GIS PROCEDURES FOR ANALYZING WILDLIFE TOPICS IN A NATIONAL PARK IN VIRGINIA

by

Gary Casabona

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APPROVED:

Robert H. Giles, Jr., Chairman

Paul L. Angermeier

Richard G. Oderwald

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(ABSTRACT)

A set of procedures for geographical information system analysis of wildlife-related problem areas associated with Virginia National Parks is presented. Analyses of both faunal and floral topics were made. The procedures presented address (1) evaluation of habitat resources available for reintroduction of bobcat (*Lynx rufus*); (2) mapping of avian species richness, (3) impacts of park boundary development on forest-interior bird species, and (4) identification of areas suitable for threatened and endangered species (e.g., the small whorled pogonia, *Isotria medeoloides*). The GRASS GIS was used for the analyses. Inputs included data on elevation, slope, soils, landuse/landcover, roads, and hydrography.

The procedures are built upon standard GIS techniques (e.g., overlays and "buffer" zones) and should be applicable to the mapping of habitat, species richness, and other information for various taxa in other resource areas.

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INTRODUCTION

Virginia ecological conditions and problems are only slightly different from those of the Eastern United States and the problems faced on National Parks of the U.S. Department of the Interior in Virginia are only slightly different from those of other parks and wildland areas around the world. Budgets are rarely sufficient to learn about each individual area, and it is useful to develop procedures that can be widely applicable.

Traditional problems for resource managers are to decide about optimum-use levels (e.g., grazing, timber harvesting, or recreational time spent by visitors). Others include optimum application levels (e.g., of fertilizers, irrigation). Optimum placement of facilities is a recurring problem and these vary for points (e.g., viewing points for visitors, camp sites, and building sites), lines (e.g., gas, oil, and other corridors), areas, (e.g., research and special use areas, and areas affected by policy or law), and volumes (e.g., viewscapes and airsheds, waste disposal). These conventional or traditional fundamental types of site-related problems have become mixed with new questions and demands as natural areas continue to be encroached upon by new developments (LaGro and DeGloria 1992).

Parkland managers of the National Park Service (Prince William Forest Park, for example) have requested assistance in analyzing parkland conditions, especially those related to the effects of outside-the-park phenomena on within-park objectives (Buechner 1987, Janzen 1983). For example, staff are requested to comment on the impacts to a park of a shopping center or housing development which might be built near a park. Similar questions are asked about developments further away but within a viewshed. The questions are difficult because the effects are largely unknown. Also, it is important to ask what it is that is affected. Is the effect on any species? All species? Habitat only? A species only during construction activities? Are the effects likely to be permanent?

The questions have been stimulated by the National Environmental Protection Act that calls for impact statements that specify potential effects on wildlife. The full range of questions needs to be addressed for there may be positive as well as negative effects of a change at the edge of any wildland area (hereafter "park"). Both need to be known within the context of what is inside and outside the park as well as what are the likely forces or agents of change associated with a proposed action. In a practical vein, once effects are known and evaluated, then there needs to be some policy that prevents those harmful to wildlife and encourages beneficial ones. Information and estimates about likely effects may, in some cases, lead to desirable consequences from human action.

Increasingly, interest has grown in restoring ecosystems and it occurs in recent law, and in a new journal (*Restoration and Management Notes*). There is interest in some areas in site-specific restoration of species. Wolves, for example, are being considered (1994) for re-introduction in Yellowstone Park.

Addressing all of these problems is of increasing importance as more species and critical habitat are lost through time. Resources are limited, some are endangered. Funds, time, and staff expertise are limited while the needs are great. It is clear that the problems are numerous and probably unique in each situation. There are analytic needs and data sets that differ. Political and regulatory contexts differ. Research is said to be needed in one case (the problem is doing the research itself) but in another case the situation is well known. The conflicts are in human value systems and peoples' willingness to take risks or to allow substitutions (Batie and Shabman 1979). Procedures are being sought that can help solve some of the problems, not only in specific cases, but in general. General algorithms or tools that can be used in more than one place or way are badly needed. There has been great progress (Scott 1992a) in an approach that promises to be responsive to many aspects of the problems outlined above. The approach is by using computer maps. Computer maps cannot address all of these problems but they can influence the process as they show potential threats, unseen tradeoffs and new perspectives on the many dimensions of parks.

I sought to develop a project that would allow me to test whether solutions could be found to some of the types of problems outlined above and to present them as examples of a more general set of problem-area solution mechanisms. I selected, on the advice from meetings with U.S. Park Service staff, 4 major areas of work. These were equivalent to objectives in a classical thesis. They included efforts to develop procedures related to the wildlife resources of parks:

1. Species reintroduction- The objective was to determine whether efforts to reintroduce the bobcat, *Felis rufus*, to the Prince William Forest Park would be feasible.
2. Avifaunal richness- The objective was to map bird species richness so that park managers could use the information to identify land areas of greatest concern for avian species conservation.

3. <u>Birdwatcher areas</u>- The objective was to map bird species richness along existing trails (one attraction for bird watchers (Gray 1993)). The map could then be used as a trail guide.

4. <u>Threatened plant areas</u>- The objective was to map suitable habitat for an endangered plant, *Isotria medeoloides*, so that park managers could focus their efforts to discover new colonies of the plant in areas where they were most likely to be found.

This thesis is devoted to presenting procedures for identifying the size and quality of suitable habitat for various taxa within and outside a large public wildland area. An hypothetical area could have been selected and a great array of methods and concepts presented. A tradeoff was made in favor of realism and because of practical constraints on time and resources. One National Park was selected for making an effective demonstration and reducing the range of potential activities. The procedures may prove to be applicable to other resource areas.

The effectiveness of setting aside isolated reserves to preserve intact remnants of ecosystems has been seriously questioned and alternate reserve systems have been proposed (Scott 1992b, Diamond 1986, Pickett and Thompson 1978). Theories on the effects of habitat fragmentation (Forman and

Godron 1986, MacArthur 1973, Robbins 1979), minimum viable breeding populations (Gilpin 1986, Gilpin and Soule 1987, Ralls 1986, Soule 1987), species dynamics of patches (Connell 1978, Diamond 1972, Levin 1976, Pickett and Thompson 1978, Sepkoski 1973, Simberloff 1974), quality of size and shapes of reserves (Diamond 1975 and 1986), gap analysis (Burley 1988, Crumpacker 1988, Scott 1992), use of corridors, networks and shelterbelts (Forman and Godron 1986, Margules 1988, Pollard 1979, Noss 1986, Simberloff and Cox 1987), and island biogeographic theory and its adaptations to terrestrial patches (Gilbert 1980, Hamilton 1964, MacArthur and Wilson 1970) have increased human understanding in this broad area often called "landscape ecology" and occasionally included within the area called "conservation biology" (Primack 1993). These studies have begun to provide insights suggesting that reserves should not be isolated areas of land, but that regions need to develop fairly contiguous reserve systems for supporting healthy wildlife and plant populations that contribute to the genetic diversity of a metapopulation within a region.

The location of PWFP, close to various types of human disturbance, implies that the Park would be an appropriate site to explore the challenges to ecosystem management that are likely to occur in other resource areas as human population centers continue to expand. GIS can be used to estimate the zones of influence and magnitudes of effect of land use changes associated with these increases in human population. Simulations of land use changes, such as new housing developments, can be mapped on existing data layers and their effects predicted according to expert opinion and existing data (Johnston et al. 1988).

METHODS AND PROCEDURES

This thesis, itself, is about methods and procedures so organization along conventional lines has not been judged to be feasible. I present information about geographic information systems (GIS), the general method used; the spatial scale (resolution); the study area that influenced the data set, an intimate part of the GIS; and about data collection. In a peculiar manner, the procedures are the "results" presented later under that topic in 4 sections.

Geographic Information Systems

GISs have been used in wildlife management since before 1965 (Fales 1965). The topic is now well known, taught in universities, has textbooks (e.g., Haines-Young et al. 1993, Burrough 1986) and several journals serve the field (e.g., International Journal of GIS, GeoInfo Systems).

Using GISs has become increasingly prevalent in the field of wildlife conservation as well as other areas of natural resource management. These systems can be used to evaluate habitat areas (Pereira and Itami 1991, Broschart et al. 1989, Donovan et al. 1987); predict effects of land use changes (Nellis et al. 1990, Turner 1990, Anderson and Sivertun 1991); map the sightings of animals or locations of radio-collar-monitored animals (Agee et al. 1989, Chandler et al. 1993, Bildstein et al. 1990); and other applications (MacMillan et al.1993, Wood and Foody 1993).

Within a GIS, managers can use already existing data which can often be obtained at low cost or even free of charge via an anonymous file transfer over the Internet. With the rapid growth of the Internet, it is likely that data from governmental agencies will become increasingly more available.

The great advantages of GIS are the low cost of obtaining some data and the efficiency with which even highly complex analyses and calculations can be conducted. The use of global positioning satellite (GPS) units will also contribute to the efficiency of data collection, registration and verification, and resource analysis. Although data collection at the microhabitat scale will still be time and labor intensive, GPS will allow for some data to be imported directly into a GIS without the need for it to be digitized. This transfer will allow for data analyses to begin immediately after data collection from satellites. If federal agency budget and staff reductions are long-term trends, developing and using GIS may represent an efficient way of allocating resources toward achieving many diverse objectives in wildlife and natural resource management.

The GRASS (Geographic Resources Analysis Support System) GIS, already in use at Prince William Forest Park (hereinafter PWFP or "the Park"), was selected for use on this project. GRASS is a product of the U.S. Army Corps of Engineers Construction Engineering Research Laboratories in Champaign,Illinois (USA CERL 1993). GRASS can handle both raster and vector map coverages, and can transform from one type to the other. It can be used for digitizing, image processing, producing maps, and other standard GIS functions. The main GRASS program modules, as well as additional, user-written modules can be obtained at no charge over the Internet (moon.cecer.army.mil).

I ran GRASS under the UNIX operating system at a SUN workstation using SOLARIS 1 with OPEN WINDOWS 3.0. The analyses and map products were in raster format, although vector coverages of roads, streams, and trails were also used. These vector coverages were converted to raster (GRASS program **v.to.rast**) to allow for calculating zones of influence around roads and streams.

Although estimating habitat areas "lost" to development or other changes is straightforward and does not require the use of GIS, there is a need for more than simple area estimates. A database within a GIS can allow for estimates of habitat areas used by a particular species, guild, or any taxonomic unit of interest to the manager. The effects of linkages, either spatial or temporal, can be predicted through employing expert systems. For example, it is generally agreed (Andren and Angelstam 1988; Hall 1984; Temple and Cary 1988; Wilcove 1985; Yahner and Scott 1988) that there is some relationship between forest fragmentation and increases in nest predation and parasitism, although the magnitude of the effects is still being debated. By specifying certain rules regarding such parameters as proximity to disturbance, habitat type, and interspersion of habitat features, the probability of each part of the forest landscape having predation and parasitism may be estimated.

The precision of the estimates of ecological effects in a scenario such as that described above is related to the quality of existing data on the subject of interest. In the case of the above relationship, no firm, precise statistical relationships have been demonstrated. However, estimates can be made that presume decreased effect with increasing distance from disturbance, and increased effect on species known to be susceptible. This topic will be further discussed in a later section on avifauna in the Park.

Scale

The analyses of potential habitat suitability for bobcat, and the analyses of bird species richness were based primarily on the map coverage of landuse/landcover which had a cell size (resolution) of 20 meters. The resulting map products were at this 20-meter resolution. The analysis of habitat suitability for the small whorled pogonia was based on both landuse/landcover (20-meter resolution) and soil (30-meter resolution) coverages. For this analysis, the landuse/landcover data was converted to a 30-meter resolution to correspond with the soil coverage. This conversion was made using the GRASS program **r.neighbors** using the mode option. The program moves a 3 x 3 matrix over the entire coverage and assigns to each center cell the most frequently occurring value in the matrix. The analyses and resulting map products for the small whorled pogonia were then at a 30-meter resolution.

Study Area

Within the spreading suburbs of northeastern Virginia, approximately 56 kilometers (35 miles) south of Washington, D.C. (Strickland 1986), there are approximately 6880 ha (~17,000 acres) of forest protected as Prince William Forest Park by the U.S. National Park Service, U.S. Department of the Interior (USNPS). Despite its unusual name, it is a conventional National Park located primarily in Prince William and Stafford Counties, Virginia. The Park staff had begun to develop a GIS at the time this study was undertaken.

This area has 31 land use types (Table 1) and ~25 miles (55 km.)of streams. The perimeter is ~132 miles (60 km.), giving a circularity index of 2.04. This is a relatively

Table 1. Land use and land cover types within the study area.

