A Geographic Information System to Identify Potential Bald Eagle Breeding Habitat for Southeastern United States Rivers and Reservoirs

David A. Buehler, *Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37901-1071*

Abstract: A geographic information system was developed for lower Melton Hill Reservoir and the adjoining Clinch River in eastern Tennessee to demonstrate the feasibility of using this tool to identify potential bald eagle (*Haliaeetus leucocephalus*) breeding habitat in the southeastern United States. Input variables in the model included land use, forest type, condition and size, distance from water, distance from human development,and acreage of aquatic foraging area. The primary limitation on habitat suitability in the Clinch River-Melton Hill Reservoir area was human development (residential and industrial) along shoreline areas. Eagle management strategies developed from the model included locating future development away from high-quality habitats, allowing forest stands near water to mature, conducting timber stand improvement (thinning) to foster growth and development in pines and hardwoods, and using eagle introductions to foster development of a breeding population.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 49:292–302

Bald eagles recently were reclassified from endangered species to threatened species in the southeastern United States as their populations increased and eagles occupied new areas in the post-DDT era. Although eagles historically bred in natural riverine and lacustrine systems in the Southeast, impacts of DDT on reproduction and human persecution on survival had extirpated the species from most of its former range (Wood et al. 1990). Nesting bald eagles now occur in many parts of the Southeast on river or reservoir systems that historically supported eagle populations or were created after the eagle decline. Continued expansion of the eagle population will require additional suitable habitat. Shoreline development has placed extreme pressure on bald eagle habitat in many areas of the Southeast (Wood et al. 1990, Buehler et al. 1991, Chandler et al. 1995). The goal of this study was to develop and demonstrate a geographic information system (GIS) that allows land managers to identify potential bald eagle nesting habitat in the Southeast. The approach was applied to the Clinch River and Melton Hill Reservoir in eastern Tennessee to demonstrate the suitability of this approach for similar aquatic habitats in the Southeast. Identification of potential habitat in this manner is the first step toward ensuring an adequate supply of habitat for continued eagle recovery in the region.

I thank P. Parr of the Oak Ridge National Laboratory and J. Evans of the Tennessee Wildlife Resources Agency for help with the project. I also thank S. Bloemer of the Tennessee Valley Authority and P. B. Wood of the National Biological Survey for review of the manuscript. Lockheed Martin Energy Systems, Inc. funded the study.

Methods

Study Area

The study area extended 60 km downstream from the U.S. Route 62 bridge over Melton Hill Reservoir, located 5 km east of Oak Ridge, Tennessee. The study area included portions of Melton Hill Reservoir and the Clinch River below the Melton Hill dam. In addition to the riverine habitat, I also evaluated terrestrial habitat within 3 km of the river/reservoir shoreline, defining an eagle management zone. Three km from the shoreline was selected as an outer limit beyond which eagles were unlikely to seek nesting habitat. Other studies in the Southeast have reported average distances from nests to aquatic foraging areas well within this limit (McEwan and Hirth 1979: all 34 nests were <3 km from water in Florida; Andrew and Mosher 1982: 95% of Maryland nests were <800 m from water; Wood et al. 1989: 96.6% of Florida nests were <3 km from water >10 ha in size; R. Hatcher, Tenn. Wildl. Resour. Agency, unpubl. data: 16 Tennessee nests averaged 350 m from water).

Characterization of Bald Eagle Breeding Habitat

An accurate description of habitat requirements is needed to evaluate habitat suitability. Based on research conducted in Tennessee and in other parts of the bald eagle's range, certain habitat requirements can be consistently identified in relation to breeding season activities (nesting and foraging). Although there may be considerable overlap in characteristics of breeding season and nonbreeding season habitat, in this study I focused on breeding season habitat because I believe it is the most critical link in maintaining a viable eagle population for a given area.

Nesting Habitat.—Nesting habitat can be defined on both the micro scale, related to the characteristics of the nest tree, and on the macro scale, related to the landscape-level patterns that provide conditions suitable for nesting and foraging.

