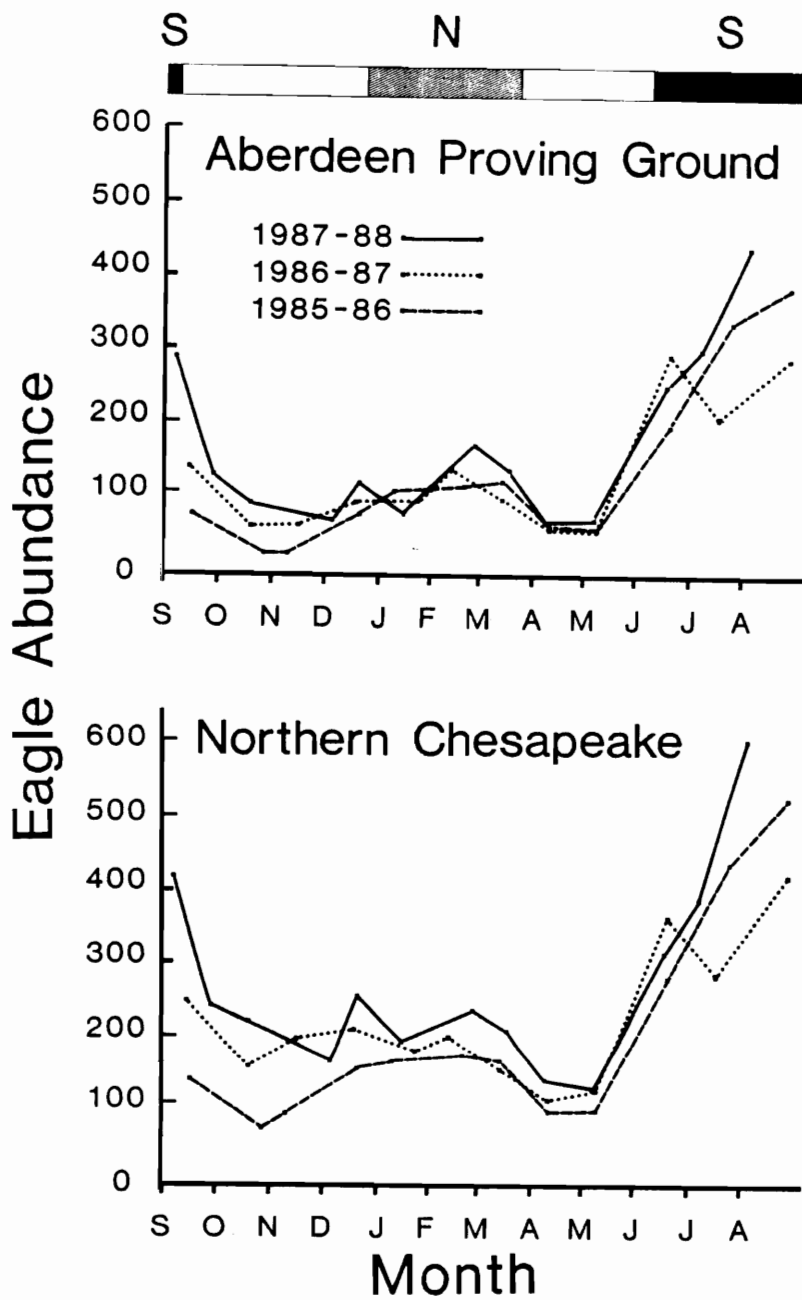


Fig. 4. Total estimated bald eagle abundance by sub-area and on the northern Chesapeake Bay, Maryland during 3 September-August survey years beginning in September, 1985. Bars at top represent the mean periods of occupancy by southern-origin (S) and northern-origin (N) eagles on the northern Chesapeake.

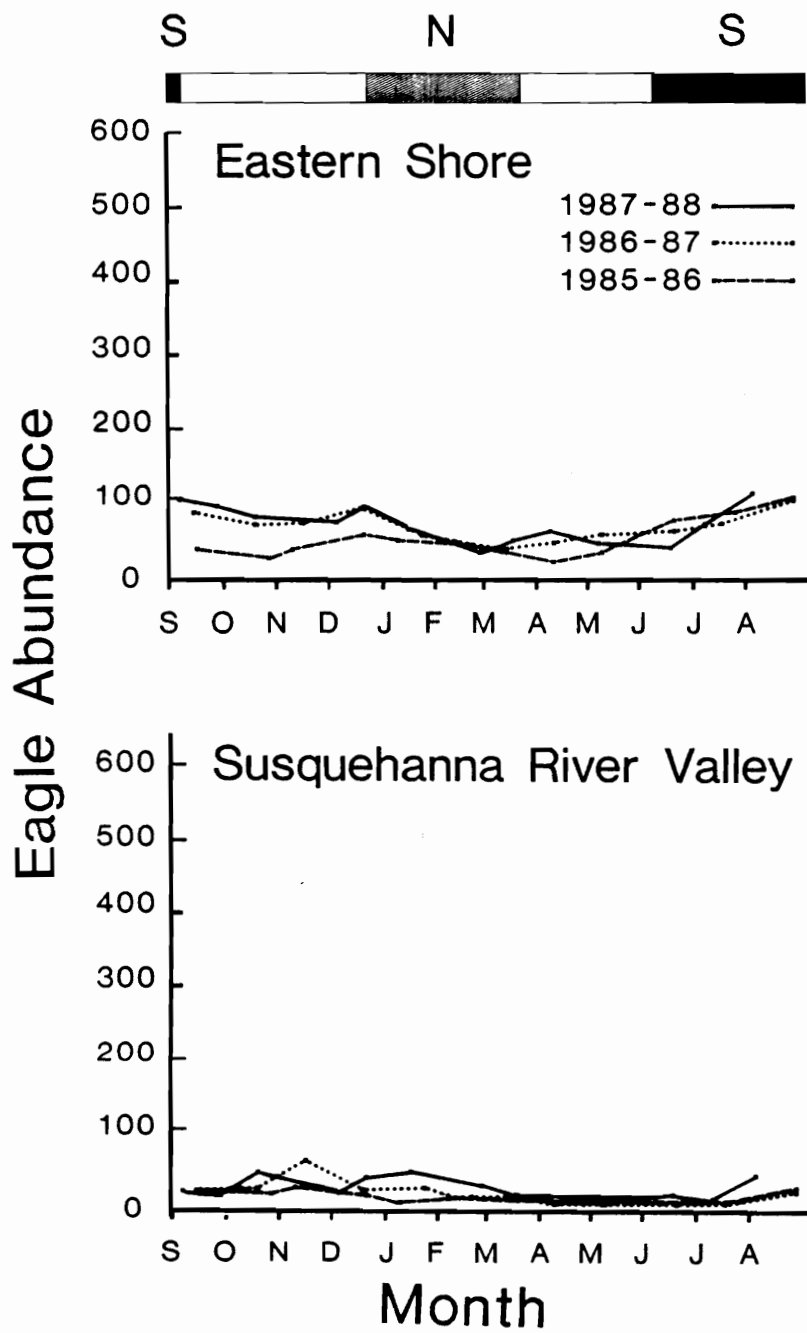


Fig. 4. (Cont.)