1	Virginia Pine Forest
2	Virginia Pine Forest (canopy closure <26%)
3	Loblolly Pine Forest
4	Loblolly Pine Forest (canopy closure 26-50%)
5	Virginia Pine-Oak Forest
6	Virginia Pine-Oak Forest (canopy closure 51-75%)
7	Loblolly Pine-Oak Forest
8	Oak-Virginia Pine Forest
9	Oak-Virginia Pine Forest (canopy closure 51-75%)
10	Oak-Virginia Pine Forest (canopy closure 26-50%)
11	Oak-Loblolly Pine Forest
12	Mixed Oak Forest
13	Mixed Oak Forest (canopy closure 51-75%)
14	Mixed Oak Forest (canopy closure 26-50%)
15	Mixed Oak Forest (canopy closure <26%)
16	Mesic Hardwood Forest
17	Mesic Hardwood Forest (canopy closure 51-75%)
18	Floodplain Forest
19	Floodplain Forest (canopy closure 51-75%)
20	Floodplain Forest (canopy closure <26%)
21	Virginia Pine Scrub
22	Sumac Scrub
23	Mixed Oak-Virginia Pine Scrub
24	Mixed Deciduous Scrub
25	Mixed Deciduous Scrub (canopy closure 51-75%)
26	Young Planted Pine
27	Grassland
28	Freshwater Marsh
29	Water
30	Developed
31	Bare Ground

high edge/area ratio in comparison to a circle, which, by definition, has an index of 1.00. A map of the Park boundary is shown as Figure 1. The GRASS program **ps.map**, (along with ADOBE ILLUSTRATOR) was used to create the figures presented in this report.

This park may have great value in protecting the flora and fauna of the region and is a resource for recreation to millions of people within the area. However, increases in the human population and expansion of the urban environment may have an adverse effect on current populations of wild flora and fauna.

The proximity of the Park to the highly-populated Washington, D.C., region makes the area surrounding the Park especially subject to change and thus to questions about the influence that changes outside the Park may have on factors inside the Park. More generally, the Park may be a focal point for developing useful GIS protocols that can be applied to other National Parks. The Park is a workable size for research and may be monitored (if the Park staff should decide to do so) on a fairly large scale to detect effects in the biotic environment caused by anthropogenic changes in the surrounding environment.

PWFP and its surroundings were farmed intensively from the 1700's to the early 1900's for corn, cotton, and tobacco.

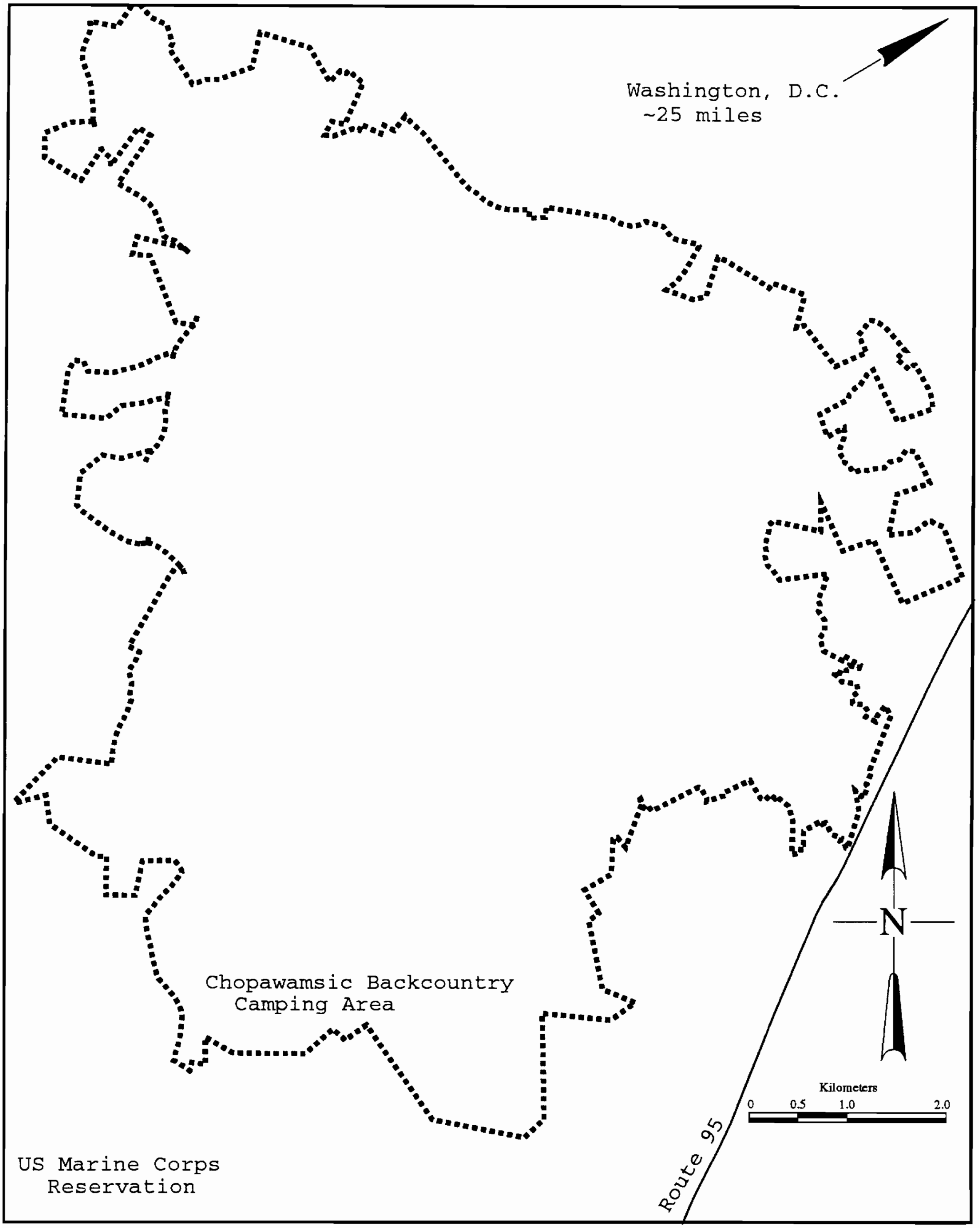

Figure 1. Map of the Prince William Forest Park boundary.

In 1933, it was set aside as Chopawamsic Recreation Area in a depression-era program directed at public relief and land reclamation. The Park was developed by the Civilian Conservation Corps and was transferred to the Department of the Interior (USDI) (Anon. 1991). Some of the facilities in the park created at that time are now on the National Register of Historical Places. In 1940, the USNPS was given authority to manage the land. The name "Prince William Forest Park" was given in 1948 and, at that time, 2,023 ha (4,997 acres) were transferred from the Park to the Navy (U.S. Marine Corps which is now Quantico Marine Corps Base) (Anon. 1991) Included in the 1948 legislation were plans to transfer an additional 324 ha (80 acres) to the Navy along with 608 ha (1,500 acres) of unidentified private lands. These actions have not yet occurred, but the Park Service has given the Navy special permit use area for 578 ha (1,429 acres) on the upper portion of Quantico Creek. This land addition would result in the loss of 1,820 ha (4,500 acres) on the Chopawamsic Creek watershed backcountry camping area which is described by the authors of the *Draft Management Plan* as having prime natural value. As the request of Park personnel, this area has been included in the analyses as being part of the Park. Authors of the *Draft Management Plan* also discussed land transfers along with active cooperation with adjacent land owners to facilitate watershed management (Anon. 1991).

The objectives in the 1991 Draft Management Plan included cultural resource management (e.g., historical preservation), watershed management, natural resource management including wildlife, interpretive services, and visitor use and development including a new visitors' center (Anon. 1991).

The *Draft Management Plan* stated that natural processes are to be managed so as to be largely uninterrupted by human activity, natural values are to be enhanced, pollution reduced, exotics reduced, and the health and growth of indigenous populations are to be promoted. Possible actions discussed include: relocating certain trails; and removing some cabins to reduce pollution and impact on water resources; establishing meadows and removing some utility corridors for additional habitat; restoring natural areas and reducing visual intrusions; removing, rehabilitating, and further studying existing dams to restore natural stream flow; mapping geological resources; conducting vegetation resource studies; making periodic biotic inventories; and monitoring threats to the Park. The latter actions are, in part, a basis for the study being proposed herein.

The Park planners described PWFP as home to numerous uncommon, rare and endangered species including small-whorled pogonia (*Isotria medeoloides*), false mermaid-weed (*Floerkea proserpinacoides)*, and diana butterfly (*Speyeria diana*). The Park plan authors noted that the location of PWFP is at the natural distribution limits for several species (these were not listed and further research is necessary) and is believed to be in a transition zone from north to south and east to west physiographic regions (Anon. 1991).

Data Collection

USGS Digital Elevation Model (DEM) data for the study area were purchased from the Virginia Department of Soil and Water Conservation. These data were imported into GRASS and used to generate raster map coverages for slope and aspect using the GRASS program **r.slope.aspect**.

USGS 1:100,000 Digital Line Graph (DLG) data from CD-ROM were obtained from the College of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University. These data were imported into GRASS and used to generate vector map coverages for roads and hydrography.

PWFP personnel provided us with raster map coverages for landuse/landcover (20 m. resolution) and soils (30 m. resolution). They also provided a vector coverage for roads which distinguished between heavily- and lightly-used roads.

ANALYSIS AND RESULTS

The following four sections describe the results of project work. Each is a complex procedure illustrating the potenial role of a GIS in historical ecology (the bobcat), several analyses of an ecosystem performance measure (avian biodiversity), and a variety of roles in preserving and managing a threatenened and endangered species (the small whorled pogonia).

Habitat Quality for Bobcat

National Park Service personnel at PWFP in northern Virginia have expressed questions about and an interest (1993) in reintroducing bobcat (*Felis rufus*) into the park. Reintroduction of biota is a US NPS policy. Consequently, questions have arisen about the potential success of a reintroduction project given the proximity of the Park to human population centers, and about the size of the Park and the area needed by bobcats. Further, assuming at least limited success in reintroduction (i.e., temporary establishment of a bobcat population that may or may not persist through time) a question has been raised about the effects of land use change on the introduced population. As part of this study of linkages among outside-the-park land use changes and inside-the-park phenomena, I investigated the likely success and feasibility of reintroducing the bobcat.

Bobcats are not endangered in Virginia. There are healthy bobcat populations throughout the U.S. with the exception of several midwestern states (Boyle 1987). Because of its widespread distribution and because of known commercial trapping of animals in the region, I assumed that bobcat once occupied the area which is now PWFP. The reasons for their disappearance are likely to be related to the growth of human populations within the area, trapping and shooting, and loss of superior habitat. The entire area of the Park was extensively farmed and mined prior to its official establishment in 1934.

Quantico Marine Corps Base lies to the south and west of PWFP and represents a contiguous area that is undeveloped and relatively unoccupied. I assumed it may be considered as possible bobcat range, along with that of the Park, for it was not likely to be extensively developed. However, hunting is permitted in-season within the Base area and some military exercises are performed, although ordnance discharge is prohibited within the areas adjacent to the Park.

In addition to the land that currently comprises PWFP, the US NPS also legally controls a large parcel of land that is currently mapped as Quantico. This Special Permit Use Land was given to the Marine Corps during World War II and it has now reverted to the control of the US NPS. This area is contiguous to the rest of the Park although it includes some inholdings. In conducting the analyses for this project, the Special Permit Use Land was included as being part of the Park land potential bobcat area, thus making the total area within the Park land boundary (excluding inholdings) about 62.6 square kilometers (15,471 acres).

The objective of this subproject of the thesis was to determine the probability of success of a program to reintroduce bobcat into the Park. This was done through evaluating habitat within the study area to determine if potential resources were available to support a minimum viable population of bobcat. Hoar (1980) did similar analyses of rare species when he explored GIS uses.

The US NPS policy is to attempt to reintroduce species, i.e., to restore the natural diversity of ecosystems, called by some "biodiversity." The bobcat appears to have once been in the Park although no evidence of its current presence exists. Thus, to attempt to reintroduce the cat seems a reasonable, required action. Whether it is feasible seems a related question.

Estimating the probability of success of a reintroduction program has several dimensions. A reintroduction program includes: analyzing habitat quality, acquiring public inputs, securing stock for a minimum viable population, making introductions, managing the animals and their habitat, assuring public benefits (e.g., observation sites), monitoring the population and the Park ecosystem, and making adjustments based on various projected conditions. Planning certain aspects of the program might be unnecessary, if it was first found that bobcats can no longer survive in the area. I decided to test the ecological feasibility before studying further, or recommending for study, the other aspects of a full-scale reintroduction program.

I compiled data from several researchers (Fendley 1982; Litvaitis 1986; Drinkwater 1982; Rucker 1989; Kitchings and Story 1984; Kitchings and Story 1979; Bailey 1974; Major 1983) in order to estimate average home range sizes (Table 2). However, in all cases, females occupied significantly smaller home ranges than did males.

