

Using a Geographic Information System to Analyse Bald Eagle *Haliaeetus leucocapthalmus* Habitat on the Chesapeake Bay, Maryland

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INTRODUCTION

A Geographic Information System (GIS) is a computer based system that can store and manipulate spatial information (Aronoff 1991). GIS technology is useful for wildlife studies because it enables us to organise, synthesise, and analyse the data we collect about a species and helps us to understand spatial and nonspatial relationships. We used this technology to study several aspects of habitat use by the endangered Bald Eagle *Haliaeetus leucocephalus* on the Chesapeake Bay.

The Chesapeake Bay is one of the most important Bald Eagle habitats in eastern North America. The Bay supports more than 200 breeding pairs of Bald Eagles and hundreds of immature eagles. The Bay also provides habitat for eagles migrating along the east coast of the United States (Buehler *et al.* 1991a).

Unfortunately, the amount of eagle habitat on the Chesapeake Bay is decreasing rapidly. A report to the Chesapeake Bay Executive Council (Gray *et al.* 1988) predicted a 73% increase in the amount of developed land in the Bay watershed in Virginia and an 80% increase in Maryland between 1978 and 2020.

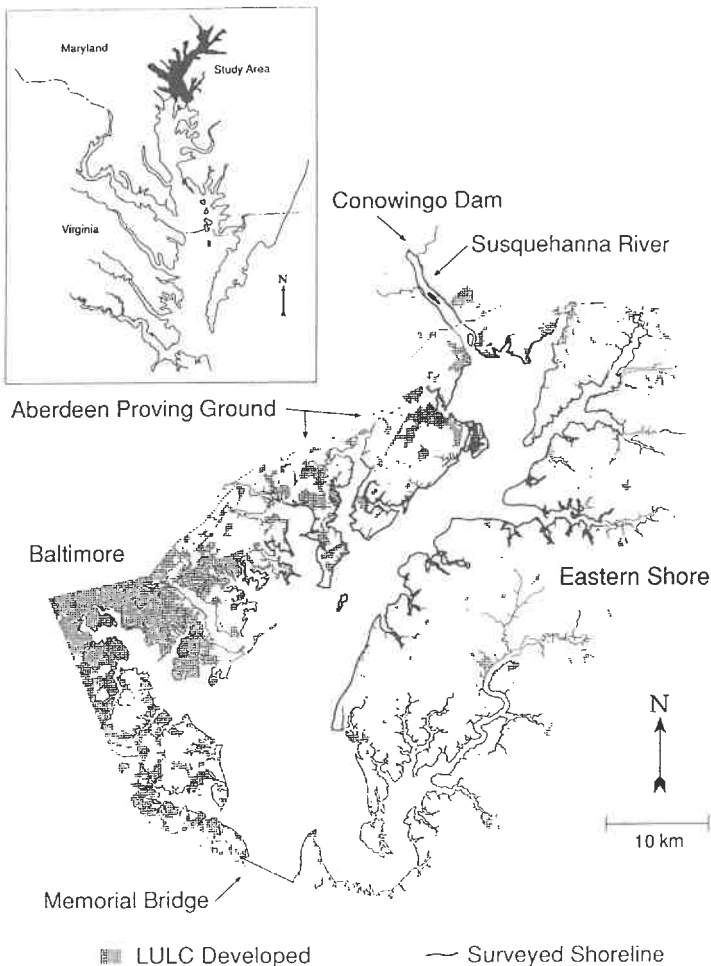
In order to understand the impact of this shoreline development on Bald Eagles, we studied eagle use of the shoreline during 1985-1991. We radio-tagged and monitored nonbreeding eagles on the northern Chesapeake Bay to identify used shoreline. We used the ARC/INFO GIS (Environmental Systems Research Institute, Inc. 1988) to analyse habitat use in light of availability and to conduct other spatial calculations. In this paper, we discuss some of the benefits and drawbacks we have experienced with this technology.