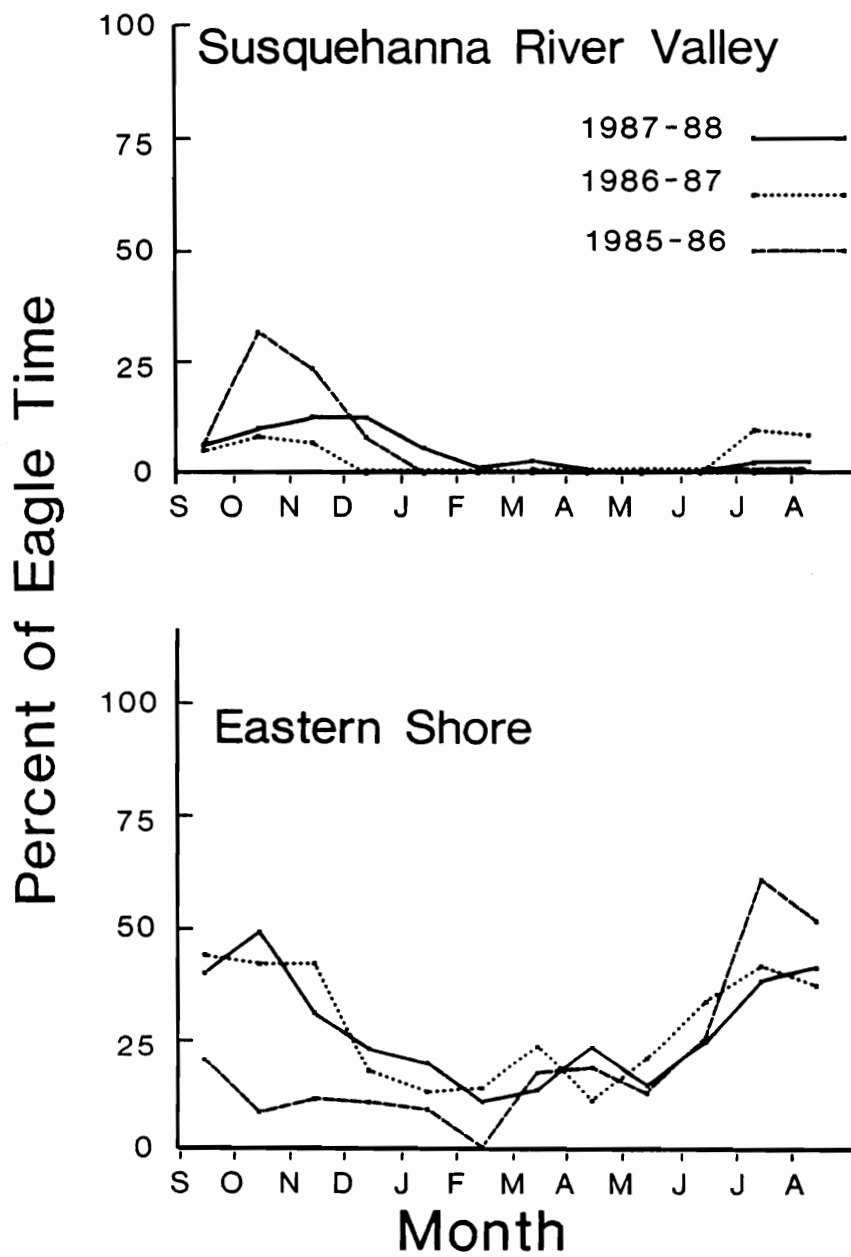


Fig. 5. Percent of time spent by radio-tagged Chesapeake nonbreeding bald eagles in each of 3 sub-areas of the northern Chesapeake, the northern Chesapeake in total, the lower Chesapeake and off of the Chesapeake from September 1985-August 1988. No monitoring of the lower Chesapeake or off the Chesapeake was conducted in September 1985-August 1986.

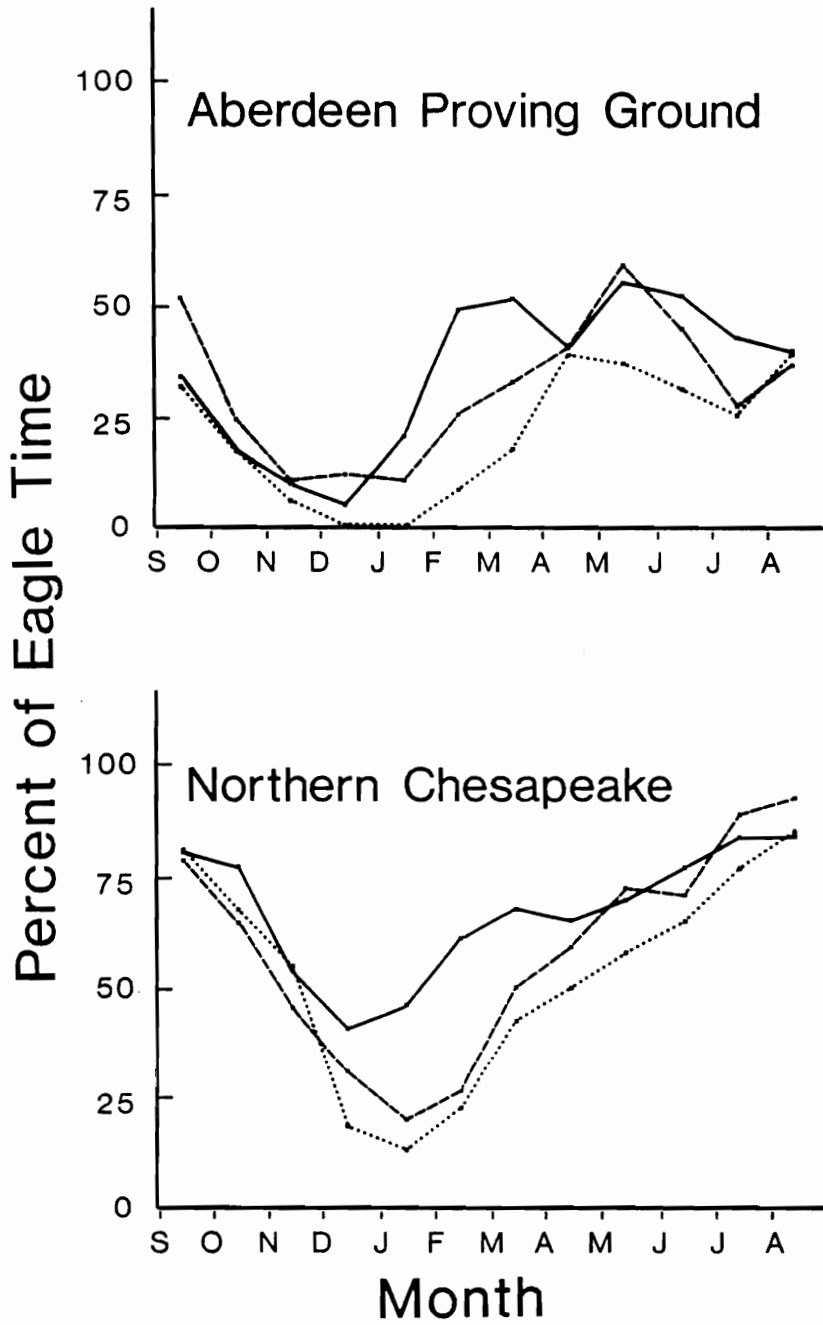


Fig. 5. (Cont.)

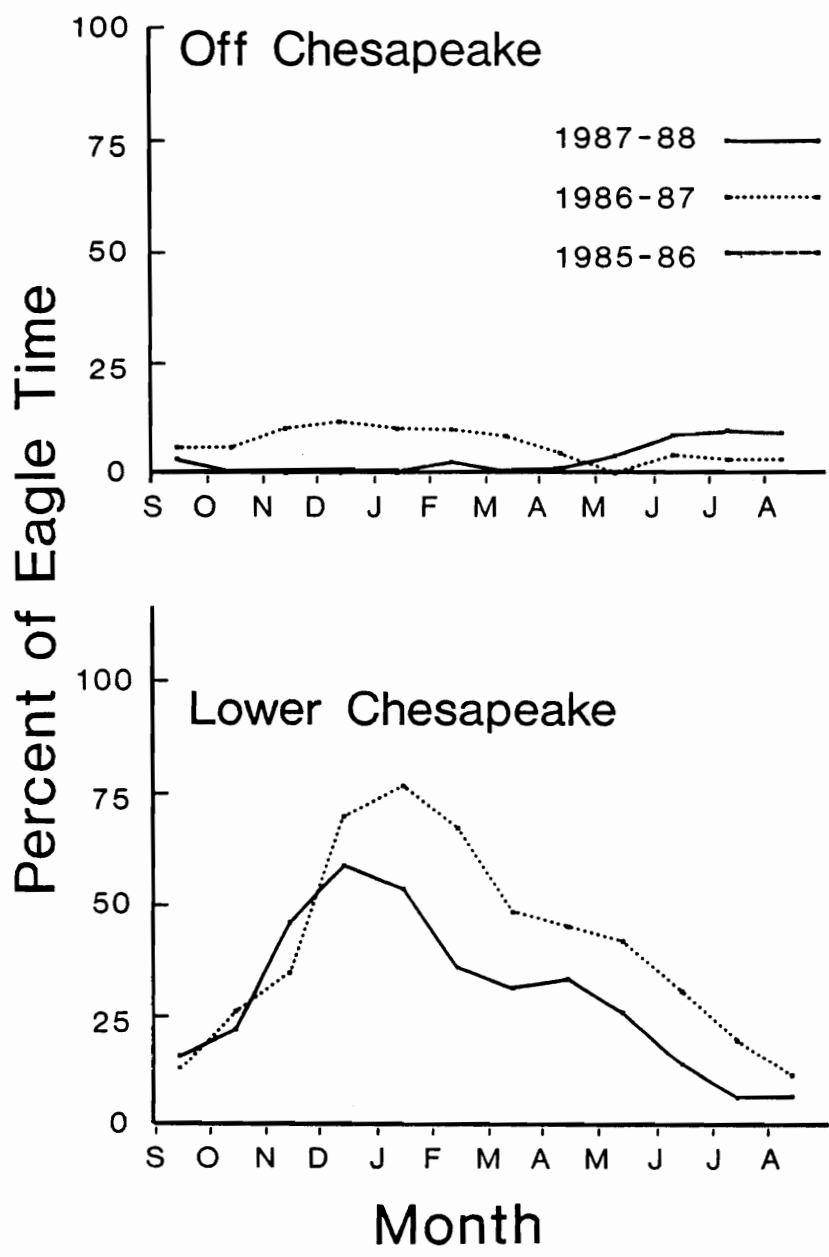


Fig. 5. (Cont.)