The U.S. Fish and Wildlife Service Habitat Suitability Index Model for bobcat (Boyle 1987) defined certain habitat areas for bobcat as those having:

1) suitable habitat which has a) food production areas,
   b) loafing areas, and
   c) denning areas; and

2) food-optimal areas which are especially productive.

I used this information to apply GRASS GIS programs to construct reclassifications, overlays, and to determine patch

Table 2. Average home range sizes in square kilometers for male and female bobcats.

Males Home Range	Females Home Range	Source
64.2	24.5	Rucker et al. (1989)
70.9	30.5	Litvaitis and Harrison (1988)
95.7	31.2	Litvaitis et al. (1986)
158.6	56.3	Kitchings and Story (1984)
138.6	27.5	Major (1983)
42.9	11.5	Kitchings and Story (1979)
4.9	1.0	Hall and Newsom (1973)
82.3	**26.1**	**Mean**

size according to varying constraints.

To complete these analyses, I used only 2 map coverages: USGS 1:100,000 DLG data sets for roads along with digitized landcover obtained from PWFP personnel (resolution = 20 m.)

I related bobcat habitat requirements to the landcover classes in the study area by applying information from the U.S. Fish and Wildlife Service Habitat Suitability Index Model for bobcat (Boyle 1987). I then formulated an hypothesis which suggested a simple approach to the analysis: it is highly unlikely that a population of bobcat will persist if reintroduced into the Park.

I found in the literature that bobcat populations require areas with high rodent and lagomorph productivity (Boyle 1987). Such areas would be grass/forb or shrub areas which are highly productive of seed foods to support small mammal populations.

I conducted the analyses based on the progressive exclusion of areas, then estimated the goodness, or suitability of each area. Each exclusionary act was based on political boundaries, ownerships, and landcover. Then I evaluated area potentials for bobcat food production. I sought to estimate an area that might be available that could be compared to an area believed to be the minimum to support a viable population.

Key information in the literature was used to set quantitative limits on the size of the habitat area required by a bobcat population. The first was that a minimum viable population of bobcat is believed to be 20 (other, more general views of minimum viable population might range from 50 to 500 (Franklin 1980). This estimate of 20 derives from 1 breeding pair being likely to survive an outbreak of feline panleukemia with 90% mortality (Boyle 1987). Although home range size varies with sex (Litvaitis 1986), it is estimated that bobcat can live at densitities as high as 1 individual/square km, but only if the habitat is of very high quality. Thus,assuming ideal conditions, a minimum of 20 square kilometers (4,940 acres) of suitable habitat is needed for a population (Boyle 1987). Recall that the Park and included study areas contain 142 square kilometers (~35,000 acres).

Also needed was an estimate of the percent of the area that is required to be optimally productive of the bobcat's preferred foods. Thirty-five percent is considered to be a reasonable estimate of the food-optimal area (noted above) that is required to sustain a maximal density of bobcats. This figure is based on long-term studies conducted at the Savannah River Plant, South Carolina (Langley and Marter 1973, Jenkins et al. 1979, Fendley and Buie 1982). In strictest terms, food-optimal areas are those covered by grass/forb or shrub cover types.

Bobcat are extremely reclusive and tend to shy away from areas where humans are present (Drinkwater 1983). Thus, buffers were constructed around roads to subtract the areas that would be very close to human disturbance and unlikely to be used by the bobcats. These "avoidance" distances were not known but were hypothesized as reasonable zones within which cats would be disturbed by hikers and other Park users.

Table 3 shows the 22 landuse and vegetation classes within the Park. The entire study area includes the Park as well as the surrounding areas comprising a total of about 142 square kilometers (~35,000 acres) and had 31 landuse classes (Table 1). Table 3 was an output of GRASS using a mask (**r.mask**) of the Park boundary over the landuse/landcover map. The mask excluded all areas not within the Park boundary and was used to show the differences in the quantity of suitable habitat throughout the study area versus that within the Park boundary only. The first step in the analysis was to reclassify the original vegetation map to represent suitable, moderately suitable, and unsuitable habitat for bobcat. In this approach, suitable habitat included loafing and denning areas (bottomland hardwood (Boyle 1987)) as well as food productive areas. The areas were reclassified (**r.reclass**) as follows from the vegetation map provided by Park personnel:

Table 3. Twenty-two land use and landcover types within the Park boundary.

Category Number	Description
1	Virginia Pine Forest
5	Virginia Pine-Oak Forest
6	Virginia Pine-Oak Forest (canopy closure 51-75%)
8	Oak-Virginia Pine Forest
9	Oak-Virginia Pine Forest (canopy closure 51-75%)
12	Mixed Oak Forest
13	Mixed Oak Forest (canopy closure 51-75%)
14	Mixed Oak Forest (canopy closure 26-50%)
15	Mixed Oak Forest (canopy closure < 26%)
16	Mesic Hardwood Forest
18	Floodplain Forest
20	Floodplain Forest (canopy closure < 26%)
21	Virginia Pine Scrub
22	Sumac Scrub
23	Mixed Oak-Virginia Pine Scrub
24	Mixed Deciduous Scrub
26	Young Planted Pine
27	Grassland
28	Freshwater Marsh
29	Water
30	Developed
31	Bare Ground

Suitable Habitat: vegetation classes 2, 10, 14-24, 26-27. These included grassland, scrub, forest with less than 50% canopy cover and all mesic and floodplain hardwoods. (Shown in black on bobcat maps).

Unsuitable Habitat: vegetation classes 28-31. These areas included freshwater marsh, water, developed areas, and bare ground. (Shown as white on bobcat maps).

Moderately Suitable: all remaining areas. (Shown in gray on bobcat maps).

The results (Table 4) are that there are 33.5 square kilometers of suitable habitat representing 23.6% of the study area. The area is larger than the 20 square kilometers required for the population. However, 23.6% cover is significantly less than the estimated requirement of 35%. These statistics and related map (Figure 2) represent the "best-case scenario" for bobcat reintroduction at PWFP because they include all areas that could possibly be of use to bobcat both within and around the Park. Table 5, which is associated with Figure 3, shows the results with road "zones of influence" removed and reclassed as unsuitable habitat. The results show 25.7 square kilometers of suitable habitat (still above the requirements) representing 18.1% cover (now about half of that required). Road-effect zones were chosen so as to subtract no more than a low but reasonable estimate of the area which bobcat would avoid. This area was

Table 4. Habitat suitability for bobcat throughout the entire study area.

Description	Square Kilometers	Percent Cover
Suitable Habitat	33.5	23.6
Moderately Suitable	101.0	71.1
Unsuitable Habitat	7.6	5.3

Table 5. Habitat suitability for bobcat throughout the entire study area showing road zones of influence as unsuitable habitat.

Description	Square Kilometers	Percent Cover
Suitable Habitat	25.7	18.1
Moderately Suitable	75.8	53.3
Unsuitable Habitat	40.6	28.6

Table 6. Potential food production for bobcat throughout the study area.

Description	Square Kilometers	Percent Cover
Food-optimal Area	11.9	8.4
Suboptimal area	122.7	86.3
Unsuitable area	7.6	5.3

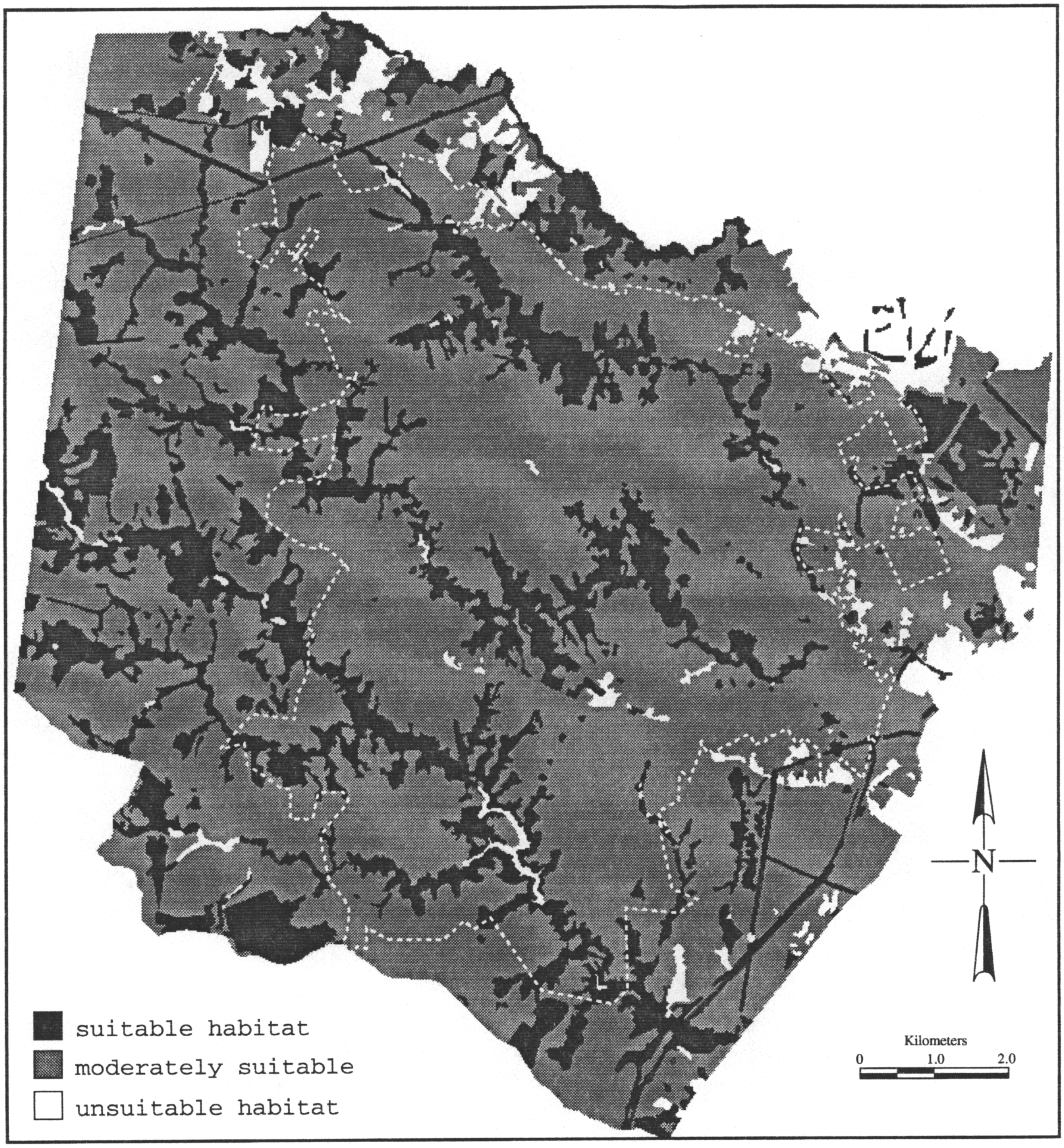

Figure 2. Map of an index to habitat suitability for bobcat throughout the study area. White dotted line is the Park boundary.

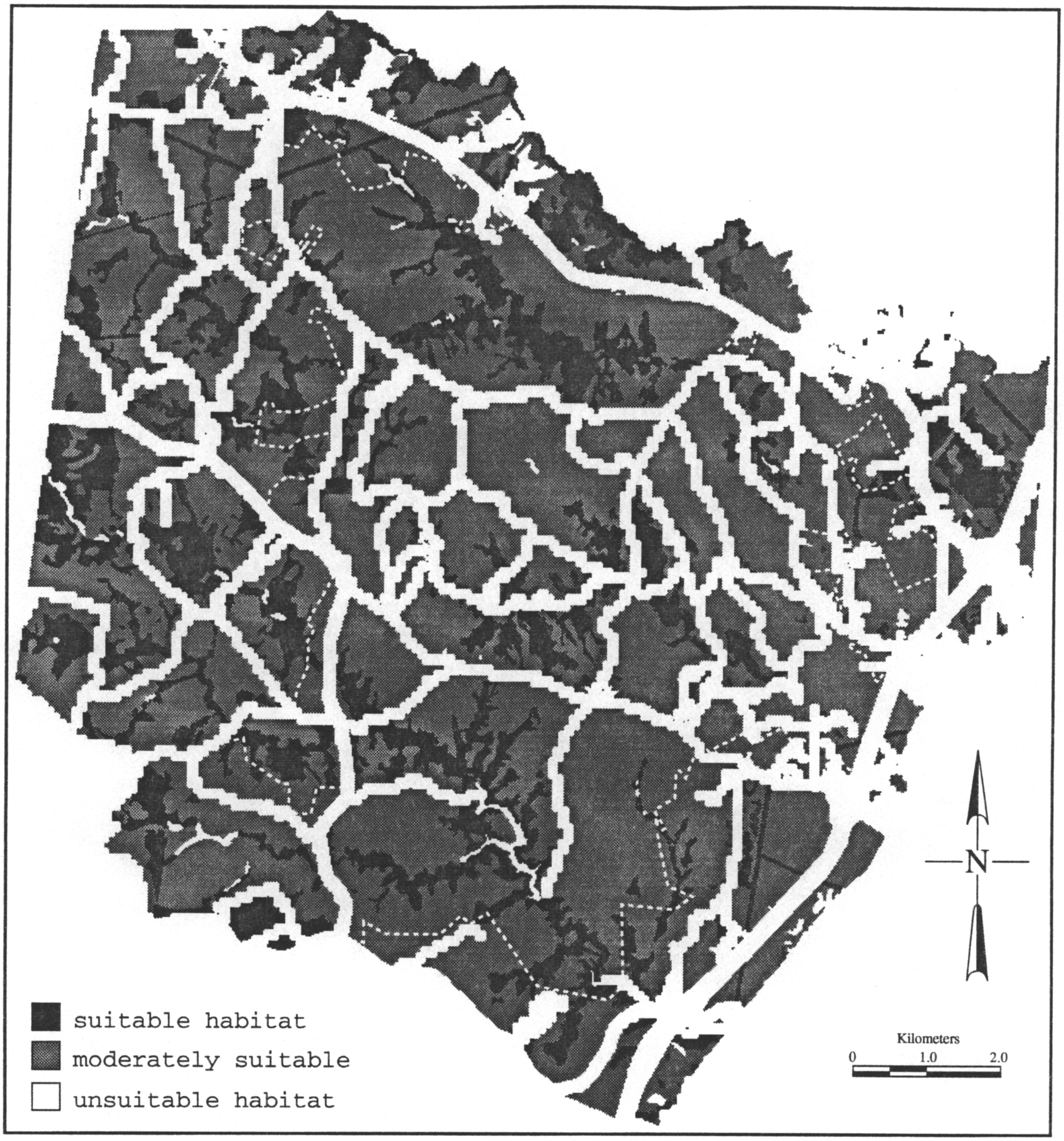

Figure 3. Map of an index to habitat suitability for bobcat throughout the study area with road zones of influence shown as unsuitable habitat. White dotted line is the Park boundary.