STUDY AREA

The study area extended from the William Preston Lane, Jr. Memorial Bridge south of Baltimore, MD, to the Conowingo Dam on the Susquehanna River. The area contained 3,426km² and included approximately 2,500km of bay, river and creek shoreline. It also included part of metropolitan Baltimore and the U.S. Army Aberdeen Proving Ground, a military installation (Figure 1).

The shoreline habitat varied greatly. Near Baltimore it was dominated by residential and commercial buildings, roads and parking lots. On Aberdeen Proving Ground, north of Baltimore, the shoreline cover consisted of oak-sweetgum (*Quercus* spp. -*Liquidambar styraciflua*) forests mixed with large marshes. The shoreline of the Susquehanna River, at the north end of the study area, was dominated by oak-hickory (*Carva* spp.)-sweetgum forests. The eastern shore of the study area had small oak-sweetgum woodlots interspersed among large agricultural fields.

Figure 1. U.S. Geological Survey Land Use and Land Cover (LULC) developed areas on the northern Chesapeake Bay (Anderson *et al.* 1976) are shaded. The 614km of shoreline surveyed for eagles is delineated by a bold line.



METHODS

Capture and Telemetry

We captured 49 eaglets in nests, and trapped 24 free-flying birds using padded leg hold traps (Young 1983) and floating noose-fish (Cain & Hodges 1989). We attached 65-g radio transmitters with solar-charged, nickel-cadmium batteries (Telemetry Systems, Inc., Mequon, WI) to all eagles. Radios were mounted on the birds in a back-pack configuration using dark brown, teflon ribbon (Bally Ribbon Mills, Bally, PA).

We tracked 73 radio-tagged eagles from a fixed-wing aircraft with strut-mounted H-antennas. We attempted to visually locate the birds on the study area 2-3 times a week during 1985-1988. Visual locations were necessary to obtain the level of accuracy required for our analyses. When ≥ 10 radioed birds were present on the study area during a flight, we randomly selected 10 for visual relocation.

We also conducted surveys of Bald Eagles along 614km of the study area shoreline from fixed-wing aircraft (Figure 1). Surveys were flown 50m from the shoreline and 50m above the water at approximately 150km per hr. The surveys began about 30 minutes after sunrise and lasted about 2.5 hours.

Eagle locations were plotted on 1:24,000 U.S. Geological Survey (U.S.G.S.) topographical maps. The Universal Transverse Mercator (UTM) co-ordinates of the locations were determined and manually entered into our ARC/INFO computer data base.

Analyses

We used ARC/INFO software on a MicroVAX II that was linked with an IBM mainframe computer and a Calcomp 1044 plotter. The analyses we describe in this paper involve habitat use versus availability, distance measurements and habitat area determination.

Habitat Use Versus Availability

Wildlife managers and researchers often need to ascertain how a raptor utilises available habitats. When an animal's home range extends over a large area, the difficulty of classifying habitats and their use increases. The first methodology described here involved determining which habitat types eagles used and comparing the frequency of eagle locations in each type with the proportion of the study area with that habitat type.

Our objective for this GIS analysis was to determine if eagle distribution was independent of the distribution of human developments. Eagle location data and the Land Use and Land Cover (LULC) data base from the U.S. Geological Survey (Anderson *et al.* 1976) were used to perform this analysis (these digital representations were referred to as "coverages"). The LULC coverage divided the study area into polygons which were categorised based on the predominant land characteristics (developed, forested, farmland, wetland and other). The minimum polygon size was 4.0ha. Land use was classified as developed if there were ≥ 4 buildings within the minimum cell size (Figure 1). The coverage was created in 1976.

The eagle location data were overlaid on the LULC coverage. The ARC/INFO Identity command was used to calculate the number of eagle locations in each habitat type, and the relative abundance of each habitat type. These data were output to our mainframe computer. The number of eagle locations in each habitat type then was compared to the proportion of the study area with that habitat type to determine if the eagles used the habitats in proportion to their availability.