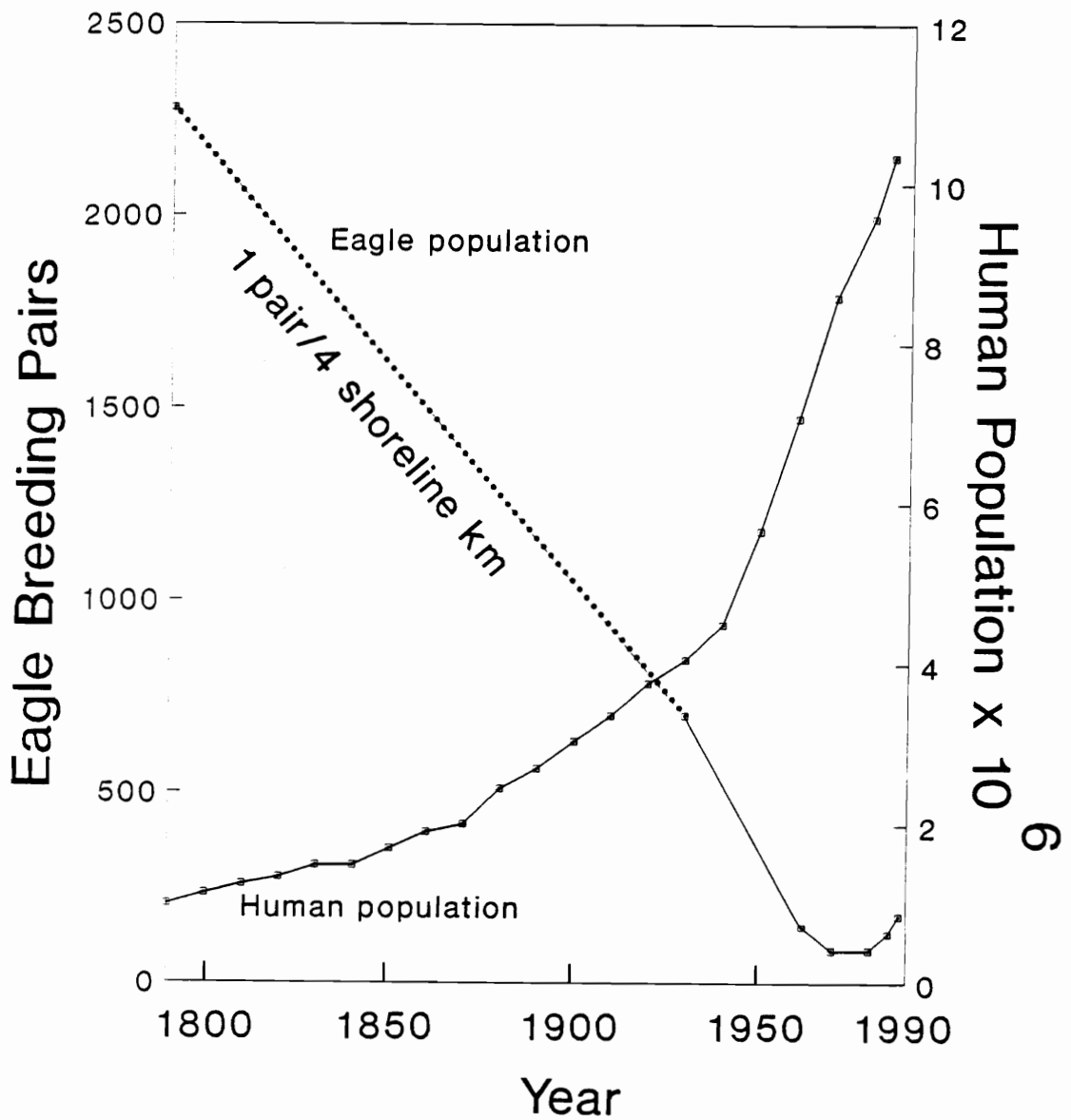


Fig. 6. Bald eagle breeding pairs and human population for the Chesapeake Bay region (Maryland and Virginia) from 1790 to 1989. The historic eagle population was estimated as being equal to that reported in southeast Alaska at 1 breeding pair/4 km of shoreline (Hodges and Robards 1982).



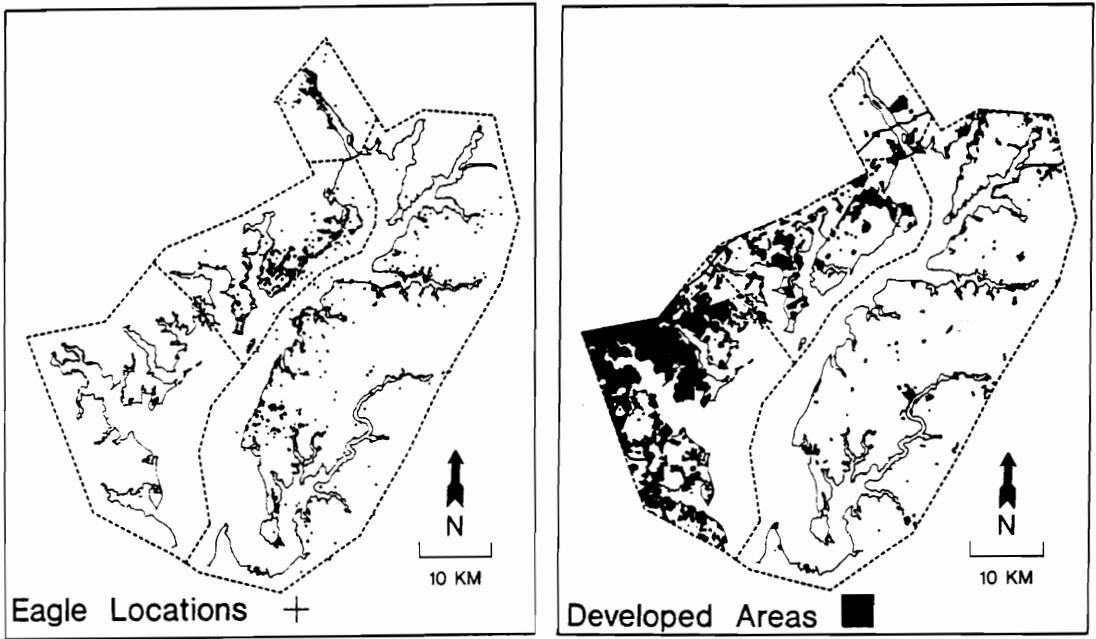


Fig. 7. Radio-tagged bald eagle locations ( $n = 1,683$ ) and developed areas of the northern Chesapeake Bay, Maryland, 1985-88.

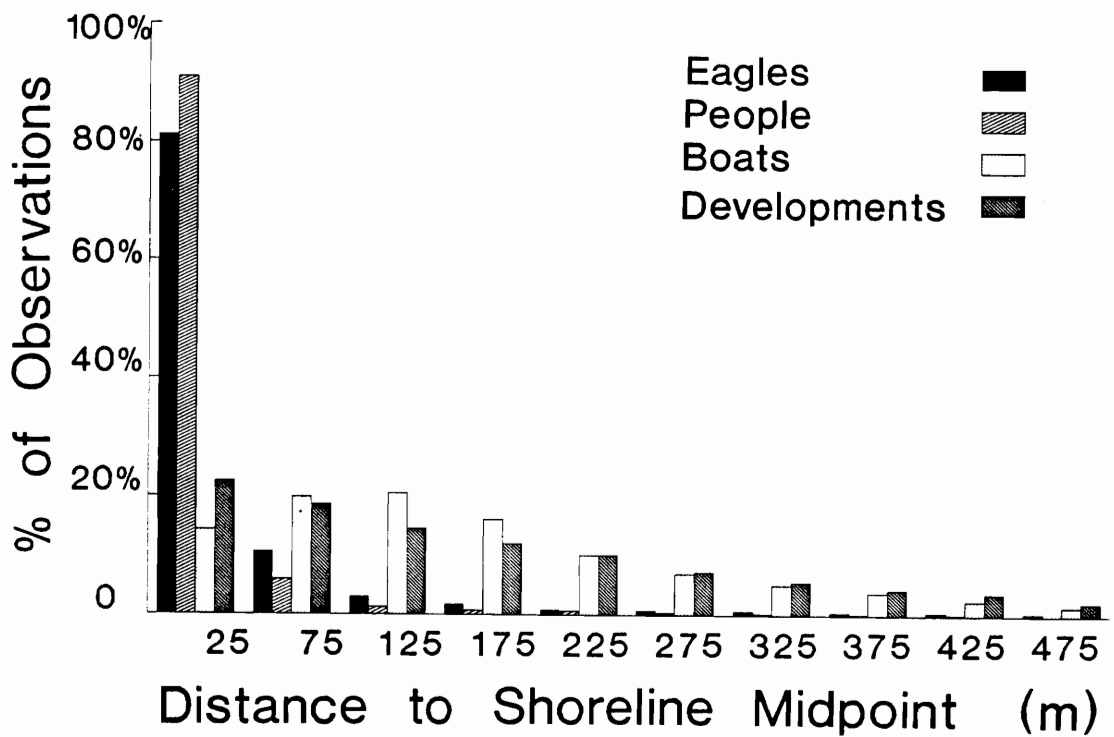


Fig. 8. Percent of bald eagles, pedestrians and boats observed within 50 m distance intervals of the shoreline during aerial surveys of the northern Chesapeake Bay, Maryland, 1985-88 and percent of development sites located on U. S. Geological Survey 7.5 minute topographic maps, updated with 1985 1:12,000 color aerial photos, within 50 m distance intervals.