estimated to be 50 meters to each side of all but the most heavily used roads which were given a 90-meter wide zone.

I used the GRASS program **r.clump** to measure the number and size of suitable habitat patches. The program moves a 2x2 matrix over the raster map and groups adjacent cells of the same category as a patch. Diagonal cells are not included in a grouping. There were 356 patches of suitable habitat with a mean patch size of 0.07 square kilometers There were only 7 patches with a size of 0.8 square kilometers or greater. Given the species requirements, the amount of suitable area seems very limited. The narrow, dendritic shapes of the suitable habitat patches might also suggest a problem with patch geometry. However, patch size, shape, or fragmentation in the landscape around the Park was not considered a problem for, generalizing from the work of Fahrig and Paloheimo (1988),the size and distance between patches was considered irrelevant to the wide-ranging cats. The large dispersal distances of the cats can enable them to travel through areas that are not suitable to get to patches that are suitable. Furthermore, there is no hazard to the cats in traveling through the areas that were deemed less than suitable.

In the next analysis (Table 6) I reclassified the previous map in order to show only areas that could be expected to produce sufficient grass and forbs to support populations of rodents and lagomorphs (preferred foods for bobcat). Vegetation cover classes 16 through 19 were taken out of the suitable category (black color on map, Figure 4) which then represented food optimal area. These 4 classes were added to the prior category "moderately suitable" which then represented "suboptimal food area." The results show that there are about 11.9 square kilometers of food-optimal area, an area which is only marginally favorable since the 20 square kilometers of habitat required can also include loafing areas. However, the food-optimal area represents only about 8.4% of the total cover, well below the 35% needed. Furthermore, much of the prime area is outside the Park boundary.

I conducted the same set of 3 analyses again after creating a mask (GRASS program **r.mask**) which included only those areas inside the park boundary. This cut the analysis down to about 63 square kilometers of total area. The results in all cases showed resource availability to be significantly below the requirements (total area and percent cover) stated in the literature. Table 7 shows the results for the area within the Park boundary. Within the Park, there are 12.75 square kilometers of suitable habitat (20.38% of the area). Table 8 shows the results after road zones of influence are subtracted. This operation left 10.52 square kilometers (only 16.81% of the area). In particular, the

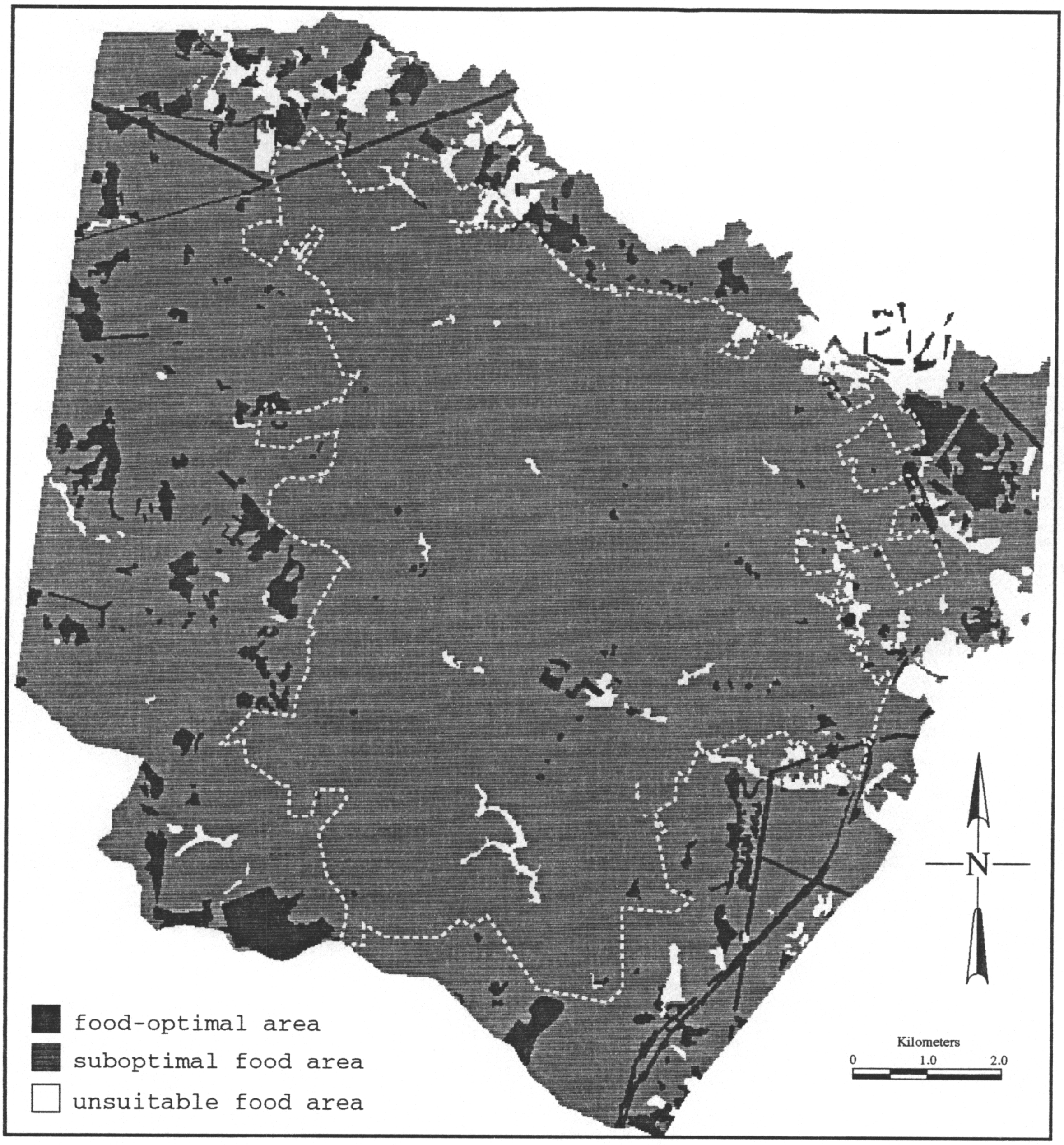

Figure 4. Potential food production areas for bobcat. Darker areas show highest potential. White dotted line is the Park boundary.

Table 7. Habitat suitability for bobcat within the Park boundary only.

Description	Square Kilometers	Percent Cover
Suitable Habitat	12.8	20.4
Moderately Suitable	49.3	78.7
Unsuitable Habitat	0.6	0.9

Table 8. Habitat suitability for bobcat within the Park boundary showing road zones of influence as unsuitable habitat.

Description	Square Kilometers	Percent Cover
Suitable Habitat	10.5	16.8
Moderately Suitable	38.5	61.6
Unsuitable Habitat	13.5	21.6

Table 9. Potential food production for bobcat within the Park boundary only.

Description	Square Kilometers	Percent Cover
Food-optimal Area	0.5	0.8
Suboptimal area	61.5	98.3
Unsuitable area	0.6	0.9

food-optimal areas were very small. They totaled only 0.5 square kilometers and represented 0.8% of the total area (Table 9). Although this last analysis is a constrained scenario, it is also believed to be the most realistic since it includes only the areas inside the Park and looks critically at the potential food production.

The analyses show that even in the best-case scenario, the requirement of 20 square kilometers of suitable habitat, (35 % of which must be food-optimal area) is not met.

Although I used only the simplest and most fundamental program modules in the GRASS GIS in order to complete these analyses, any attempt to answer these questions without GIS would have required more time and resources.

The accuracy of these analyses is dependent upon the accuracy of the landuse/landcover coverage provided by PWFP personnel. Although it is likely that there are some inaccuracies in the boundaries of different landcover categories, it seems unlikely that the total areas in each landcover class would be so inaccurate as to have a significant effect on the results of these analyses.

Avian Species Richness

The conservation of avian species is one important objective of the US NPS and other park systems throughout the world. Healthy populations of diverse species of avifauna are critical not only for their role in ecological relationships (e.g., consumption of insects) but also as part of the wildlife resource that is a large component of the attraction that National Parks hold for users. Birdwatching is a growing recreational activity (50 million adults participated in 1985; Gray 1993:98). It contributes much to the total economic value of resource areas ($20 billion in North America (Hvenegaard et al. 1989)). Birders contribute to the local economy near National Parks as well as paying entrance fees to certain parks. Rare, threatened, and endangered species not often seen (by virtue of their rarity). They have particularly high recreational and aesthetic value.

Society has become enamoured of the words "diversity" and "biodiversity" and even though the words have many meanings (Angermeier 1994), one common thread is the meaning of no-species-loss or that of maintaining the number of species now present and in some cases attempting to restore to natural abundance any species lost or very rare.

The number of species is called species richness. I have selected bird species richness as the general category within which to demonstrate the mapping of expected or predicted bird species richness associated with different habitat types. The demonstration is in 6 categories:

(a) parkwide richness

(b) richness as related to riparian areas

(c) richness related to recreation areas (e.g., trails)

(d) richness related to threatened and endangered birds

(e) richness related to residential development at the boundary, and

(f) richness related to neotropical migrant species.

These demonstrations were selected to show how total richness can be mapped, how limited group richness (such as likely rare or neotropical migrant species only) can be mapped in response to national research programs, and how landcover categories may be visually related to the more general maps already shown.

The predicted richness of the maps relies entirely on the assignment of each species to all of the cover types in which it is likely to be found (Hamel 1992), at any time throughout the year. I did not create separate maps to show differences in bird species richness during different seasons since many of the species in the Park use the same types of habitat throughout the year. The map of neotropical migrant species richness indicates which habitat areas might have the highest overall value in contributing to avian species richness during the summer months. Most of the habitat patches were large, suggesting that reductions in avifaunal richness often associated with small patches would not significantly affect the analyses. The procedure presented here could be modified to exclude patches of insufficient size for each individual species.

Parkwide

I used a US NPS parkwide list of bird species that have been sighted in PWFP. There were 90 species on the list. Two species, the ruby-throated hummingbird (*Archilochus colubris*) and the long-eared owl (*Asio otis*) were listed as likely to have been accidental sightings. Swainson's thrush (*Catharus ustulatus*) is listed in the inventory as being present in the Park. However, according to the literature (Hamel 1992), this species requires spruce/fir habitat which is not found in the Park and thus, the species was eliminated from the list. Two other species, the rose-breasted grosbeak (*Pheuticus ludovicianus*) and the yellow-bellied sapsucker (*Sphyrapicus varius*) were not believed to occur so close to the coast at low elevations according to range maps in the literature (Hamel 1992). They were omitted.

A second list of bird species was obtained from the Fish and Wildlife Information Exchange in Blacksburg, Virginia. This list was from the official information system on the fauna of the state managed by the Department of Game and Inland Fisheries. It was of bird sightings recorded over many years for the 7.5 minute quadrangle maps named Joplin, Quantico, and Independent Hill. These 3 quadrangle maps encompass the whole of PWFP and much of the surrounding area. Through comparison of the two lists, I eliminated all species that did not appear on both lists. This resulted in eliminating all questionable species discussed above with the exception of *A. colubris* since it appeared on the second list even though it was thought to be an accidental sighting recorded on the first.