Distance Measurements

For raptor studies, it is often necessary to know the distance from some point to an object or edge. GISs are well suited to such analyses. In this analysis, we determined the distance from the shoreline to all buildings within 500m of the shore. We also calculated building density. The objective was to assess the effects of building density and distance from the shore on Bald Eagle use of the shoreline.

We created an ARC/INFO coverage of the locations of all buildings (houses, marinas, farms, commercial buildings, industrial buildings and military buildings) within 500m of the shoreline.

Table 1. Land Use Land Cover (LULC) classification at radio-tagged Bald Eagle locations and abundance (km²) in each LULC classification on the study area (obs, exp under the hypotheses of homogenous proportions, and associated cell χ^2 values), northern Chesapeake Bay, Maryland, 1985-88.

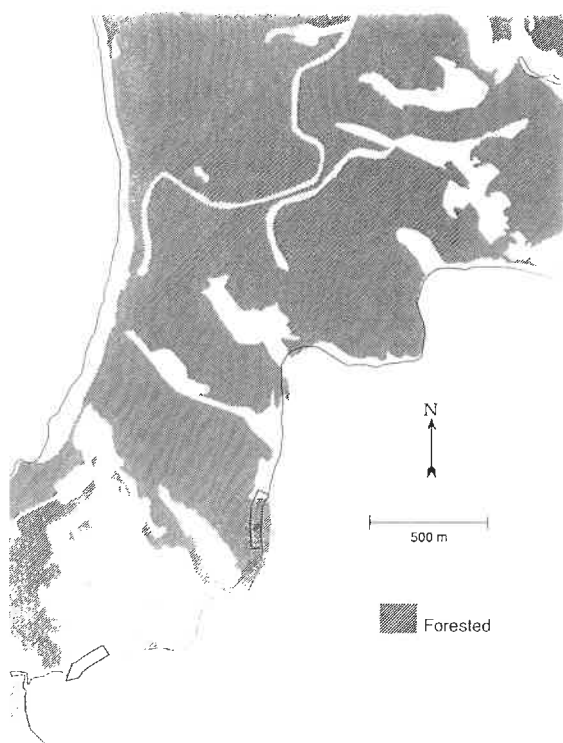
	LULC Classification									
	Developed		Farmland		Forested		Wetland		Other	
	Obs	Exp Cell χ^2	Obs	Exp Cell χ^2	Obs	Exp Cell χ^2	Obs	Exp Cell χ^2	Obs	Exp Cell χ^2
Eagle Locations ^a	55	153.3 63.0	338	480.0 42.0	562	402.9 62.9	161	72.1 109.7	1	8.8 6.9
Northern Chesapeake Bay ^a	400	301.7 32.0	1,087	945.0 21.3	634	793.1 31.9	53	141.9 55.7	25	17.2 3.5

^a LULC classification at eagle locations differed from abundance in LULC classifications on the northern Chesapeake Bay (χ^2 428.9, 4 df, $P < 0.001$). (Adapted from Buehler *et al.* 1991b).

The buildings were digitized from 1:24,000 U.S.G.S. topographical maps (Buehler *et al.* 1991b). Because some of the maps were outdated (1953-85), we used 1985 1:12,500 colour aerial photographs to update the building locations.

Using Advanced Revelation computer software, we divided the shoreline coverage digitized from 1:24,000 topographical maps into 250m sections. We then calculated the distance from the shoreline to the closest building for each section and the density of buildings within 500m of each section. We used ARC/INFO to overlay the eagle locations onto the sectioned shoreline and considered a section used if we located ≥ 1 eagle within 50m of that section (Buehler *et al.* 1991b).