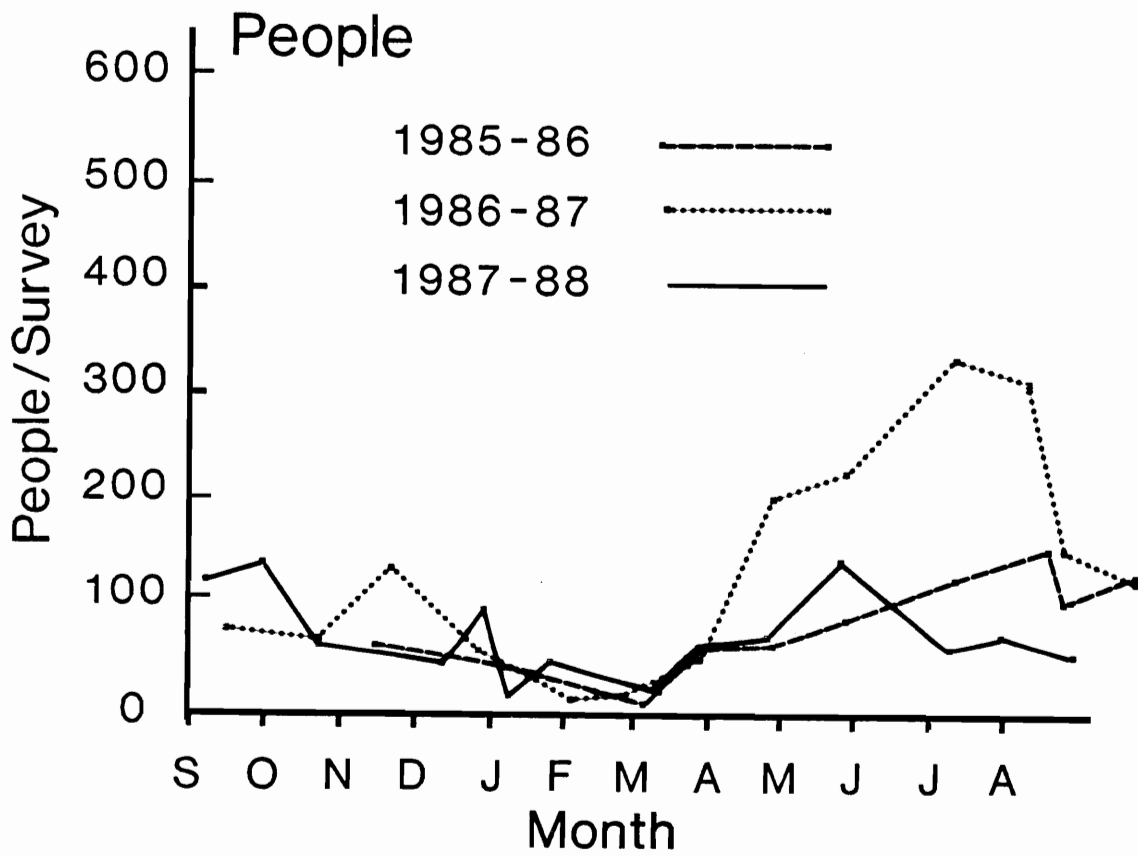


Fig. 9. Number of pedestrians observed within 500 m of the shoreline during monthly aerial surveys of 614 km of the northern Chesapeake Bay, Maryland, 1985-88.

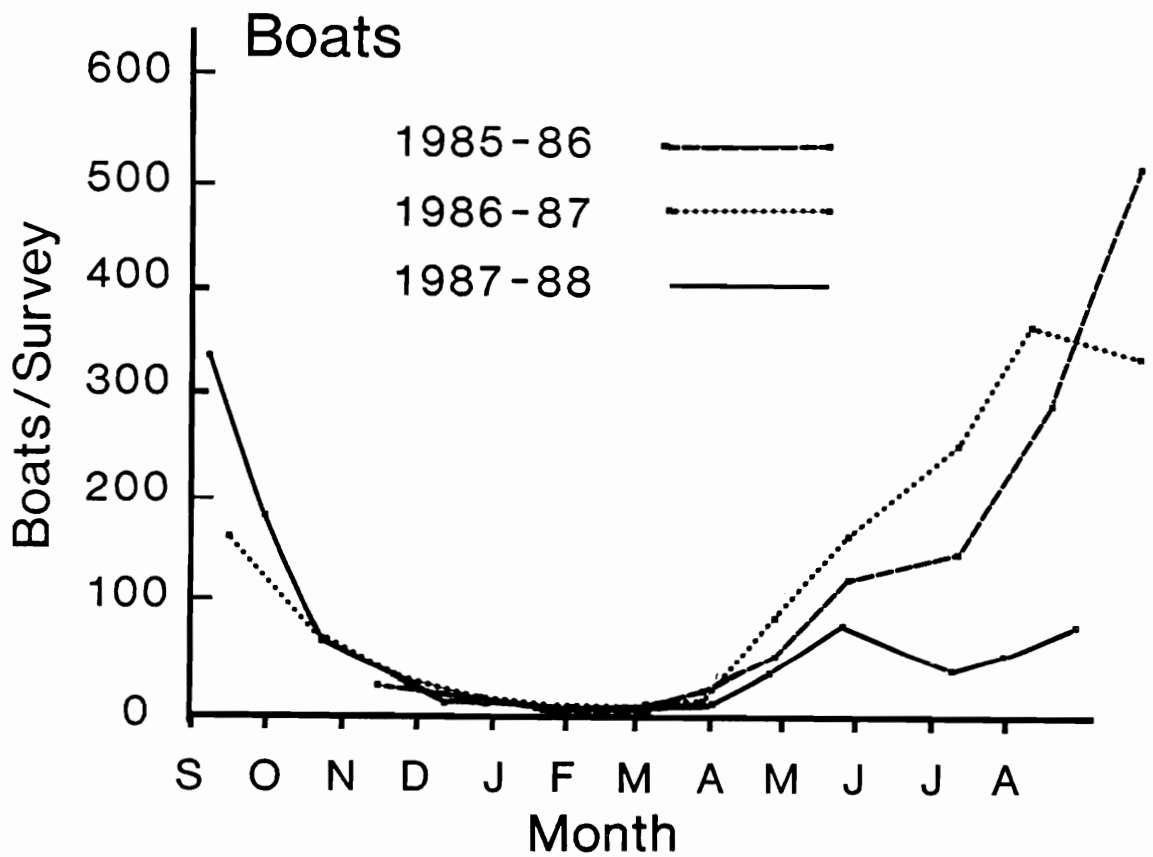


Fig. 10. Number of boats observed within 500 m of the shoreline during monthly aerial surveys of 614 km of the northern Chesapeake Bay, Maryland, 1985-88.

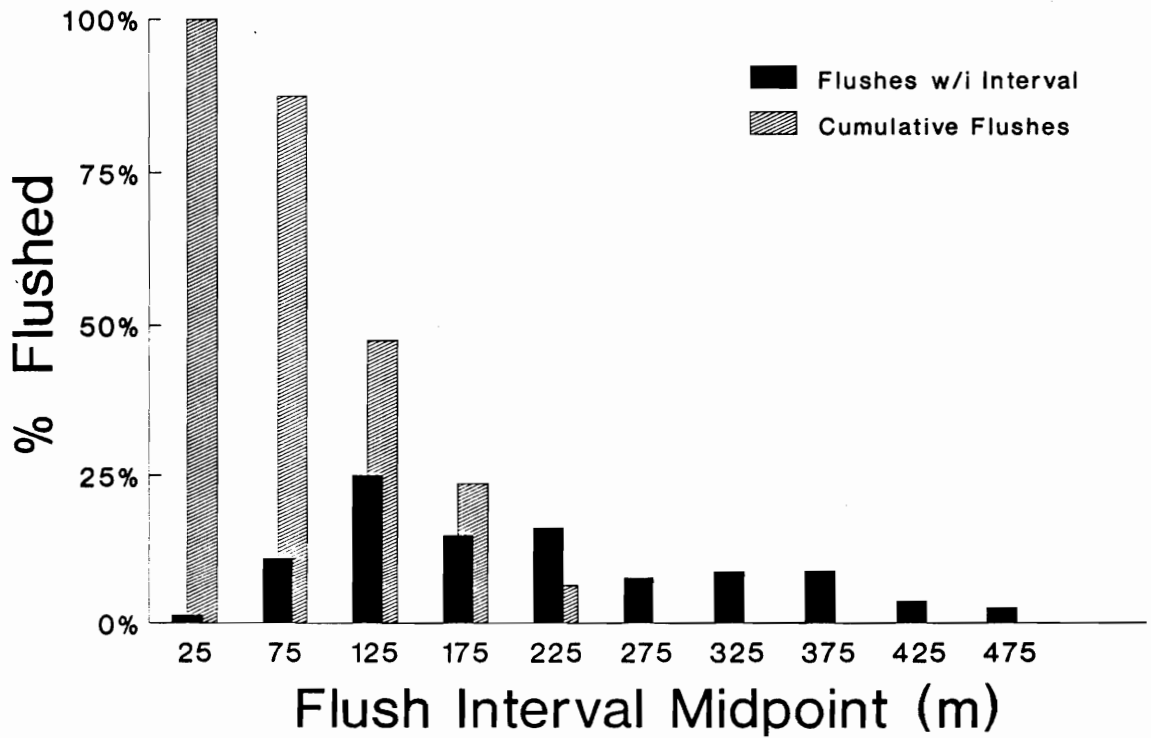


Fig. 11. Percent of bald eagles that flushed from experimental approach by boat ( $n = 76$ ) within 50 m distance intervals and cumulative percent flushed on the northern Chesapeake Bay, Maryland, 1987-88.