Since much of the current discussion regarding optimal management of public lands centers on the concept of "biodiversity", it is appropriate to address the relationship between species richness and diversity. Angermeier (1994) raised the question of whether exotic species contribute to biodiversity though they clearly raise the raw numbers of species richness. There are only 3 exotic species that add to PWFP richness: the house finch (*Carpodacus mexicanus*), which is native to the Southwest, the house sparrow (*Passer domesticus*), and the european starling (*Sturnus vulgaris*). The latter 2 are Old World species introduced to North America. Since these 3 species will make relatively little difference to the graphic representation of bird species richness, I did not create a separate map to reflect the exclusion of exotics. However, *P. domesticus* and *S.vulgaris* are known to exert a negative influence through competition for faunal space with native Eastern bluebirds (*Sialia* *sialis*) (Zeleny 1976). These exotics are strongly associated with areas of human activity, such as at points along the PWFP boundary.

The final, culled list had 71 species. Table 10 shows the 19 species on the PWFP list not included in the analysis. The remaining species were assigned to the appropriate landcover types in which they are normally found (Appendix). This was done through using the descriptions of habitat selection according to *The Land Manager's Guide to the Birds of the South* (Hamel 1992). All habitats used by each species, for breeding or wintering, were assigned.

The map of bird species richness was generated by reclassifying the landuse/landcover coverage to show the number of species associated with each habitat type. However, certain species that show a particularly strong preference for certain habitat types were keyed into only those areas, while species that show no strong preferences were assumed to be present in all the habitat types in which they are normally observed. No allowance was made in this analysis for species which require a minimum patch size. Table 11 shows the number of species associated with each habitat type. The map (Figure 5) was produced in grey scale with darker areas corresponding to greater numbers of bird species. Richness was highest in the riparian areas, which, to a large extent, fall outside the western boundary of the

Table 10. Species on the Prince William Forest Park list not included in the analysis. Scientific names are from Hamel (1992). These species did not appear on both of the lists (PWFP and Fish and Wildlife Information Exchange) of bird species sighted in the Park.

Spotted Sandpiper, *Actitis macularia*
Long-Eared Owl, *Asio otis*
American Bittern, *Botaurus lentiginosus*
Bufflehead, *Bucephala albeola*
Rough-Legged Hawk, *Buteo lagopus*
Pine Siskin, *Carduelis pinus*
Hermit Thrush, *Catharus guttatus*
Swainson's Thrush, *Catharus ustulatus*
Brown Creeper, *Certhia americana*
Yellow-Rumped Warbler, *Dendroica coronata*
Little Blue Heron, *Egretta caerulea*
Dark-Eyed Or Northern Junco, *Junco hyemalis*
Northern Parula, *Parula americana*
Rose-Breasted Grosbeak, *Pheucticus ludovicianus*
Yellow-Bellied Sapsucker, *Phyrapicus varius*
Ruby-Crowned Kinglet, *Regulus calendula*
Golden-Crowned Kinglet, *Regulus satrapa*
Barn Owl, *Tyto alba*
White-Throated Sparrow, *Zonotrichia albicollis*

Table 11. Bird species richness associated with each habitat type within the study area.

	Habitat Type	Bird Species Richness
1	Virginia Pine Forest	8
2	Virginia Pine Forest (canopy closure <26%)	17
3	Loblolly Pine Forest	8
4	Loblolly Pine Forest (canopy closure 26-50%)	not in study area
5	Virginia Pine-Oak Forest	11
6	Virginia Pine-Oak Forest (canopy closure 51-75%)	15
7	Loblolly Pine-Oak Forest	11
8	Oak-Virginia Pine Forest	11
9	Oak-Virginia Pine Forest (canopy closure 51-75%)	17
10	Oak-Virginia Pine Forest (canopy closure 26-50%)	22
11	Oak-Loblolly Pine Forest	11
12	Mixed Oak Forest	13
13	Mixed Oak Forest (canopy closure 51-75%)	20
14	Mixed Oak Forest (canopy closure 26-50%)	20
15	Mixed Oak Forest (canopy closure <26%)	22
16	Mesic Hardwood Forest	14
17	Mesic Hardwood Forest (canopy closure 51-75%)	17
18	Floodplain Forest	32
19	Floodplain Forest (canopy closure 51-75%)	32
20	Floodplain Forest (canopy closure <26%)	33
21	Virginia Pine Scrub	14
22	Sumac Scrub	12
23	Mixed Oak-Virginia Pine Scrub	12
24	Mixed Deciduous Scrub	11
25	Mixed Deciduous Scrub (canopy closure 51-75%)	12
26	Young Planted Pine	9
27	Grassland	27
28	Freshwater Marsh	18
29	Water	6
30	Developed	15
31	Bare Ground	1

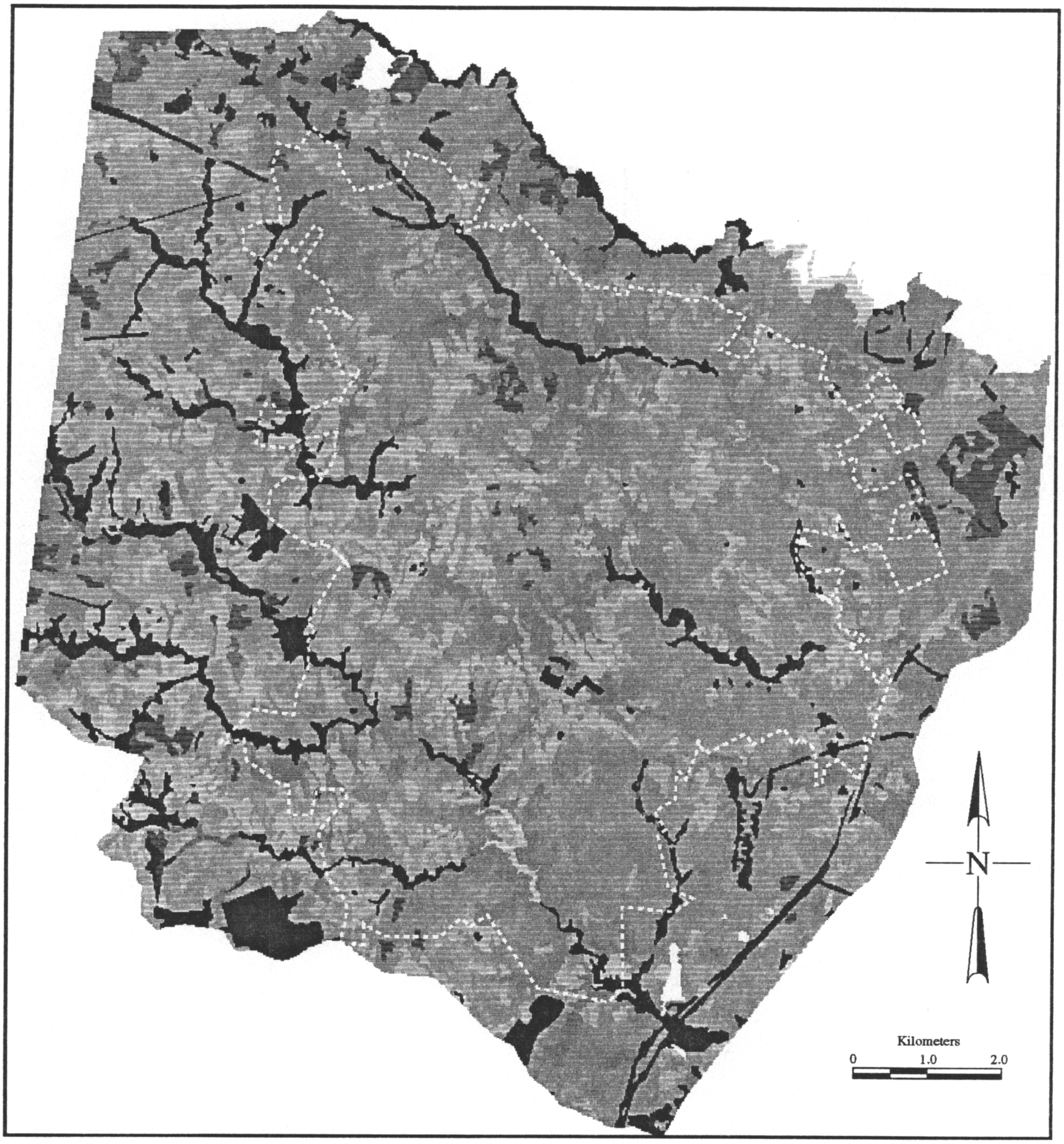

Figure 5. Predicted bird species richness throughout the study area. Darker areas indicate higher richness. White dotted line is the Park boundary.

Park (thus, outside the control of PWFP staff).

Riparian

Species richness is often high in riparian areas (Stauffer and Best 1980). Because of the great national interest in riparian communities (Swift 1984, Tellman et al. 1993), I wanted to measure the extent of the zones of high richness centered in, but not strictly limited to the riparian areas which contribute to high quality habitat for many species. I estimated (GRASS program **r.measure**) that most of the areas of high bird species richness (the darkest areas on Figure 5) fell within 200 meters of streams. I then constructed a mask (**r.mask**) which excluded all areas within that 200-meter zone of influence. Table 12 shows that there is far less area supporting high bird species richness outside of the 200-meter zone of influence than within that zone. Most notably, the highest species richness (33 species) is found on 1.5 ha (3.8 acres) within the zone, while there are no areas outside the zone that support 33 species. There are 804 ha (1688 acres) within the riparian zone which support 32 species. Outside the zone, only 121 ha (300 acres) support 32 species. Streams can be regarded as naturally occurring transects and the habitat types through which they pass determines the area totals for this analysis.

Table 12. Comparison of the amount of areas supporting high bird species richness inside and outside of the 200-meter riparian zone of influence.

Number of species	Inside Riparian Zone Hectares	Outside Riparian Zone Hectares
33	1.5	0
32	804	121
27	466	72
22	55	12
20	356	40

For this Park, managers should seek to limit disturbances throughout the 400 meter zone centered over streams.

Trails

Recreational birding was addressed through using data on the PWFP trail system. Vector maps of the park trails were converted to raster format (as was done for streams) through the use of the GRASS program **v.to.rast**. The resulting raster map coverage consisted of 20-meter cells through which the original vector lines had passed. This raster map was then used to create a mask (excluding all areas not along the trails), through which was displayed the map of bird species richness. This resulting map (Figure 6), shows the areas along the trail system that are predicted to have the highest bird species richness. The numbers along the trails correspond to the landcover categories inside the Park (Table 3). Table 13 shows the landcover categories and a notable bird species likely to be associated with each type.

Threatened and Endangered Birds

The conservation of rare, threatened, and endangered species is, of course, a high priority for resource managers. There are only 4 species found in PWFP that are listed as endangered, threatened, rare, or "of special concern" in Virginia. These are the Cooper's hawk (*Accipiter cooperii*),