Nest trees in Tennessee and the Southeast generally are "super-canopy" trees or located on a habitat edge and contain accessible limbs capable of holding the nest structure (McEwan and Hirth 1979, Andrew and Mosher 1982, Stalmaster 1987, Wood et al. 1989). Nest tree species vary in the Southeast because different tree species achieve dominance in the wide variety of forest types found in the region (see Stalmaster [1987:184–185] for review). Pines (*Pinus* spp.) are used in areas where pines become dominant in the canopy. Deciduous trees, including oaks (*Quercus* spp.), hickories (*Carya* spp.), and cottonwoods and aspens (*Populus* spp.) are used in areas where large conifers are absent. In Tennessee, nests have been built in bald cypress (*Taxodium distichum*), oaks, yellow poplar (*Liriodendron tulipifera*), hickories, eastern cottonwood, sycamore (*Platanus occidentalis*) (R. Hatcher, Tenn. Wildl. Resour. Agency, unpubl. data), and loblolly pine (*Pinus taeda*) (S. Bloemer, Tenn. Valley Authority, unpubl. data).

Nest trees are generally large, although size is variable depending on the individual tree species available and how that compares with the surrounding canopy. Deciduous trees used for nesting on the Chesapeake, similar in species to the limited number of nest trees found in Tennessee, averaged 82 cm dbh and 28 m tall (Andrew and Mosher 1982). Five nest trees at Land Between the Lakes (LBL), on the border between Kentucky and Tennessee, averaged 77.2 cm dbh and 33.3 m tall (R. Lackey, Tenn. Valley Authority, unpubl. data). Eagles in the Southeast usually build nests in live trees, although adjacent snags often are used for perching (McEwan and Hirth 1979, Stalmaster 1987, Wood et al. 1989).

At the macro scale, nests usually occur in mature, forested areas that are relatively close to a body of water with suitable foraging opportunities (Stalmaster 1987). The actual distance to water varies within and among populations, although as mentioned earlier, nests are almost always within 3 km. In some cases, distance to water is not as critical as the quality of the foraging area that is present. Foraging area quality may depend on the diversity of the prey base (Livingston et al. 1990) and the structural characteristics of the aquatic habitat, such as the presence of shallow water (MacDonald and Austin-Smith 1989).

In areas with considerable shoreline development or human activity (e.g., Florida, Chesapeake Bay), eagles nest farther from the shoreline than eagles nesting in less developed areas, such as Alaska (Robards and Hodges 1977, Andrew and Mosher 1982, Wood et al. 1989). Most nest sites throughout the bald eagle's range occur within 3 km of water. In Tennessee, 16 nest sites averaged 350 m from water, although a few sites have been reported >3 km from water (R. Hatcher, Tenn. Wildl. Resour. Agency, unpubl. data). Five nests studied at LBL averaged about 200 m from water (R. Lackey, Tenn. Valley Authority, unpubl. data).

The size of the forest tract holding the nest tree may be unimportant if the tract is isolated from human development and disturbance. The minimum distance from an eagle nest to human development in some southeastern nesting populations is <100 m. The average distance in most populations, however, is >500 m and reflects habitat selection away from these developments (Andrew and Mosher 1982, Wood et al. 1989). LBL eagle nests were located, on average, 3.9 km from the nearest building (R. Lackey, Tenn. Valley Authority, unpubl.

data). Forested tracts used for nesting tend to have either relatively open canopies, some form of habitat discontinuity or edge, or high levels of foliage height diversity, which provide access to nest trees (McEwan and Hirth 1979, Wood et al. 1989).

Foraging Habitat.—Foraging habitat during the breeding season can be delineated where foraging opportunities are located close to suitable nesting habitat. Because eagles are opportunistic foragers, eagle food habits in the Southeast are highly varied (Mersmann 1989). Food habits tend to be site-specific, based on prey species available in a given area. On the Chesapeake, bald eagles sought out aquatic habitats and preferred fish whenever available (DeLong 1990).

In Tennessee, eagles probably show a similar tendency to be opportunistic foragers and to prefer fish. Good foraging habitat for eagles can be defined by conditions that make fish available to the limited fishing ability of eagles. Eagles typically forage at or near the surface of any body of water. Shallow water increases the likelihood that live fish will be available to eagles because the limited depth of the water brings the fish closer to the surface (Todd et al. 1982, Stalmaster 1987, MacDonald and Austin-Smith 1989, Mersmann 1989, Livingston et al. 1990).

The quantity of foraging habitat within a given distance from nesting habitat also contributes to habitat suitability. Areas with greater water surface area, everything else being equal, will have better habitat. The amount of foraging habitat actually required, however, depends on the quality of that habitat. The amount of aquatic surface area within a 2- to 3-km radius around the nest would be one measure of foraging habitat quantity. A better measure, however, would be the surface area of "shallow" water within that 2- to 3-km radius around the nest. Shallow water on the northern Chesapeake was defined as water <2-m deep (Mersmann 1989).