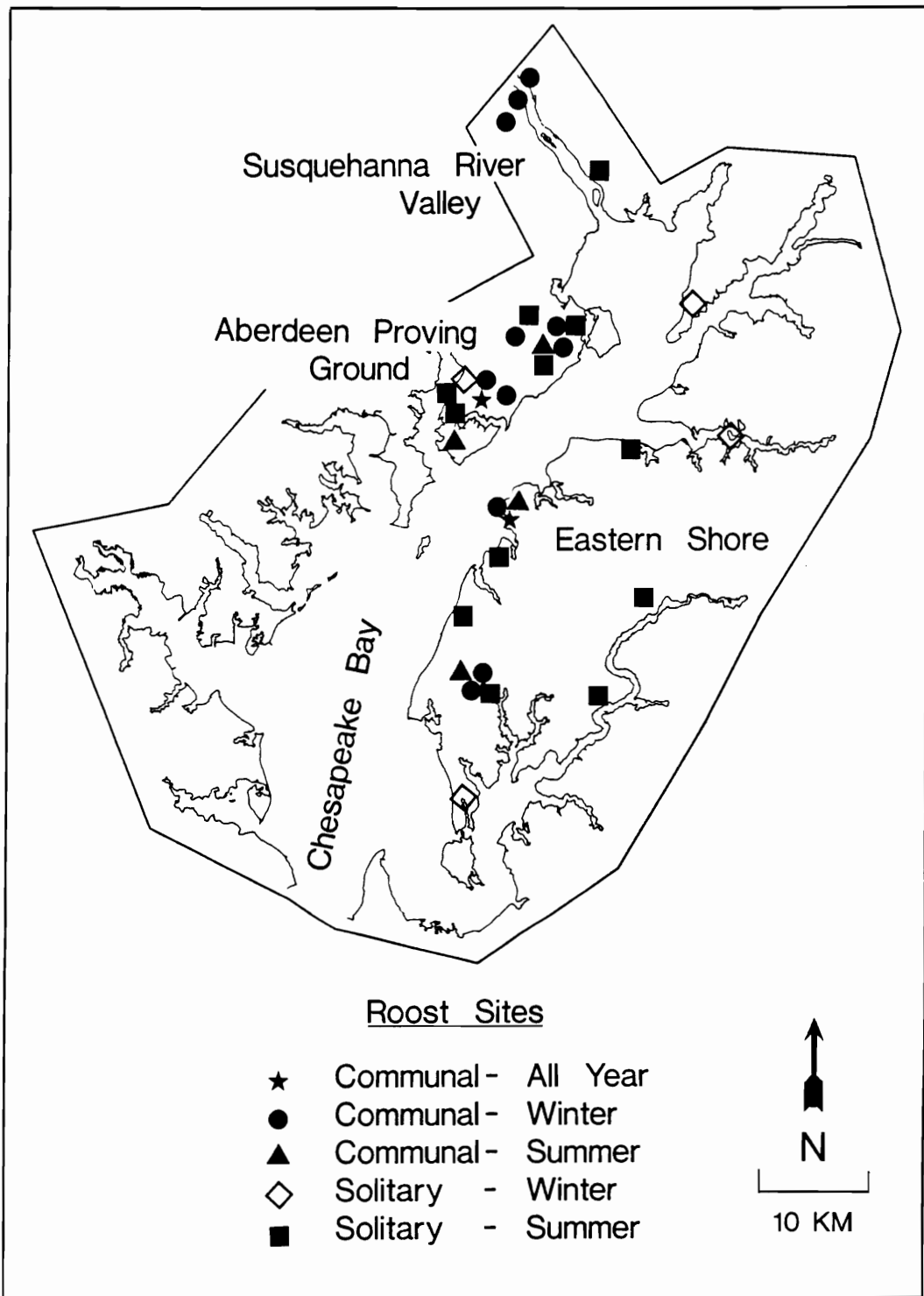


Fig. 12. Bald eagle roost sites, northern Chesapeake Bay, Maryland, 1984-89.

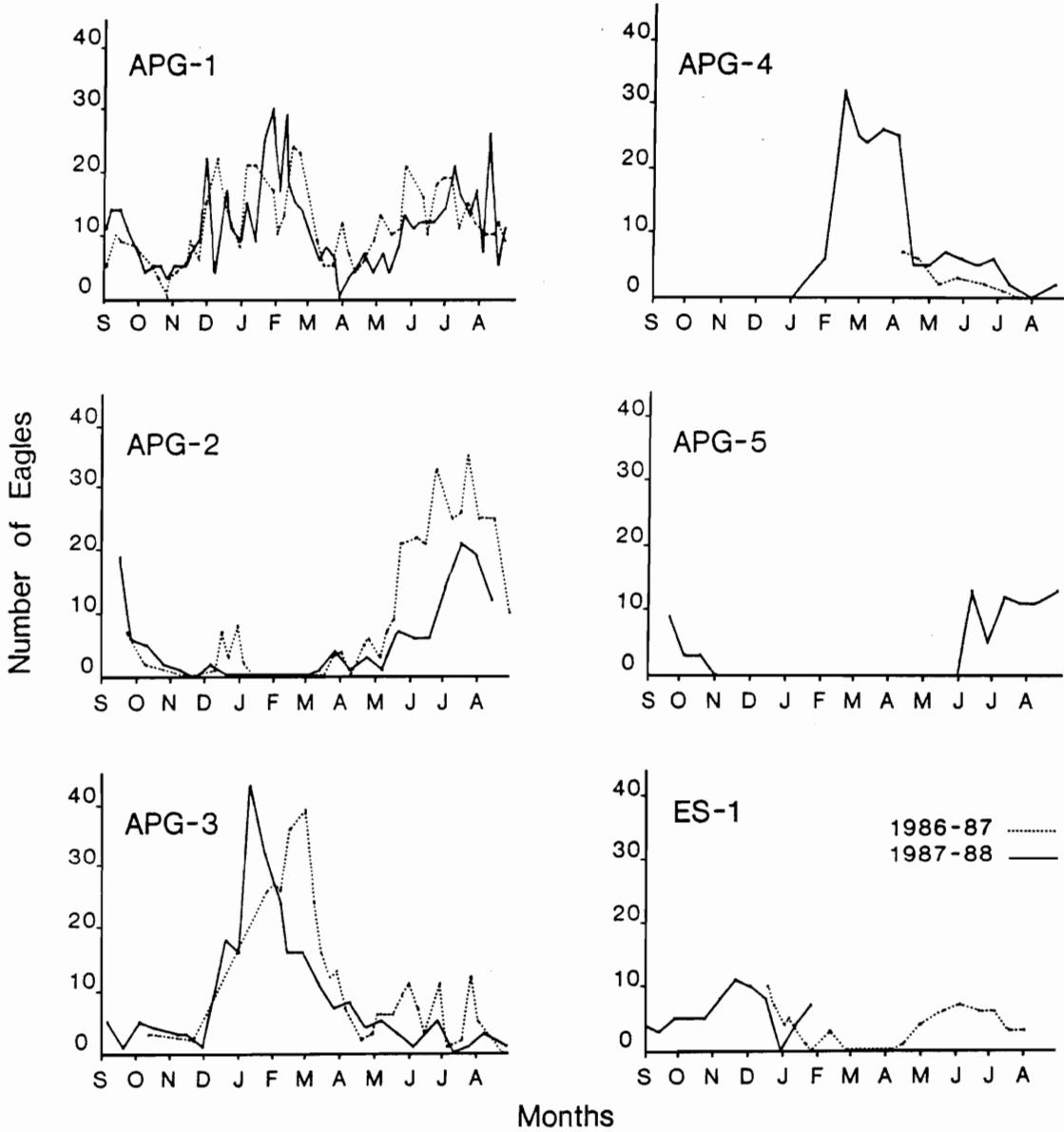


Fig. 13. Bald eagle counts at communal roosts, northern Chesapeake Bay, Maryland, 1985-88, by geographic area (APG = Aberdeen Proving Ground, ES = Eastern Shore and SRV = Susquehanna River Valley).