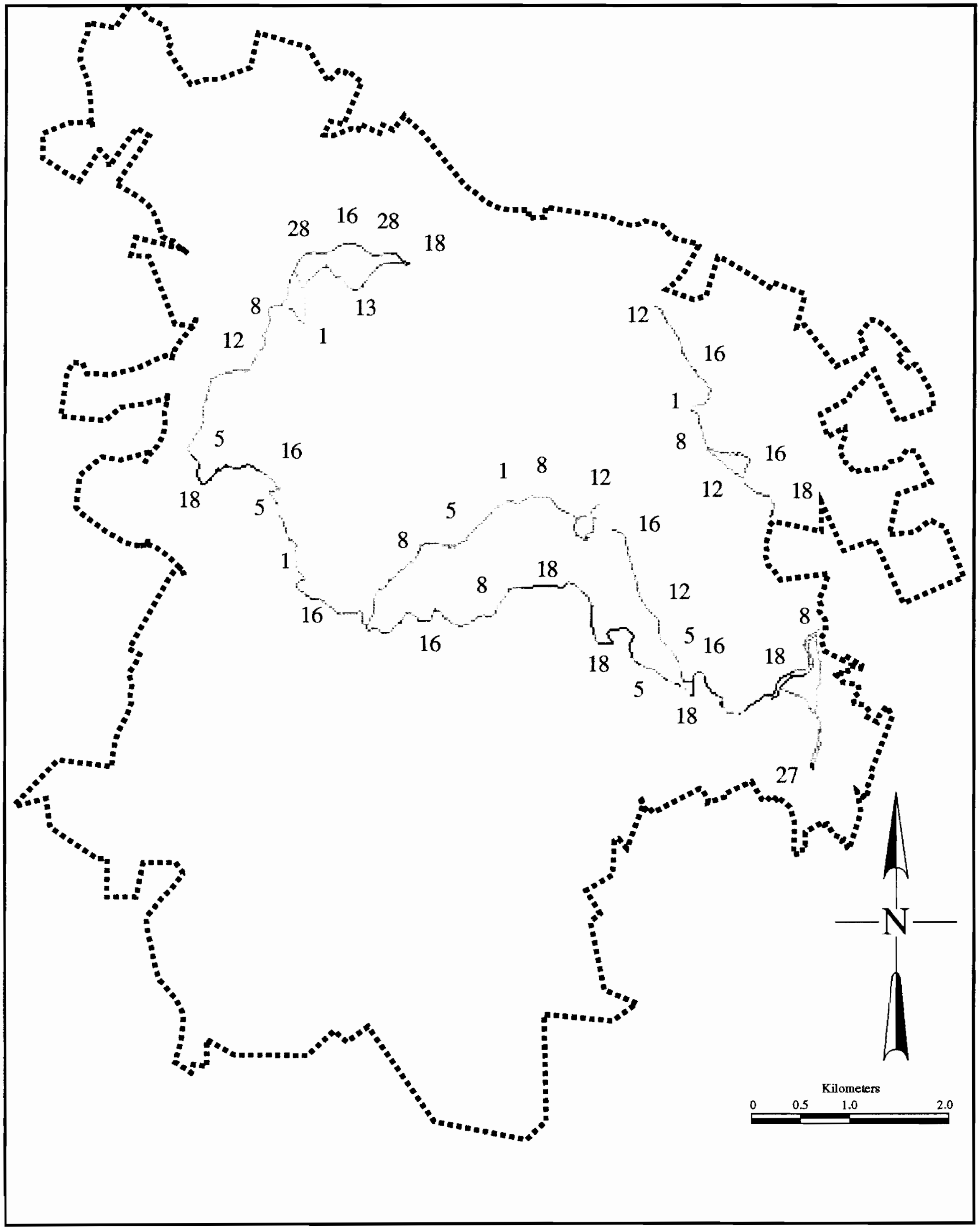

Figure 6. Map of predicted bird species richness along the Park trail system. Darker areas indicate higher species richness. Numbers correspond to landcover types and representative bird species given in Table 13.

Table 13. Landcover categories (Table 3) along the Park trail system and representative bird species for each cover type.

Category		Associated Species
1	Virginia Pine Forest	Pine Warbler, *Dendroica pinus*
5	Virginia Pine-Oak Forest	Carolina Chickadee, *Parus carolinensis*
8	Oak-Virginia Pine Forest	Great Horned Owl, *Bubo virginianus*
12	Mixed Oak Forest	Scarlet Tanager, *Piranga olivacea*
13	Mixed Oak (closure 51-75%)	Ovenbird, *Seiurus aurocapillus*
16	Mesic Hardwood Forest	Tufted Titmouse, *Parus bicolor*
18	Floodplain Forest	American Redstart, *Setophaga ruticilla*
27	Grassland	American Goldfinch, *Carduelis tristis*
28	Freshwater Marsh	Great Blue Heron, *Ardea herodias*

sharp-shinned hawk (*Accipiter striatus*), green-backed heron (*Butorides striatus*), and bald eagle (*Haliaeetus leucocephalus*). Since the Cooper's and sharp-shinned hawks are thought to make use of virtually all habitat types, the map (Figure 7) shows only the preferred habitat areas for the green-backed heron and bald eagle. This map emphasizes the importance of riparian and freshwater marsh (category 28) areas in supporting rare species as well as total species richness noted earlier.

Development Effects on Interior Bird Species

Deforestation and forest fragmentation throughout the eastern United States have adversely affected the populations of many avian species (Askins et al. 1987; Lynch and Whigham 1984; Whitcomb 1977) through loss of preferred habitat, and increases in other species. Emigration of animals and plants from neighboring areas of human use (e.g., sububurban or agricultural) creates disturbance within forest communities. The smaller the park "island" the greater this potential interference (Janzen 1983). One type of interference is that of brown-headed cowbird (*Molothrus ater*) nest parasitism. Although the extent to which cowbirds are contributing to population declines is currently being debated, there is strong evidence that they are having at least some effect on

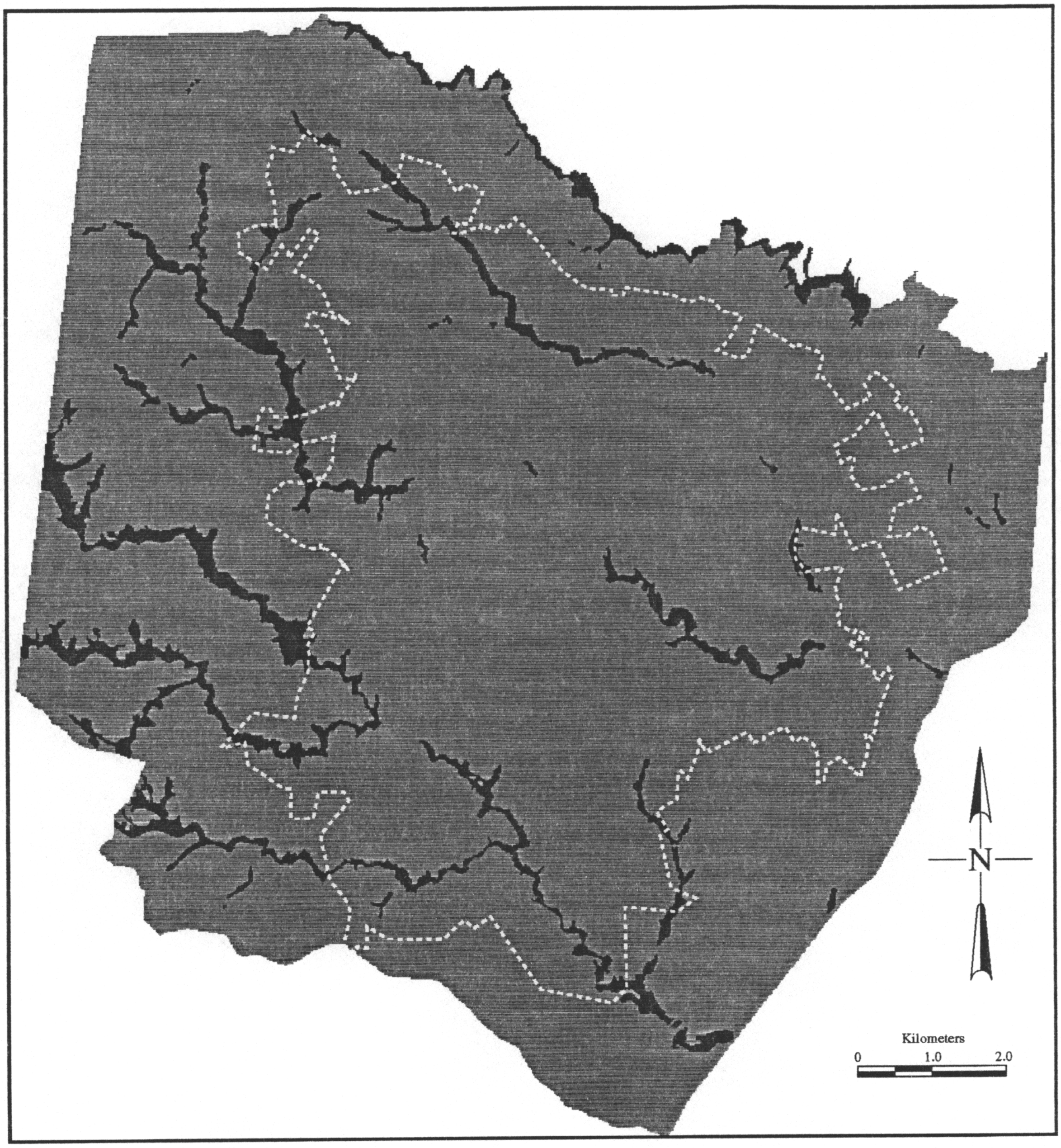

Figure 7. Map of habitat suitability for 2 endangered species within the study area. Black areas represent preferred habitat for the bald eagle (*Haliaeetus leucocephalus*) and the green-backed heron (*Butorides striatus*). The white dotted line is the Park boundary.

certain preferred host species (Bohning-Gaese 1993; Ortega and Cruz 1991; Trail and Baptista 1993). There have also been studies of the relationship between forest fragmentation and increases in both nest predation and parasitism (Andren and Angelstam 1988; Hall 1984; Temple and Cary 1988; Wilcove 1985; Yahner and Scott 1988).

Accurately predicting the effects of development along the PWFP boundary on nest predation and parasitism would be impossible without thorough field studies encompassing many years of study. However, it is possible to analyze the landscape to identify which species and habitat areas might be most susceptible to increased hypothesized pressures.

I began by compiling a list of species found within the Park (and surroundings) that required interior forest habitat. The list comprised 13 species of birds (Table 14). I reclassified the original landuse/landcover map to reflect only the species richness of these 13 species by habitat type. I then began to delimit the area of the Park that could be considered interior forest habitat. The first step was to eliminate all non-forest areas. These were the grassland, freshwater marsh, water, developed, and bare ground cells (categories 27-31). I identified a 3-cell wide (60 m.) zone of influence around these areas using the **r.buffer** program, then subtracted the resulting areas from the rest of the study area. I created a mask of the

Table 14. Species known to occur in the study area and considered to be forest interior birds (Hamel 1992).

Cooper's Hawk, *Accipiter cooperii*
Sharp-Shinned Hawk, *Accipiter striatus*
Pileated Woodpecker, *Dryocopus pileatus*
Acadian Flycatcher, *Empidonax virescens*
Wood Thrush, *Hylocichla mustelina*
Black-Throated Blue Warbler, *Dendroica caerulescens*
Worm-Eating Warbler, *Helmitheros vermivorus*
Black-And-White Warbler, *Mniotilta varia*
Kentucky Warbler, *Oporornis formosus*
Scarlet Tanager, *Piranga olivacea*
Hooded Warbler, *Wilsonia citrina*
Ovenbird, *Seiurus aurocapillus*
Louisiana Waterthrush, *Seiurus motacilla*

remaining area and displayed the map of interior species richness through it. The map (Figure 8) and Table 15 show the result. At this point, the amount of interior forest area was 11,741 ha (29,000 acres), with ~2500 ha (6175 acres) having been eliminated by the masking process.

The next step was to eliminate the roads (and a 60 m. zone to each side of them) from the map of interior area. This left a final forest interior map (Figure 9) of 10,046 ha (24,813 acres). Using the GRASS program **r.clump**, I found that this area comprised 161 patches having a mean size of 62.4 ha. Table 16 (with Figure 9 noted above) shows the interior bird species richness through the final mask of interior area. While there are relatively large areas harboring from 2 to 4 species of interior forest birds, only 5.1 ha of habitat supports the maximum of 10 species.

Since there are housing developments being constructed along the Park boundary at the time of this writing, I wanted to measure the possible influence that such development might have on interior birds. Since there are 5 species of warblers among the 13 forest interior species, I hypothesized that brown-headed cowbird nest parasitism might affect these birds in areas near the new developments. Paton (1994) stated that edge effect should be studied no more than 100-200 m. from an edge. I therefore created 2 zones of influence around an area along the Park boundary which is now being