Figure 2. Shoreline on the northern Chesapeake Bay, Maryland, showing sampled sections (dark outline) and forested areas based on aerial photographs (shaded). The shoreline and forested areas are poorly aligned. The forest should meet the shoreline on the west and is overlapping approximately 50m on the eastern shore of the peninsula. Shown at 1:12,500 scale.



Habitat Area Determination

Ascertaining the amount of area dominated by different habitats can be an important part of raptor studies. In our study, we determined the area (m^2) of forest within shoreline sections 250m long and 50m wide (Figure 2). Our objective in this analysis was to determine if eagle use of shoreline perching areas was related to the percentage of area covered by forest. We used the coverage of the study area shoreline, the eagle locations coverage and a coverage of forested areas along the shoreline. The forest coverage was digitized from 1985, 1:12,500 colour aerial photographs. We randomly selected a sample of 115 shoreline sections used by eagles and 112 unused sections.

Initially, we ocularly estimated the percentage of forest covering each section using the 1:12,500 colour aerial photographs. Each section's boundary was traced onto transparencies and overlaid on the photos. A 1mm dot grid was then used to estimate the percentage of forest on each section.

To produce similar forest cover estimates using ARC/INFO, we used the Buffer function to create a 250 x 50m shoreline area for each selected section. We used the ARC/INFO Intersect command to superimpose the coverage containing the buffered shoreline sections onto the coverage with forested areas (Figure 2). The resulting coverage identified the amount of forested and nonforested area within each selected shoreline section. We then calculated the percentage of each section covered by forest.

RESULTS AND DISCUSSION

Habitat Use Versus Availability

The study area contained 2,199 km² of terrestrial area. The LULC data base classified 400km² (18.2%) of this area as developed, 1,087km² as farmland (49.4%), 634km² as forest (28.8%), 53km² as wetland (2.4%) and 25km² as other (1.1%) (Buehler *et al.* 1991b).

Eagle distribution was not independent of development. Eagles used developed land less than expected and forested land more than expected under a model of independence. Only 55 of 1,117 (4.9%) radio-tagged eagle locations occurred on LULC developed areas, although 18.2% of the study area was developed ($\chi^2 = 428.9$, 4 df, $P < 0.001$; Table 1). Most of the locations on developed land (44 of 55, 80.0%) were on Aberdeen Proving Ground, where human activity was low relative to other developed areas, and few buildings occurred. Of the 1,117 eagle locations, only 11 (1.0%) occurred in a nonmilitary-developed area, even though developed areas other than military accounted for 14.8% of all terrestrial area (Buehler *et al.* 1991b).

Distance Measurements

There were 5,120 buildings within 500m of the shoreline we surveyed. Of the 2,532 surveyed sections, 1,673 (66.1%) had buildings within 500m of the shore. The average density of these buildings was 0.09 ± 0.003 (SE) buildings per ha. The density of buildings within 100m of the shore was greater than within 500m (Wilcoxon signed rank, $x = 1.24 \pm 0.05$ buildings/ha, $P < 0.001$); 245 developed sections had 21 buildings per ha.

Eagles were located less often on shoreline with buildings than would be expected if eagles selected shoreline sections independent of development (Buehler *et al.* 1991b). Sections with 0.01-0.99 buildings per ha within 100m of the shore (94 of 455, 20.7%) were used more frequently than sections with 21 buildings per ha (17 of 245, 6.95%). We observed eagles on 565 of 1,832 sections (30.8%) with no buildings within 100m of the shore ($\chi^2 = 73.4$, 2 df, $P < 0.001$) (Buehler *et al.* 1991b).

Eagle use of shoreline sections was inversely related to the density of shoreline development (logistic regression, $\beta = -4.57$, $SE = 0.97$, $\chi^2 = 22.1$, $P < 0.001$) and directly related to the distance of the development from shore (logistic regression, $\beta = 0.001$, $SE = 0.001$, $\chi^2 = 5.3$, $P = 0.02$) (Buehler *et al.* 1991b).