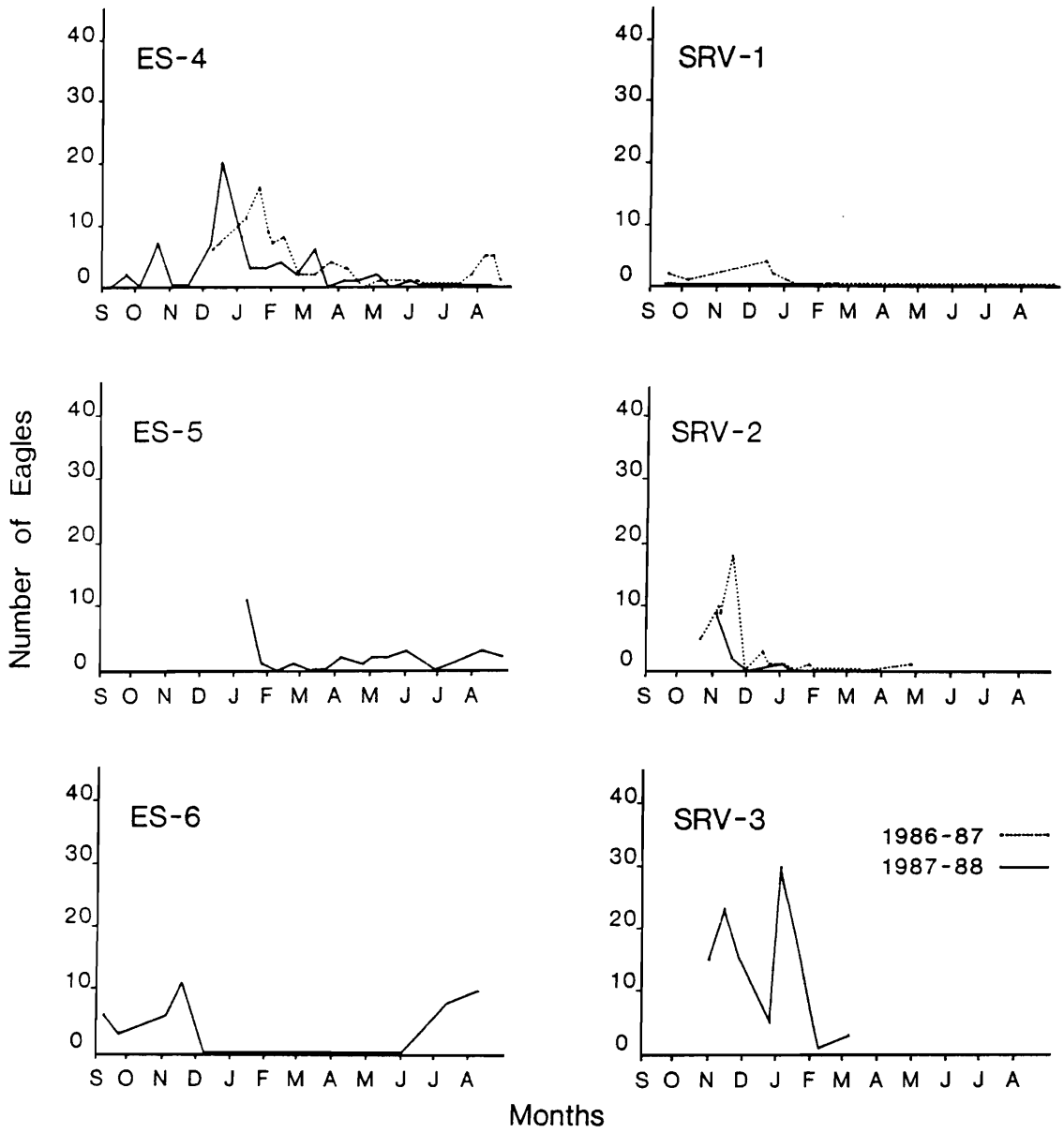


Fig. 13. (Cont.)



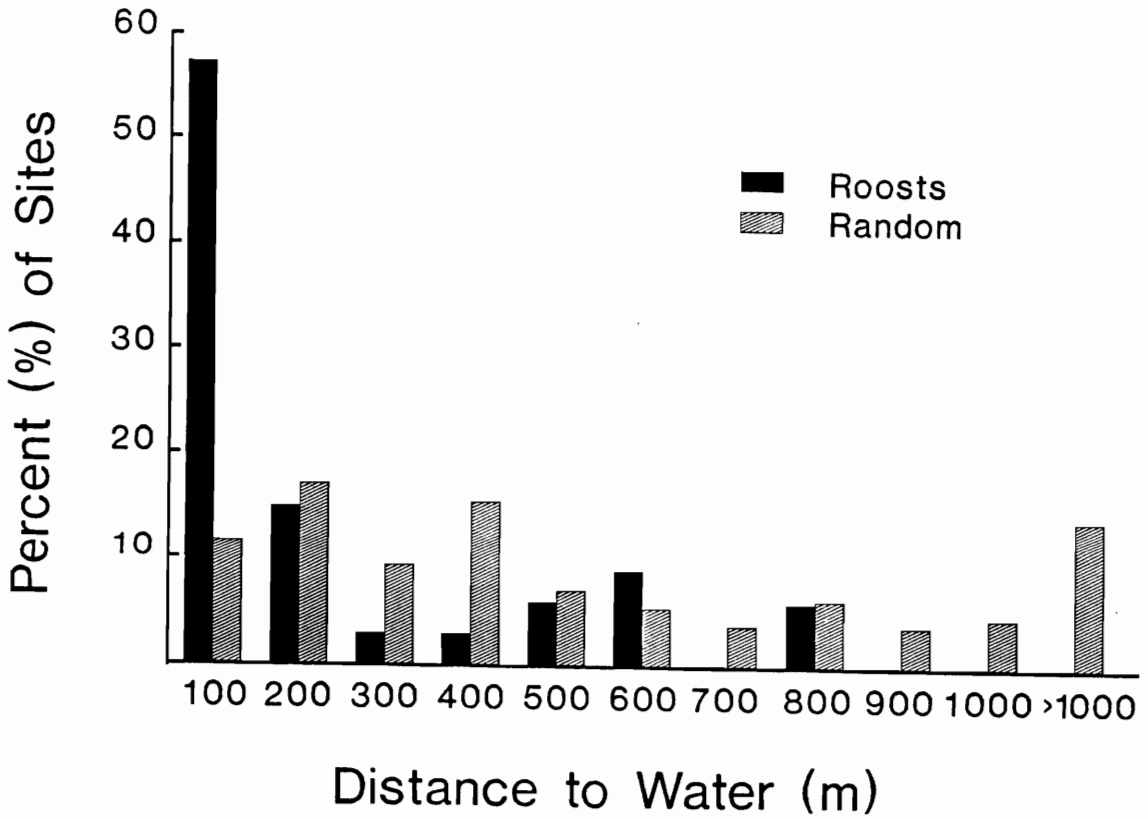


Fig. 14. Distance to water (m) (Chesapeake Bay, rivers, creeks, rills, or ponds) from roost ( $n = 33$ ), and random sites ( $n = 127$ ), northern Chesapeake Bay, Maryland, 1984-89.

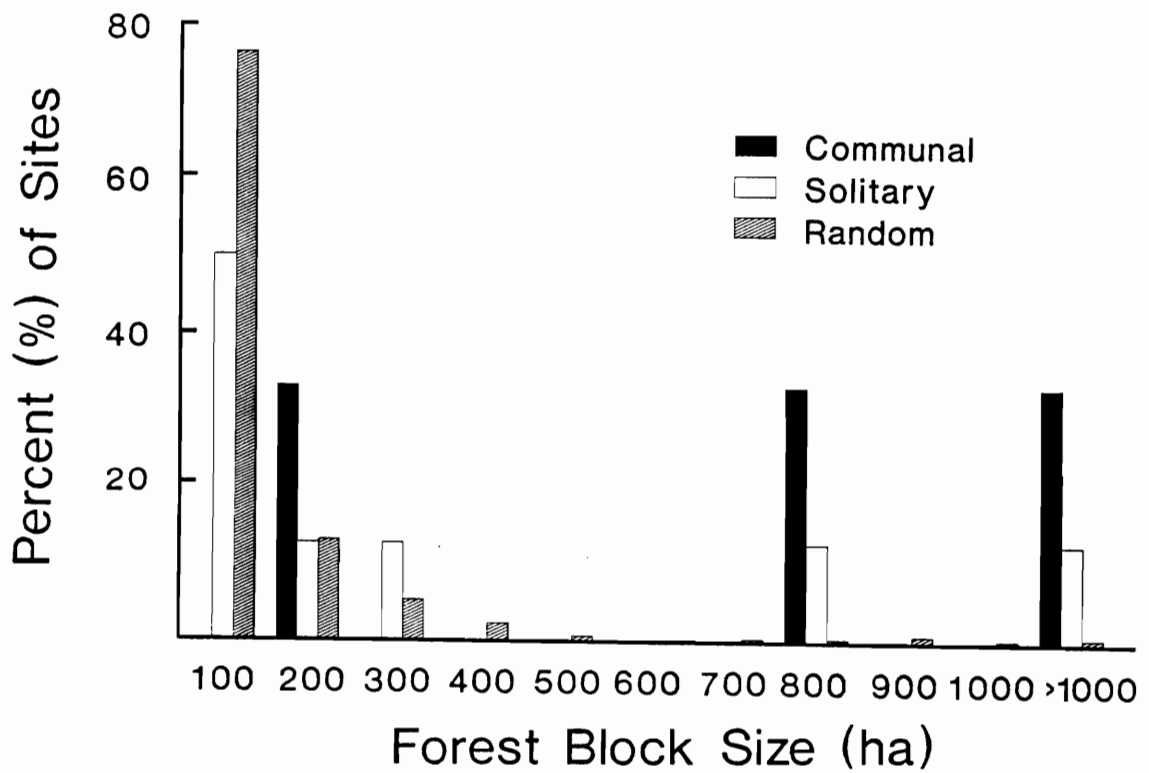


Fig. 15. Size of forested blocks by 100 ha intervals in which communal roosts ( $n = 6$  different blocks), and solitary roosts ( $n = 8$  blocks) occurred, and random forested block size ( $n = 558$ ), on northern Chesapeake Bay, Maryland, 1984-89.