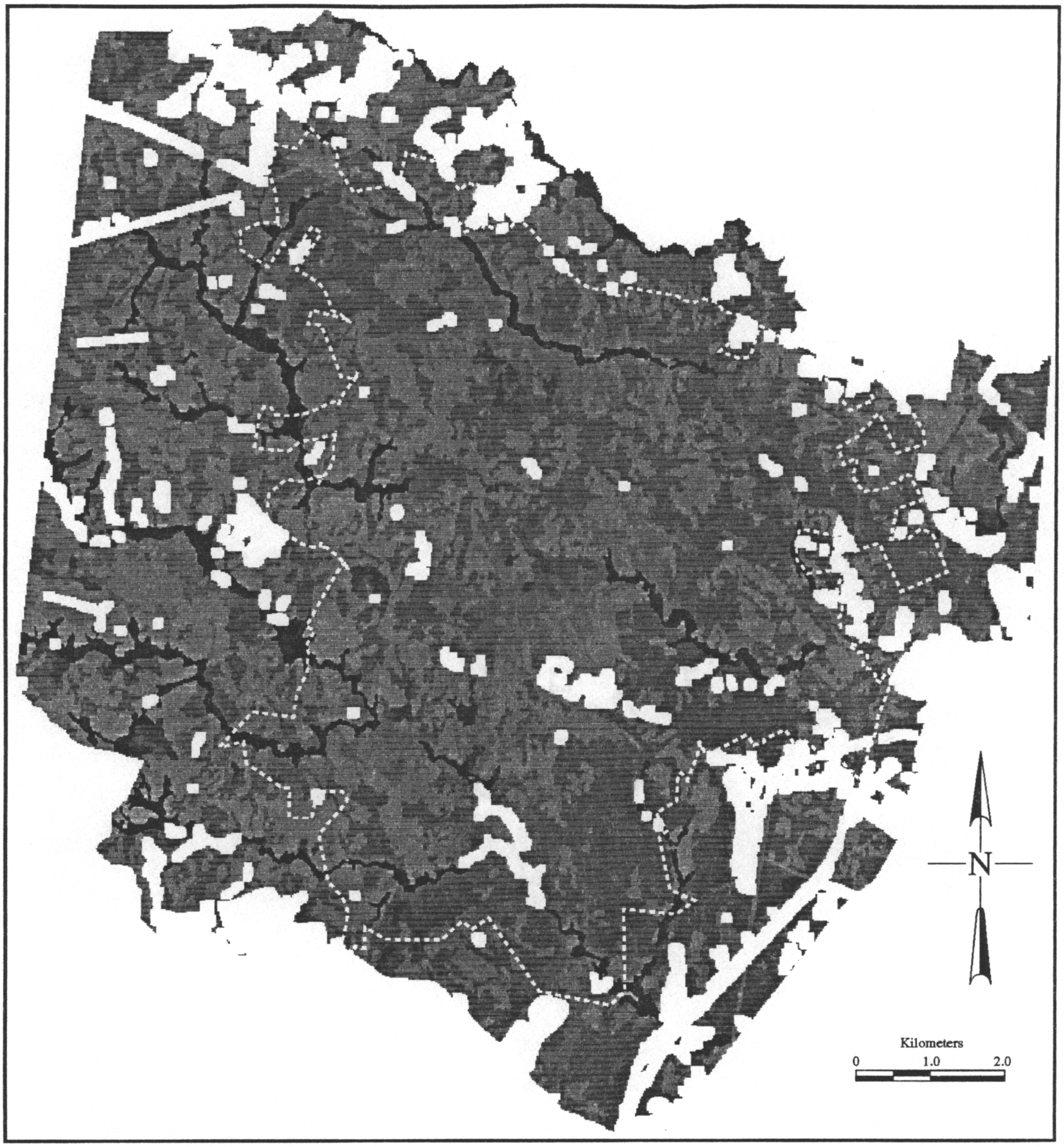

Figure 8. Map of predicted interior bird species richness within the study area. Darker areas show higher species richness. White dotted line is the Park boundary.

Table 15. Richness of forest interior bird species in the study area. Area totals are calculated after excluding "non-forest" areas.

Number of Species	Hectares	Acres	Percent Cover
2	4533	11,202	38.61
3	1466	3,622	12.48
4	4753	11,745	40.48
5	261	645	2.22
9	723	1,785	6.15
10	5	13	0.04

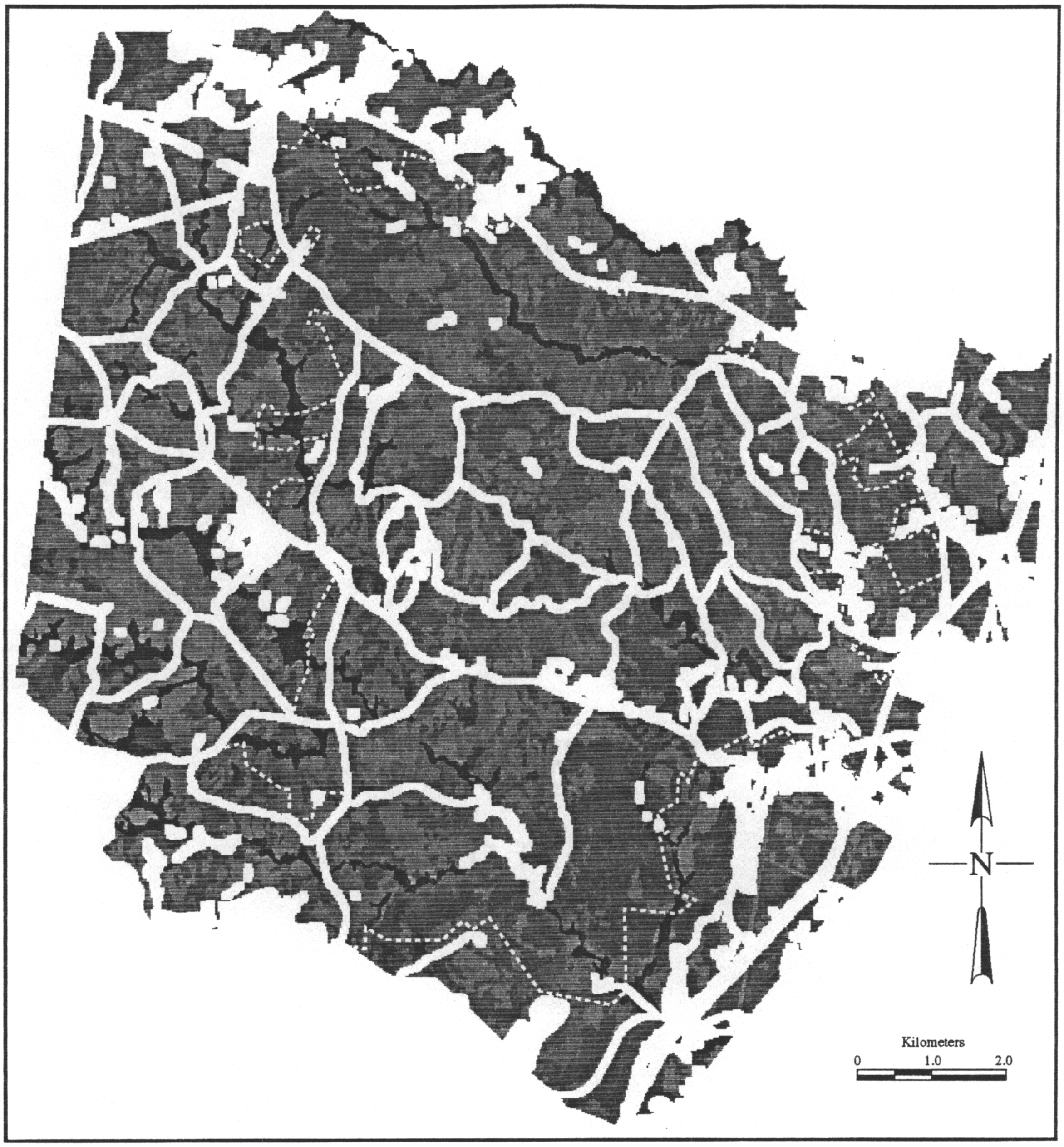

Figure 9. Map of predicted interior bird species richness within the study area after road zones of influence have been excluded. Darker areas indicate higher richness. The white dotted line is the Park boundary.

Table 16. Richness of forest interior bird species in the study area. Area totals are calculated after excluding "non-forest" areas and 60-meter road zones of influence.

Number of Species	Hectares	Acres	Percent Cover
2	3700	9143	36.83
3	1319	3258	13.13
4	4150	10,255	41.31
5	232	572	2.31
9	641	1583	6.38
10	5	13	0.05

developed. I accomplished this by reclassifying areas as being "developed" (landcover-type category 30, Table 1) using the GRASS program **d.rast.edit**. The reclassified developed area approximated the size (17.2 ha (42.4 acres)), shape, and geographic location of the actual development. The zones of influence (hereinafter "impact zones") were a 100 m. (328 ft.) buffer presumed to be highly linked to the developed area and therefore highly susceptible to interference. Another was a buffer zone of an additional 100 m. (thus 200 m. from the edge of development), which was presumed to have a weaker linkage to the developed areas and therefore to be only moderately susceptible to interference by the parasitic birds or other factors. Table 17 shows that the 100 meter impact zone affected 15.9 ha (39.2 acres) of interior habitat (~0.16% of the total interior) and that the 200 meter impact zone affected 41 ha (101.3 acres) of interior habitat (~0.4% of the total interior). Although the percentage of interior area affected is quite small, this analysis represents only one development along the Park boundary. It is possible that the effects of additional developments, and the widening of Route 234 on the northern boundary, may, in aggregate, have a significant effect on forest interior birds in PWFP. Of the forest interior species known to occur in the study area, acadian flycatcher (*Empidonax virescens*), ovenbird (*Seirus aurocapillus*), black-and-white warbler (*Mniotilta varia*), and

Table 17. Proportion of impact zones around a particular simulated land development in each of the only 2 richness zones of forest-interior bird species proximal to the development.

Richness Zone (Number of Interior Species)	Hectares	Acres	Proportion
100 meter impact zone			
2	3.28	8.1	0.207
4	12.59	31.1	0.703
Total Area Affected	15.87	39.2	1.000
200 meter impact zone			
2	10.64	26.3	0.260
4	30.31	74.9	0.740
Total Area Affected	40.95	101.2	1.000

kentucky warbler (*Oporonis formosus*) are known to be susceptible to edge effect (Kroodsma 1984). Wood thrush (*Hylocichla mustelina*), hooded warbler (*Wilsonia citrina*), and scarlet tanager (*Piranga olivacea*) are less susceptible (Kroodsma 1984). Birds in smaller patches near a new development would probably be more strongly affected than those in larger patches (Blake and Karr 1984).

Neotropical Migrant Species

The conservation of neotropical migrant bird species is also of prime concern to resource managers (Hall 1984). Of the 71 avian species in PWFP, 39 are considered to be migratory, though some spend the entire winter in the southern United States (Hamel 1992). I reclassified the original landuse/landcover map to reflect only the species richness of neotropical migrants (Figure 10). As with the forest interior species map (Figure 9) and the map for all bird species (Figure 5), riparian areas showed the highest species richness. Park managers can use the information in this map to protect areas that are valuable habitat for neotropical migrants. For example, the Park is currently conducting treatments for gypsy moths, and, given the information in this map, they can avoid treating habitats that migrants may be using during the summer months.

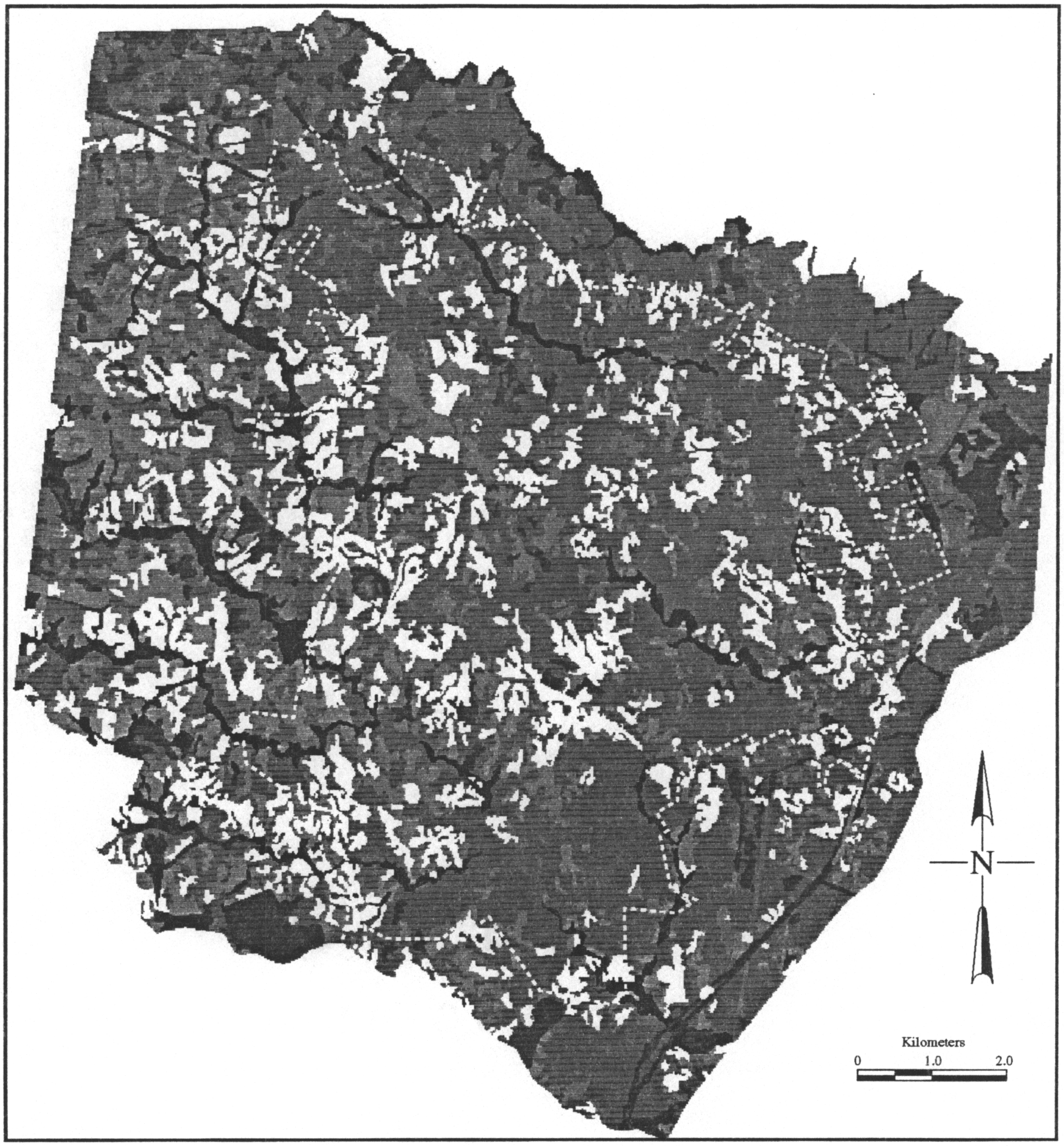

Figure 10. Predicted neotropical migrant species richness throughout the study area. Darker areas indicate higher richness. The white dotted line is the Park boundary.