GIS Model Development

The locations of all human developments (residential, commercial, industrial, and agricultural buildings) on the study area were digitized from 1985 U.S. Geological Survey (USGS) 1:24,000 topographic maps using ARC/INFO computer software (Environ. Systems Res. Inst., Redlands, Calif.). Developments on the USGS map were updated in 1993 after a shoreline survey by boat of the study area. A 500-m buffer zone was delineated around each human development to create a human-development coverage for the habitat suitability model. The buffer distance (500 m) was selected based on a review of the literature concerning eagle tolerance of human development in the Southeast (Andrew and Mosher 1982, Wood et al. 1989, Buehler et al. 1991).

An additional development coverage was created from the USGS Land Use Land Cover (LULC) database (Anderson et al. 1976) by selection of human-developed polygons from that coverage and delineation of 500-m buffers around each polygon. When combined with the development coverage described above, the final coverage contained all but the most recent (post-1993) developments. Areas that fell within the development zone received a habitat suitability score of 0; areas outside the development zone received a suitability score of 1 (Fig. 1).

The vegetation on the study area was evaluated in a 2-step process. The USGS LULC database was used to delineate basic cover types and land-use classes: human-developed (residential, commercial, industrial, transportation, and public utility), farmland (row crops and pasture), forest (deciduous, coniferous, and mixed), transitional (changing from 1 land use to another, e.g., being developed), and water (reservoirs, rivers, creeks, ponds, and wetlands) (Anderson et al. 1976) (Fig. 2).

Field surveys were conducted in April–May 1993 to evaluate the suitability of all individual polygons related to bald eagle habitat requirements. I visually assessed and noted tree-diameter classes and heights, tree species composition, and stand canopy cover in each polygon. Based on the on-site inspection, covertype polygons were assigned a habitat suitability score of 0–1.0. A score of 0 implied the habitat was unsuitable for eagles, primarily because human develop-

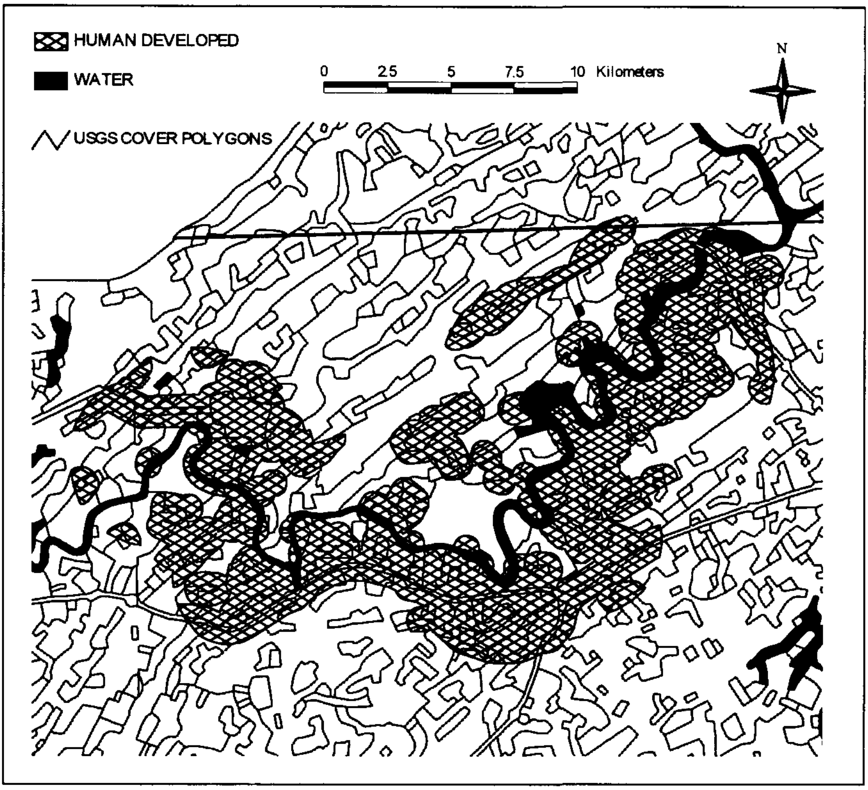

Figure 1. Unsuitable habitat in the 3-km eagle management zone, based on a 500-m buffer around human developments.