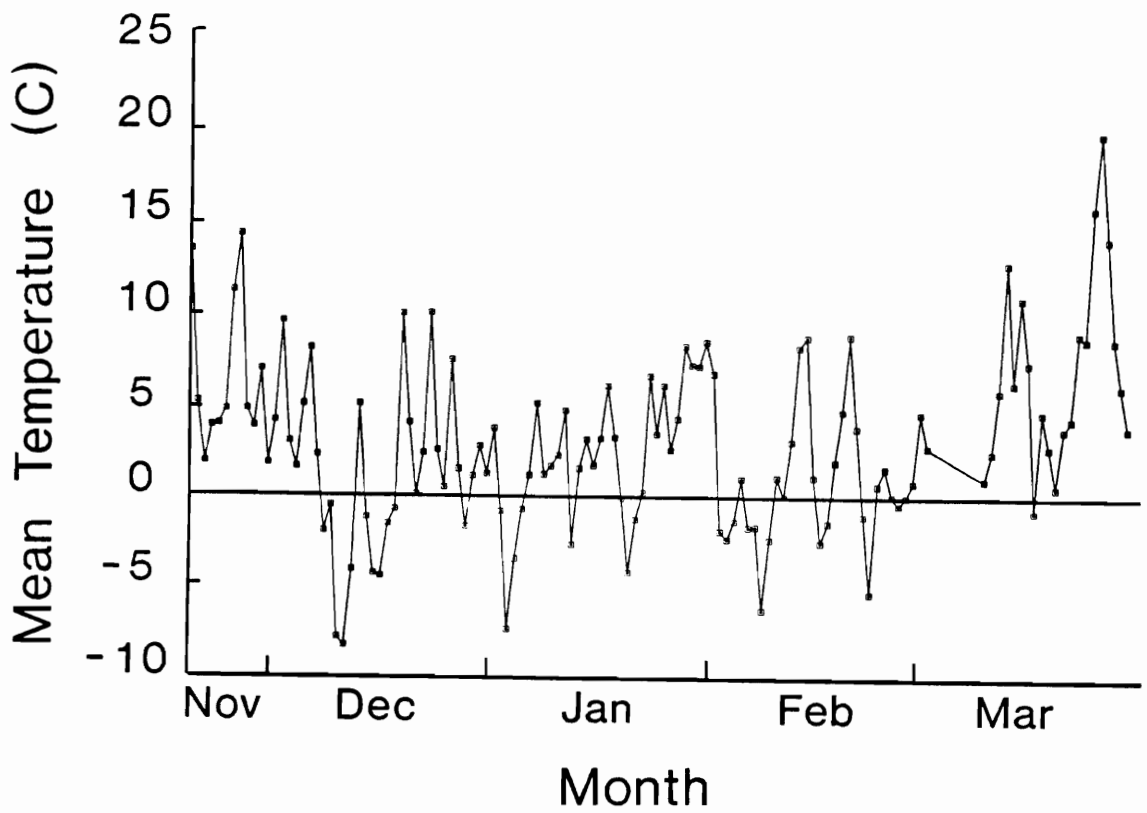


Fig. 16. Mean nightly temperature ( $^{\circ}\text{C}$ ) in 3 bald eagle communal roost sites monitored on the northern Chesapeake Bay, Maryland, November 1988 - March 1989.

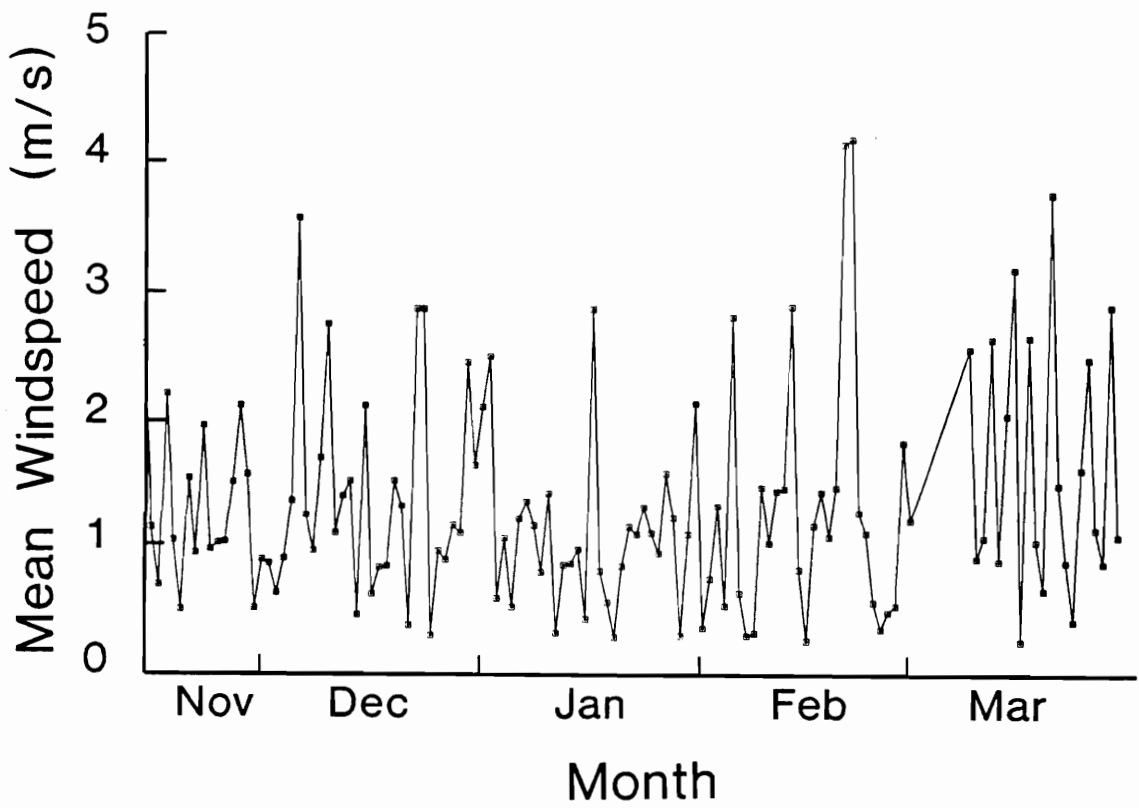


Fig. 17. Mean nightly wind speed (m/s) in 3 bald eagle communal roost sites monitored on the northern Chesapeake Bay, Maryland, November 1988 - March 1989.