Comparison of Results from Aerial Photo Data and LULC Data

Comparing the locations of houses from aerial photographs and maps with the LULC area classification data, we found that only 143 of the 245 (58.4%) sections with ≥ 1 building per ha within 100m as calculated from aerial photos, were classified as developed in the U.S.G.S. LULC data base (Buehler *et al.* 1991b). This was probably because of additional development since 1976 when the LULC data were collected.

Eagles almost never used shoreline sections with ≥ 1 buildings per ha. This is consistent with the lack of radio-tagged eagle use of sections considered developed (≥ 4 buildings/4 ha) by the LULC data. Radio-tagged eagles used areas identified as forest by the LULC data more frequently than expected based on availability, whereas eagle use of developed and agricultural land was used less than expected based on availability (Buehler *et al.* 1991b). Thus the LULC data base can be

used to locate areas which are **not** eagle habitat.

However, eagles did **not** use some of the areas classed as forested in the LULC data base. This was apparently because some areas had been developed since 1976 when the data base was created. Thus LULC forested areas must be examined by some other means to determine which forested sections are likely to be used. Recent aerial photographs or topographical maps provide more up-to-date information on the locations of houses and the configuration of forested areas than the 1976 LULC data.

Habitat Area Determination

Using the aerial photo estimates, we found the percentage of forest cover on sections used by eagles was greater ($\bar{x}$ = 51.5%) than that on unused sections ($\bar{x}$ = 41.1%, Wilcoxon rank-sum, n = 115 and 112 sections, respectively, P = 0.022). The same comparison performed using the ARC/INFO estimates also resulted in significant differences between the used and unused sections (Wilcoxon rank-sum, n = 115 and 112 sections, respectively, $\bar{x}$ = 40.5% vs. 27.9%, respectively, P = 0.004). Thus, the ARC/INFO and the dot grid methods appeared to perform similarly when testing for differences in the percentage of forest on shoreline used or unused by eagles.

Unfortunately, when the estimates from both methods were directly compared, discrepancies became apparent. The percentage of forest cover estimates produced by the two techniques were significantly different (P < 0.0001; Table 2). Estimates for 21 of 227 sections were $\geq$ 40 percentage points different. Six of those 21 estimates were $\geq$ 67 percentage points different. The ARC/INFO method predicted less forest cover than the aerial photo method for 148 of 227 sections, whereas the aerial photo method predicted less forest cover for 33 sections.

Examination of a plot of both the study area shoreline and the forest polygons revealed errors in the alignment of the coverages of 40m or more in some areas, principally on the northern end of the study area (Figure 2). Because the coverages were digitized from different sources (i.e. aerial photographs and topographical maps) at different scales, the forest polygons and shoreline did not precisely match in shape. Therefore these coverages do not have the mutual consistency needed for the determination of the area of shoreline with forest. However, we believe this methodology could be used effectively with coverages created from the same source material.

Table 2. Percentage of forest on northern Chesapeake Bay, Maryland shoreline sections calculated using 1985 aerial photographs and ARC/INFO Geographic Information System coverages created from 1985 aerial photographs and 1970-1985 U.S.G.S. topographical maps.

Method	Percentage of forest (%)			
	n	x	SE	Range
Aerial photo ^a	227	34.3	2.37	0-100
ARC/INFO ^a	227	46.4	2.20	0-100

^a Percentage of forest on sections differed between methods, based on Wilcoxon signed rank, $\bar{x}$ difference = 12.1%, P < 0.0001.

CONCLUSIONS

Telemetry techniques can allow an unbiased approach to habitat studies. Combining telemetry with GIS technology facilitated spatial analysis of the eagle locations and habitat data. The GIS enabled us to efficiently analyse the relationship between eagle use of the shoreline and human development.