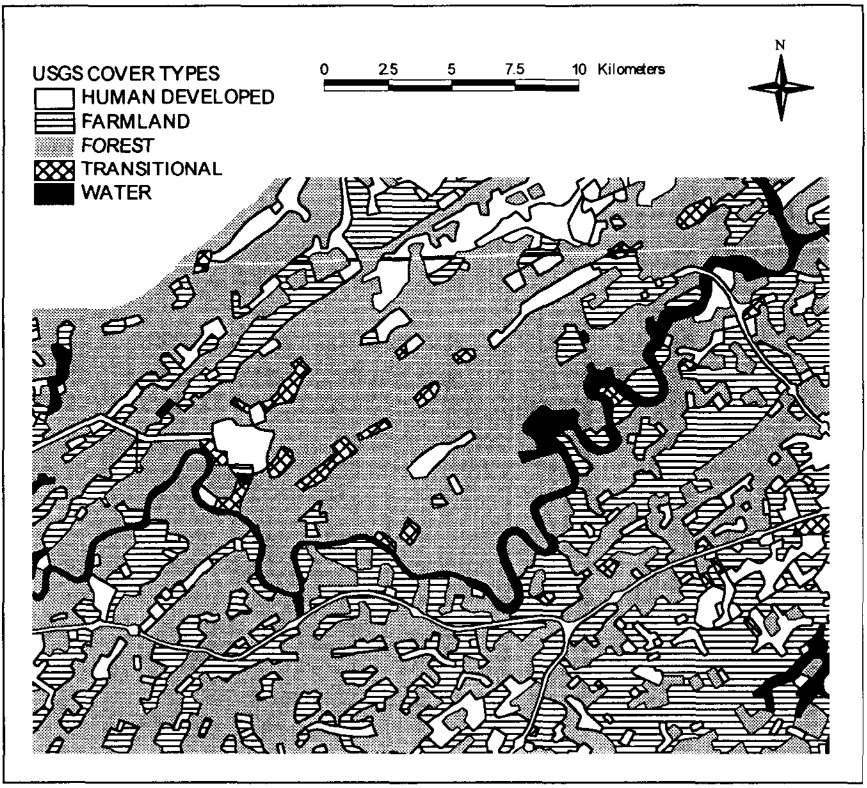

Figure 2. U.S. Geological Survey Land Use and Land Cover types on the study area, from Anderson et al. (1976).

ment in the area precluded eagle use. A score of 0.33 was assigned to marginal-quality habitats, reflecting the general lack of forest cover (pasture and field covertypes). Eagles could nest in this habitat if a suitable tree was present along a fencerow or in a small woodlot, although eagle use would be unlikely. Habitats with fair suitability received a score of 0.67. These habitats were forested, but stand age and structure were marginal and contained only a few trees capable of supporting nests. Habitats receiving a rank of 1.0 reflected highly-suitable conditions, including the presence of many mature trees suitable for nesting with little human disturbance in the immediate area. In field surveys, some polygons were reclassified to other covertypes (e.g., cropland to human-developed), based on changes in the vegetation or land use that have occurred since 1978. In addition, some polygons were sub-divided to reflect field-documented changes over a portion of the polygon.

The shoreline boundaries of Melton Hill Reservoir and the adjacent areas of the Clinch River were digitized from the USGS topographic map. The effect of distance from the water was incorporated into the habitat suitability evaluation by creation of 3 1-km buffer zones in ARC/INFO radiating outward from Melton Hill Reservoir and the Clinch River (Fig. 3). Three km was selected as the outer limit of the analysis for reasons stated earlier. I assumed the energetic cost to an eagle of locating a nest further away from water affected habitat suitability in a linear fashion such that habitats within 1 km of water received a distance score of 1.00, habitats 1–2 km from water a distance score of 0.67, and habitats 2–3 km from water a distance score of 0.33. Areas outside the 3-km zone received a distance score of 0.

To determine the foraging habitat suitability, I divided Melton Hill Reservoir and the Clinch River into 5-km sections in ARC/INFO. I used ARC/INFO to calculate the ratio of the aquatic area present within each section to the total area within each section (including the 3-km buffer). I scored these ratios from 0 to 1.0 by dividing each section's ratio by the ratio from the section with the most optimal conditions. This resulted in each section being scaled based on how it compared with the best section in terms of relative aquatic area available. Although water depth also is an important determinant of foraging habitat quality, it was not included in the analysis because of the lack of an existing digital database. As these data become available in digital format for southeastern rivers and reservoirs, water depth should be included in model development. Foraging habitat scores ranged from 0.24 for the section with the least relative amount of water to 1.00 for the section with the greatest water (Fig. 4).