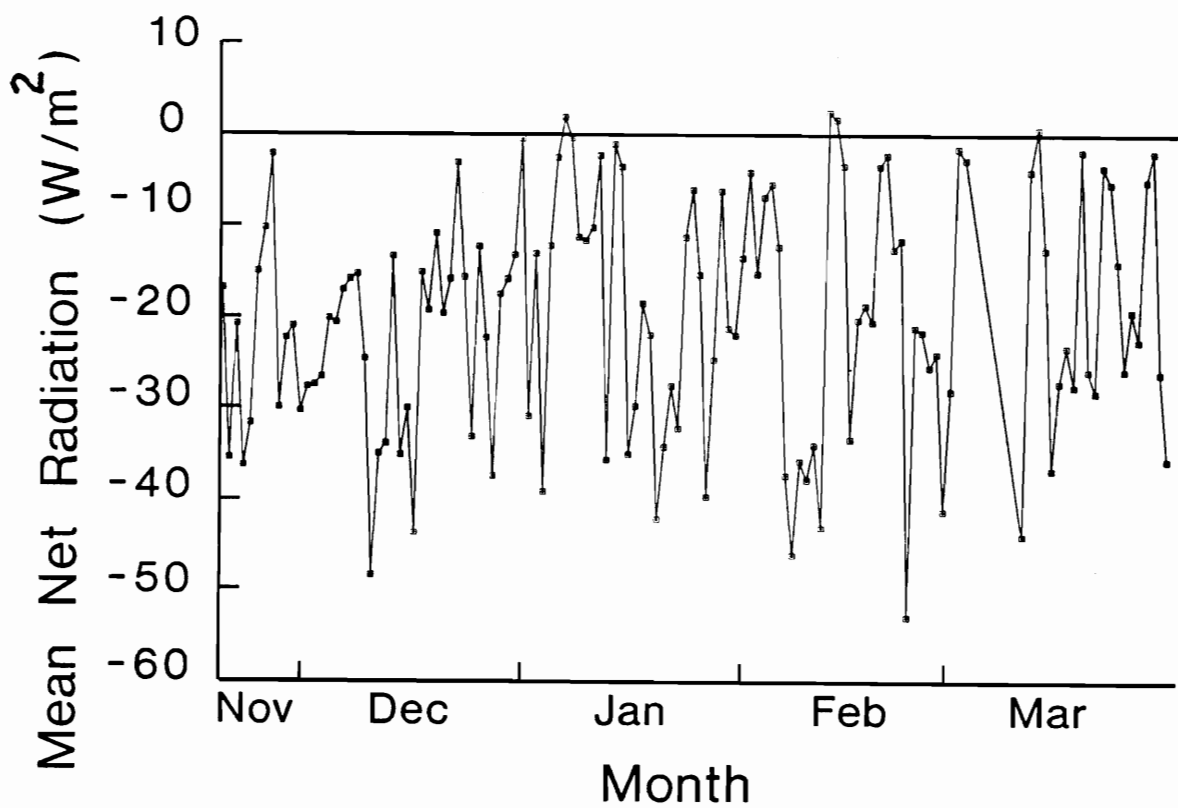


Fig. 18. Mean nightly net radiation (W/m<sup>2</sup>) in 3 bald eagle communal roost sites monitored on the northern Chesapeake Bay, Maryland, November 1988 - March 1989.

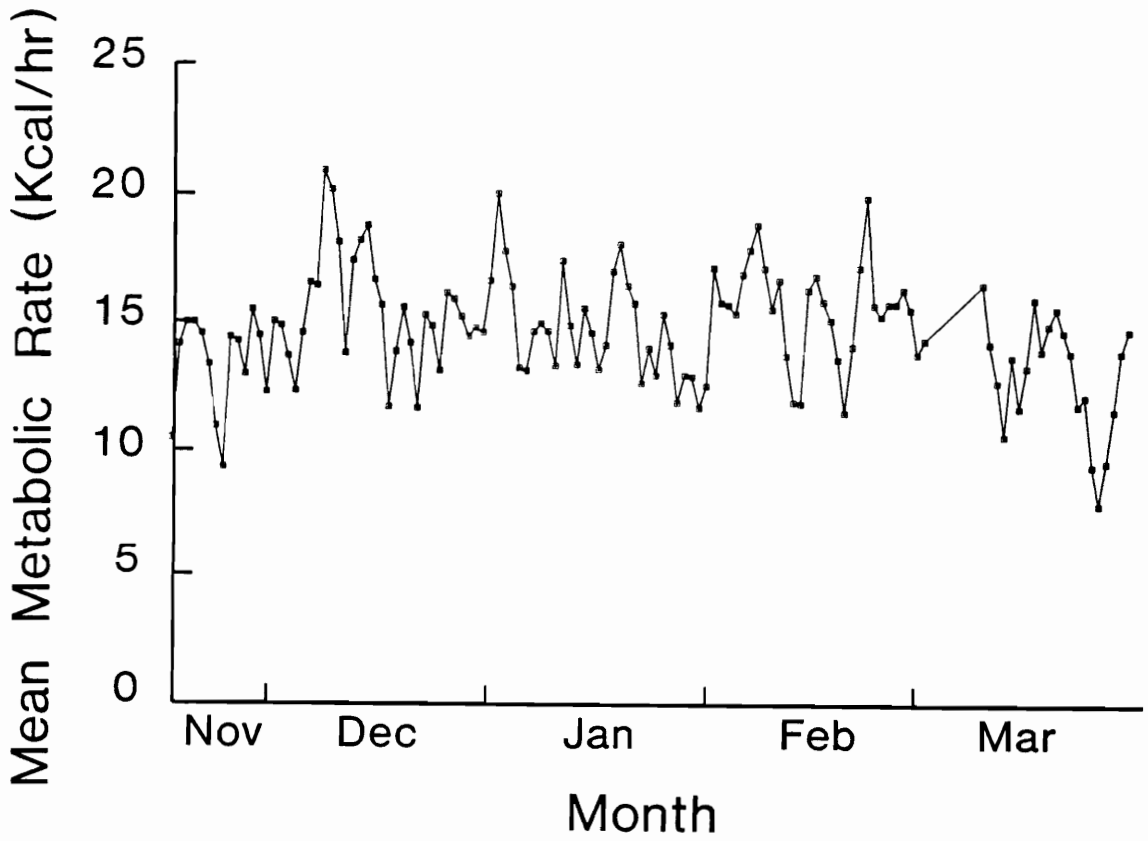


Fig. 19. Mean nightly metabolic production rate (kcal/hr) in 3 bald eagle communal roost sites monitored on the northern Chesapeake Bay, Maryland, November 1988 - March 1989.

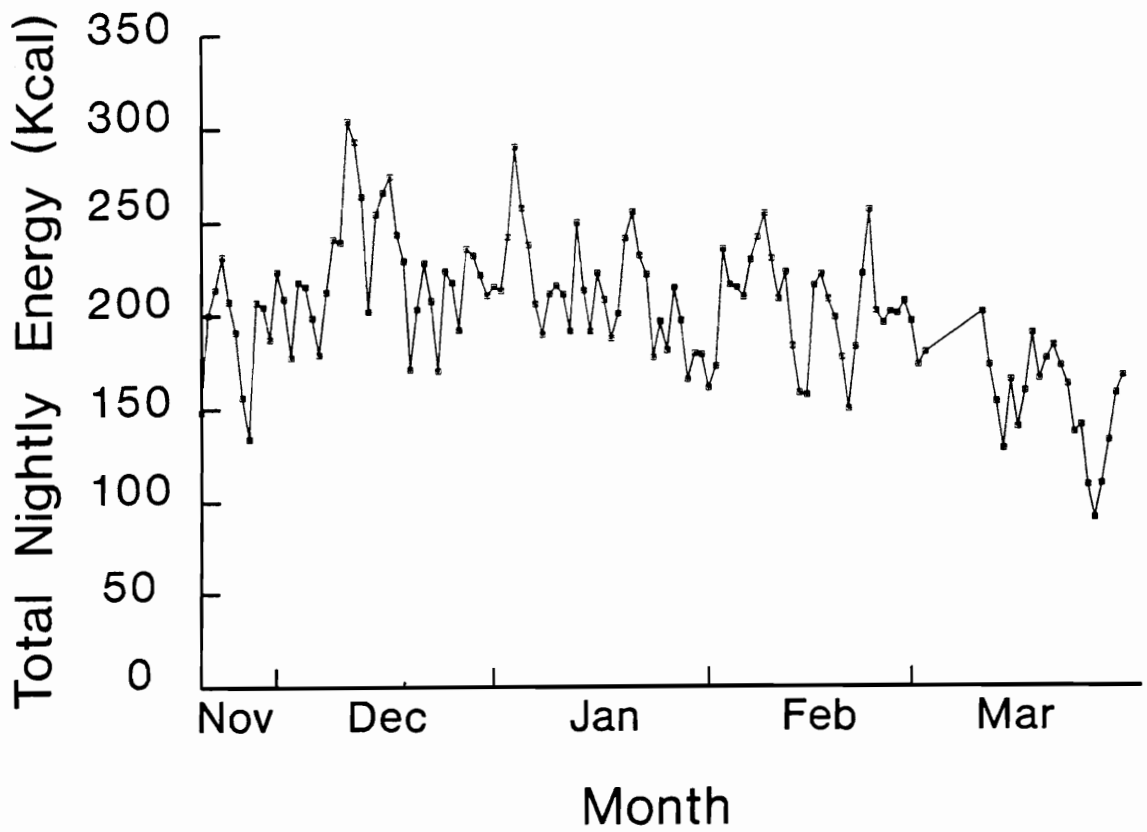


Fig. 20. Total nightly energy expended (kcal) in 3 bald eagle communal roost sites monitored on the northern Chesapeake Bay, Maryland, November 1988 - March 1989.

## VITA

David A. Buehler was born on September 5, 1955 in Rhinelander, Wisconsin to M. Edward and H. Jean Buehler. His early childhood was spent in the outdoors of northern Wisconsin where he gained a deep appreciation for wildlife and environmental quality and also observed his first bald eagles. He enrolled in the University of Wisconsin-Madison in fall, 1973 and spent three years working towards a degree in Nuclear Engineering. He changed majors in 1977 to Wildlife Ecology and completed his Bachelor's of Science degree in 1978. David continued at the University of Wisconsin-Madison and completed his Master's of Science degree in Wildlife Ecology in 1981, working with Dr. Lloyd B. Keith. His Master's thesis is entitled "Snowshoe hare distribution and habitat use in Wisconsin". After spending 3 years working for the Wisconsin Public Service Commission on environmental planning and impact assessment, David enrolled at Virginia Polytechnic Institute and State University in 1984 in the Department of Fisheries and Wildlife Sciences to pursue his doctorate working with Dr. James D. Fraser on bald eagles on the northern Chesapeake Bay.

*David A Buehler*