The alternative to using GIS techniques is to use maps and overlays. For example, one

alternative for our distance measurements analysis would have been counting the buildings and measuring distances to shore by hand. However, this would have been prohibitively time consuming due to the 5,120 buildings on the study area. Furthermore, maps and overlays are much more cumbersome to use. They also are not as easily updated and in many cases must be replaced after several uses. With a GIS, a map becomes an inexpensive output product that can be generated quickly and customized for a special application (Aronoff 1991).

As in all methodologies, there also are disadvantages associated with GIS technology. The cost associated with data base creation can be extremely high. For example, the cost of data base creation can be 75% or more of the total cost of implementing a GIS (Aronoff 1991). If coverages of the study area are not readily available they must be digitized or entered into the GIS programme manually from an external data source. This can be time consuming and expensive, depending on the size and complexity of the area.

If the needed coverages are available, expenses are considerably reduced. However, one should ascertain that available coverages are appropriate for the planned analysis before they are purchased.

Data bases become less accurate over time due to land changes, especially human development. The ability to update a coverage should be considered when it is intended to be used over a period of years. The maintenance required to keep a data base current also can be costly.

When more than one coverage must be used, consistency between the coverages should be assessed. This will avoid problems such as the ones we experienced with the shoreline forest analysis where the coverages were not appropriately consistent for the analysis we attempted. Our data were not only collected from different sources, but also at different times and at different scales.

Accuracy levels of data should be requested from the creator of all acquired data and compared across data sources. Even if the data base completely reflects the characteristics of the data source used to build the coverage, the original data source, for example a topographical map, may not reflect reality. It is wise to ground truth data before conducting analyses.

GIS technology is a powerful tool that can increase the speed and accuracy with which spatial data can be analysed. It enables researchers and managers to synthesise data from several sources to solve problems more effectively. Acquiring the necessary hardware, software and coverages can be expensive, but GIS technology can greatly increase the ability of researchers to analyse telemetry and other geographic data.

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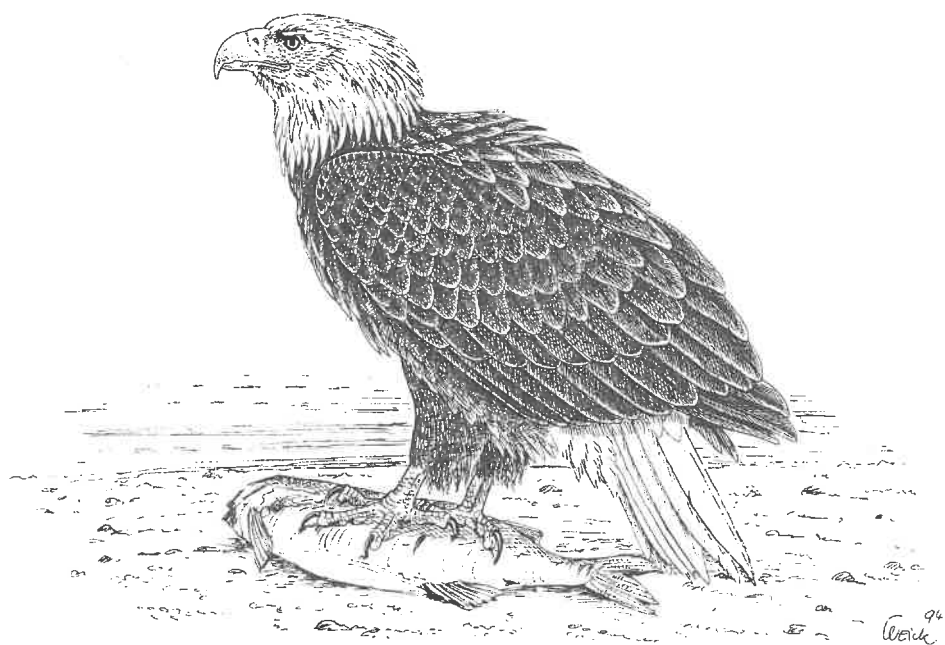
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