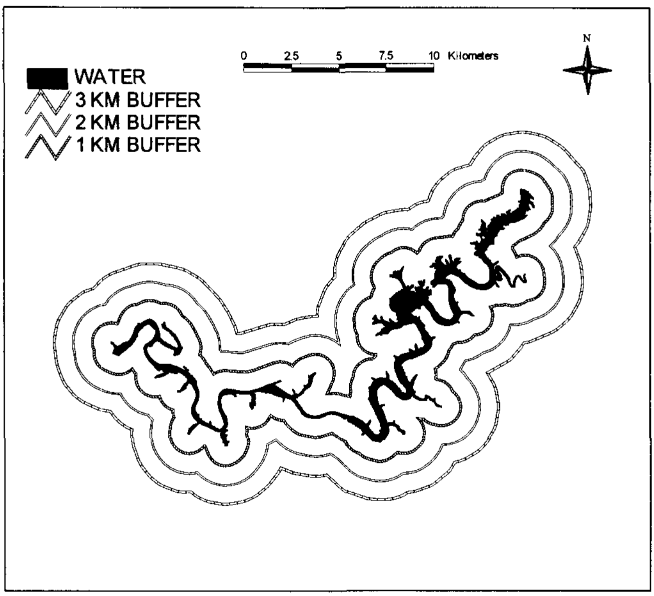

Figure 3. Distance buffer zones (1-km, 2-km, 3-km) around Melton Hill Reservoir and the Clinch River, Tennessee, used to evaluate the effect of distance on eagle habitat suitability.

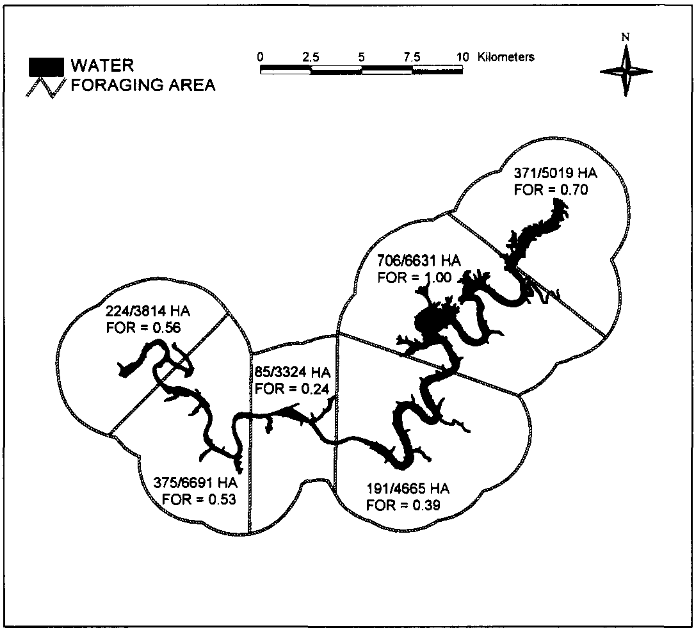

Figure 4. Bald eagle foraging habitat suitability score (FOR) for Melton Hill Reservoir and the Clinch River, Tennessee, calculated as the ratio of water surface area (numerator) to total land area (denominator) divided by the score for the section with the greatest value.

The bald eagle habitat suitability model (Fig. 5) was developed by overlaying successive coverages (Figs. 1–4) of human development, vegetation, distance zones, and foraging area in ARC/INFO. I assumed that each habitat layer was of equal importance in defining habitat suitability. The habitat suitability for each polygon in the study area was therefore calculated based on the following formula:

$$\text{HABITAT SUITABILITY} = \text{DEV} \times \text{VEG} \times \text{DIS} \times \text{FOR}$$

where: DEV = development score; VEG = vegetation score; DIS = distance score; and FOR = foraging area score.

As a result of defining this habitat suitability model, the final habitat suitability score for each polygon ranged from a low of 0, reflecting unsuitable conditions, to a high of 1.0, reflecting the highest suitability on the study area.

Results and Discussion

Habitat quality on Melton Hill Reservoir and adjacent areas of the Clinch River was largely limited by the presence of human developments. Of the 28,000 ha of terrestrial habitat available for eagle use in the 3-km zone defined around

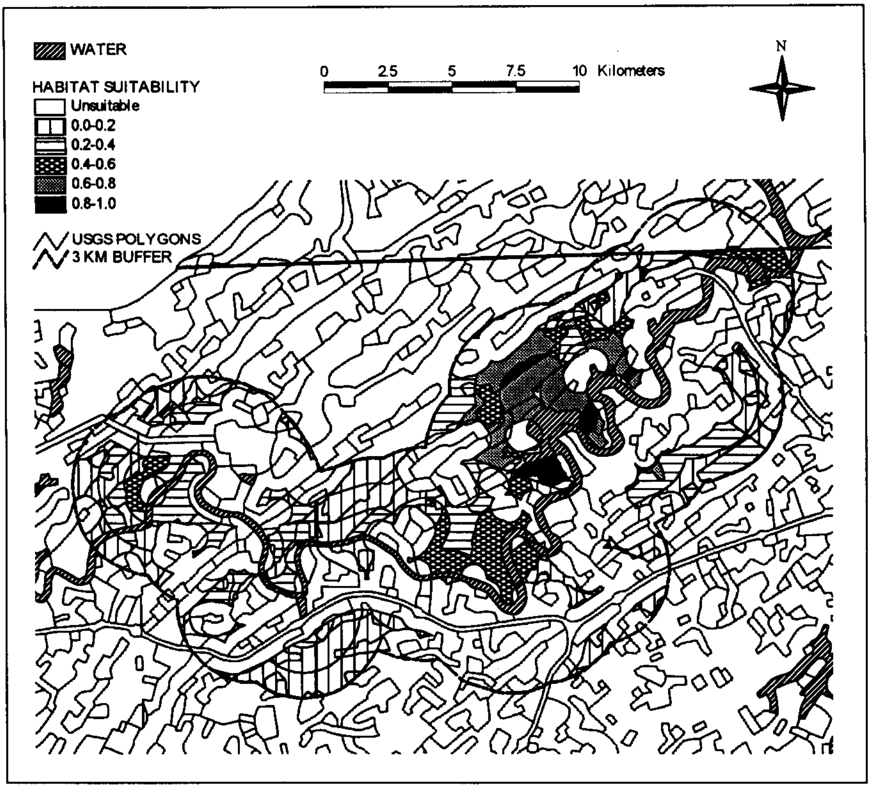

Figure 5. Bald eagle habitat suitability scores for Melton Hill Reservoir and the Clinch River, Tennessee.

the aquatic areas, 63% (17,765.3 ha) was deemed unsuitable because of human development. Almost the entire privately-owned southern side of the study area was predicted to be unsuitable because of human development (Fig. 5). This pattern contrasted with habitat suitability on the federally-owned northern side of the aquatic areas. Even on the northern side, however, human development accounted for a considerable portion of the available area in the eagle management zone.

Only 5 polygons covering a total of 270.8 ha contained high-quality habitat (areas with habitat scores of 0.81–1.0) in the Melton Hill-Clinch River area (Table 1, Fig. 5). All of the high-quality habitat was located in the area around Bearden Creek and Gallaher Bend and owned by the U.S. Department of Energy. All of the 1,206.2 ha of good-quality habitat (habitat scores of 0.61–0.80) also was located in the Bearden Creek-Gallaher Bend area (Fig. 5), suggesting that this area contained the best habitat on the study area. Large amounts of low-quality habitat existed throughout the rest of the study area, yielding a total of 10,427.0 ha of suitable habitat contained in the 30,144 ha eagle-management zone (Table 1).

Table 1. Area (ha) of potential bald eagle habitat of differing qualities on the Melton Hill-Clinch River study area.

N Polygons	Mean size (ha)	Habitat score	Total area (ha)
132	34.3	0.01–0.20	4,524.1
95	32.1	0.21–0.40	3,048.6
25	55.1	0.41–0.60	1,377.3
23	52.4	0.61–0.80	1,206.2
5	54.2	0.81–1.0	270.8
Total area of eagle habitat (habitat scores >0.00)			10,427.0
Total area of water within 3 km zone			1,951.7
Total area within 3 km zone unsuitable (score = 0.00)			17,765.3
Total area within 3 km zone			30,144.0

Most of the suitable habitat was associated with Melton Hill Reservoir, rather than the Clinch River, primarily because Melton Hill provided more aquatic foraging area than did the Clinch River (Fig. 4). If water depth had been included in the analysis, the results would not have changed, because the area around Gallaher Bend represents one of the largest shallow-water areas on Melton Hill.

Model Limitations

It is important to note that results described above identify areas of potential bald eagle habitat. The underlying model was developed from data on habitat relationships from throughout the Southeast. Because nesting was never documented on the study area, the model could not be developed with site-specific habitat selection data (a preferred approach). Eagle habitat selection patterns in the future, such as avoidance of humans, also may change as selective forces change over time. For these reasons, or possibly simply because of chance, actual habitat selection by eagles on the study area in the future may differ from predicted patterns. In addition, this model has yet to be tested to determine how well it works on areas that already contain nesting eagles. More testing of this model is necessary before it should be applied in the Southeast.

Management Implications

Similar to many river/reservoir systems in the Southeast, Melton Hill Reservoir and adjacent areas of the Clinch River contained modest amounts of potential bald eagle habitat, limited primarily by human development patterns. If establishment of a bald eagle breeding population on Melton Hill or a similar aquatic system in the Southeast was to become a management priority, land managers could consider pursuing one or several of the following strategies: 1) minimize development in areas identified as high-quality habitat; 2) allow natural forest maturation to progress within 1 km of shoreline areas to enhance perching and nesting habitat suitability; 3) use timber stand improvements (thinning) to promote desirable forest conditions within 1 km of shoreline areas; and/or 4) introduce juvenile eagles to the system (hack) to accelerate colonization of suitable habitat.

Literature Cited

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geol. Surv. Professional Paper 964. 28pp.

Andrew, J. M. and J. A. Mosher. 1982. Bald eagle nest site selection and nesting habitat in Maryland. J. Wildl. Manage. 46:383–390.

Buehler, D. A., T. J. Mersmann, J. D. Fraser, and J. K. D. Seegar. 1991. Effects of human activity on bald eagle distribution on the northern Chesapeake Bay. J. Wildl. Manage. 55:282–290.

Chandler, S. K., J. D. Fraser, D. A. Buehler, and J. K. D. Seegar. 1995. Perch trees and shoreline development as predictors of bald eagle distribution on Chesapeake Bay. J. Wildl. Manage. 59:325–332.

DeLong, D. C. Jr. 1990. Effects of food on bald eagle distribution and abundance on the northern Chesapeake Bay: An experimental approach. M.S. Thesis, Va. Polytechnic Inst. and State Univ., Blacksburg. 153pp.

Livingston, S. A., C. S. Todd, W. B. Krohn, and R. B. Owen, Jr. 1990. Habitat models for nesting bald eagles in Maine. J. Wildl. Manage. 54:644–653.

MacDonald, P. R. N. and P. J. Austin-Smith. 1989. Bald eagle, *Haliaeetus leucocephalus,* nest distribution on Cape Breton Island, Nova Scotia. Can. Field-Nat. 103:293–296.

McEwan, L. C. and D. H. Hirth. 1979. Southern bald eagle productivity and nest site selection. J. Wildl. Manage. 43:585–594.

Mersmann, T. J. 1989. Foraging ecology of non-breeding bald eagles on the northern Chesapeake Bay, Maryland. M.S. Thesis, Va. Polytechnic Inst. and State Univ., Blacksburg. 132pp.

Robards, F. C. and J. I. Hodges. 1977. Observations from 2,760 bald eagle nests in southeast Alaska. Progress Rep. 1969–76. U.S. Fish and Wildl. Serv., Juneau, Alaska.

Stalmaster, M. V. 1987. The bald eagle. Universe Books, New York. 227pp.

Todd, C. S., L. S. Young, R. B. Owen, Jr., and F. J. Gramlich. 1982. Food habits of bald eagles in Maine. J. Wildl. Manage. 46:636–645.

Wood, P. B., D. A. Buehler, and M. A. Byrd. 1990. Raptor status report—bald eagle. Pages 13–21 *in* B. Giron Pendleton, ed. Proceedings southeast raptor management symposium and workshop. Natl. Wildl. Fed., Washington, DC.

———. T. C. Edwards, Jr., and M. W. Collopy. 1989. Characteristics of bald eagle nesting habitat in Florida.