Habitat Quality for Small Whorled Pogonia

The GIS methods described in this thesis for gaining insights into management of faunal species can be applied to plant species as well. (Whether "wildlife" or wildlife management should apply to plant species remains a debated topic). Depending upon the requirements of a particular taxon, the characteristics of the resource area, and the objectives of the study or management plan, useful information can be extracted from relatively few map layers.

Map coverages of slope and aspect were generated from digital data on elevations such as that available as a Digital Elevation Model (DEM), using various existing methods for their estimation. The GRASS program module called **r.slope.aspect** was used to produce these slope and aspect maps, also called layers, or coverages for an area. A raster map coverage of soil type was obtained from PWFP staff.

Through site analyses of soil type, insolation, slope, aspect, erosion, rainfall, and presence of other flora, appropriate areas for action such as reintroducing, preserving, studying, and managing particular taxa can be identified.

As a result of being listed as a federally endangered terrestrial orchid, the small whorled pogonia (*Isotria medeoloides*) has been the subject of recent studies (Vitt 1991; Mehrhoff 1988; Keeman 1988; Mehrhoff 1983; Ware 1991) including a GIS analysis to predict potential habitat for the plant in New Hampshire and Maine (Sperduto 1993). The plant is extremely rare, existing only in a few scattered colonies in Michigan, New York, Pennsylvania, Vermont, New Hampshire, Maine, Massachusetts, Connecticut, New Jersey, Virginia, North Carolina, and Missouri. Since the plants may lie dormant for several years without flowering (Williams and Williams 1983), locating additional extant colonies is likely to be difficult. A Recovery Plan for the species has been drafted (US Fish and Wildlife Service 1992). My study of this plant was completed to suggest how a GIS might be used:

1) To record observations
2) To find relations of factors to observed occurrence
3) To help find new populations
4) To relate anthropogenic effects on populations
5) To evaluate extent of suitable space
6) To acquire or otherwise protect areas of value
7) To find places for re-introduction.

Unlike animals, plants do not disperse after introduction (at least not as individuals and not very rapidly) and can easily be held in stewardship in order to maximize the chance of success after an investment of agency resources. Similarly, even when reintroducing plant material is not being considered, identifying potential habitat close to existing populations can be useful as a conservation tool.

Such areas can then be protected from disturbance so that species of interest may come to establish themselves or be reintroduced later.

GIS analyses for other threatened or endangered flora may need to address the relationship between plant and pollinator. Since *I. medeoloides* is self-pollinating (Mehroff 1983), such relationships were not germane to this analysis.

Several colonies of the pogonia are known to exist within the Park. The exact locations of these colonies are being kept confidential by Park personnel to prevent disturbance by inquisitive members of the public. One such colony is close to a private inholding within the Park boundary and may be subject to disturbance by development there.

The species is found mostly in upland sites with mixed deciduous or mixed deciduous and conifer forest in second- or third-growth successional stages (Mehroff 1988). Soils are generally highly acidic and nutrient-poor with moderately high moisture. Sparse to moderate ground cover in its microhabitat allows light to penetrate to the short (10-25 cm) plants as does proximity to features that create breaks in the canopy (USFWS 1992).

To create a map showing areas suitable for the plant, I began by reclassifying the soil coverage according to the Soil Survey of Prince William Forest Park (Virginia

Polytechnic Institute and State University 1979). I excluded areas having soils with a pH greater than 5.1 in the top ('A' horizon) of the soil. I based the decision about the pH limit on the work of Mehroff (1988) who studied 9 populations of the plant and found that the soil ph was no higher than 5.1 at any of the sites. Since most populations are found in mesic to dry-mesic deciduous woodlands (Mehroff 1988), I also excluded areas which were very wet even if they had the appropriate soil pH. This soil classification step resulted in excluding 3025 ha (7,474 acres) representing 48.9 % of the total area of the Park (Table 18).

Since the plants are known to be associated with deciduous or mixed deciduous and conifer types, I excluded all areas on the landcover layer that did not fit these criteria. Since the plants are most closely associated with deciduous woodlands in the presence of deep leaf litter (Williams and Williams 1983), I also decided to exclude all areas of mixed deciduous and conifer trees. These are typically transitional areas, progressively losing conifers. I then created a cross product of the soil and landcover maps (GRASS program **r.cross**) which identified the areas that had not been excluded in either coverage. The result showed that 1,762 ha (4,354 acres) representing 28% of the area inside the park was potentially suitable habitat for the pogonia based upon soil acidity and forest cover type (Table 18).

Table 18. Potentially suitable habitat for the small whorled pogonia based on soil acidity and forest covertype.

Soil Acidity	Covertype	Hectares	Acres	Percent Cover
Suitable	Suitable	1762	4354	28.48
Suitable	Unsuitable	1401	3462	22.64
Unsuitable	Suitable	1884	4655	30.45
Unsuitable	Unsuitable	1141	2819	18.43

In order to discriminate further within the remaining suitable areas, I took into account the apparent need of the plant for breaks in the canopy to allow for light penetration (Mehroff 1988; USFWS 1992). Since natural canopy breaks often occur near streams, I used the vector coverage of streams in the Park (USGS 1:100,000 DLG) and mapped a zone of influence of 1 cell (30 m. x 30m.) on each side of all streams. Using the map calculator program (**r.mapcalc**) I then subtracted the stream (water) cells from the map showing streams plus their zone of influence to give a map coverage of only 30 m. wide cells adjacent to streams. By crossing this coverage with the map showing potentially suitable habitat, I was able to identify areas which satisfied all 3 criteria: proper soil acidity, related forest cover type, and proximity to canopy breaks.

The areas meeting the 3 criteria, shown darkest (black) on the map (Figure 11) represent a total of about 26.2 ha (64.8 acres), only about 0.4% of the area within the Park.

Using the GRASS program **r.clump**, I calculated that there were 156 patches of potential habitat for the plant. These patches have an average size of 1,684 square m. (1.87 cells). I believe that the chances of locating previously unknown colonies of the pogonia will be significantly higher if Park personnel concentrate their searches only in these cells.

Mehroff (1989) found no colonies in areas having slope

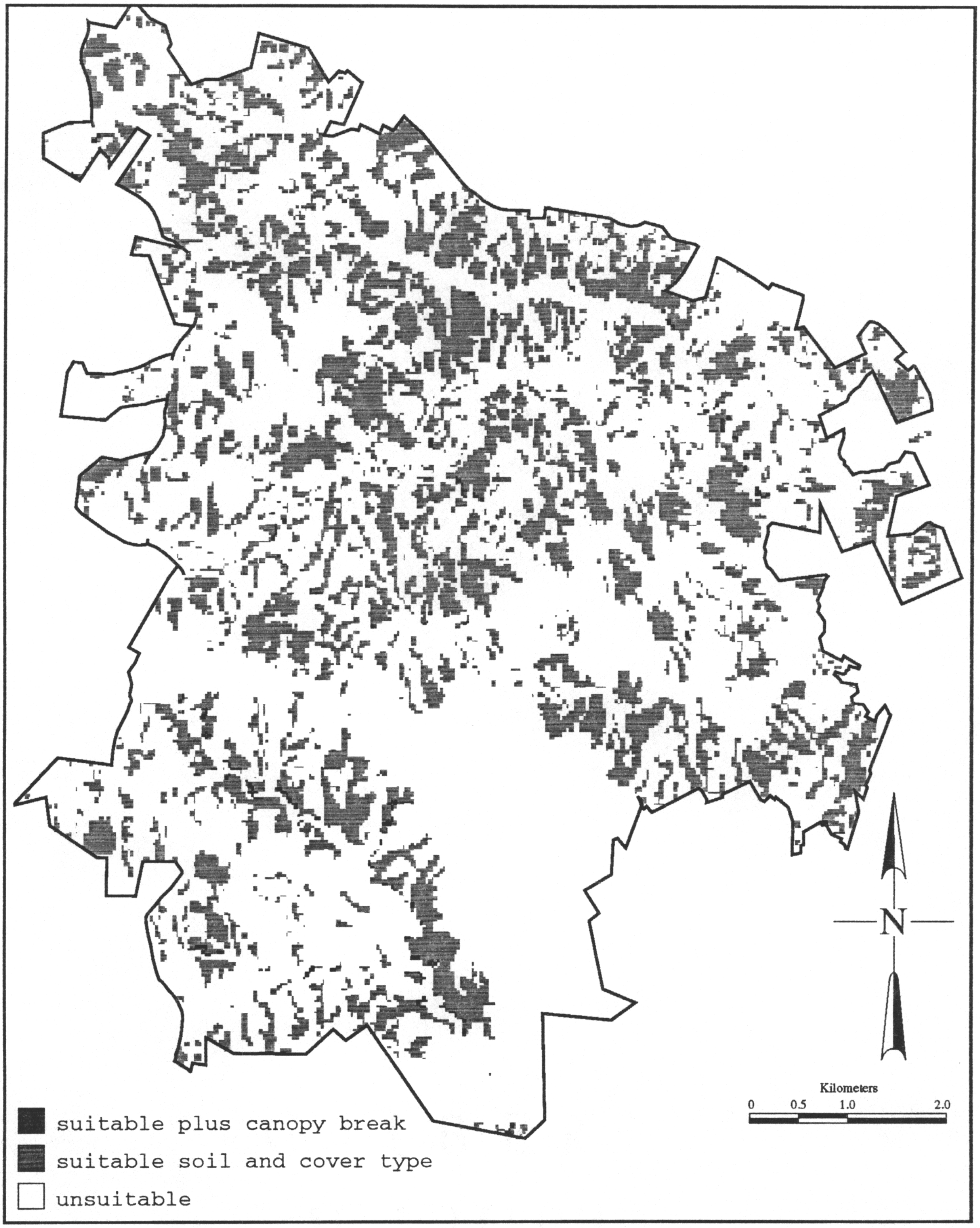

Figure 11. Habitat suitability for *Isotria medeoloides*.

greater than 30%. Of the 156 patches of highly suitable habitat in the Park, 1 patch, having a size of 1 cell had a slope of 30%. Since no patches had slope > 30%, no further exclusion, based on slope, was necessary.

GIS programs that calculate slope and aspect from digital elevation models can produce inaccuracies, especially when the study area is relatively flat, as is the case with PWFP. It is unlikely that such errors would significantly affect the analysis. However, research personnel attempting to locate new colonies of *I. medeoloides* in the areas identified by the map should be aware that small patches on the landscape may be too steep to provide suitable habitat for the pogonia. Some degree of error is inherent in GIS work, since data layers are usually interpolated from the results of field sampling (e.g., random, stratified random). The relatively small cell size (30 m.) of the data used in this analysis implies that the results should be accurate enough for the purposes of this study. However, this also assumes that the soil and landcover coverages are accurate enough to support the analysis at this resolution.

I contacted staff of the PWFP and presented my maps. They reported that they were unaware of any plant colonies being in the cells I selected as of high probability of occurrence. They did report occurrence in the next most likely cells. A staff member of the Park confirmed that my map did show at least 2 areas where she had seen the plant. Invalidation (Holling 1978) remains the challenge, for intensive surveys have not been made and, as noted, the plants flower only for short periods and not every year, and are also difficult to see.

All data sets used in this project were sent to the PWFP staff.

DISCUSSION

This thesis is a report of a project in developing methodology and procedures. Data were collected from many sources and developed into a common data format. No new data were collected (as from field plots or research) because of the objectives of the project and its temporal and financial limits.

An existing software system, GRASS, one in common use in the US NPS, was used. The project was designed to be, simultaneously, educational, developmental for select staff of the US NPS, and demonstrational for staff, students and others of some of the potential applications of GIS technology in wildland management.

I found that within GRASS I could develop many map layers using only elevation data obtained from the Virginia Department of Soil and Water Conservation. GRASS commands, for example, allowed me to produce maps of slope percent and aspect. Several of these were used in the analyses.

Using the information now available in the system and delivered to the Park, it is possible to extract or produce all of the maps shown in the List of Illustrations (page vi). I attempted to satisfy diverse interests of Park staff, to demonstrate non-trivial applications, yet avoid problems that are unique or site specific.

The creation of maps to convey information visually is the best known use of GIS. However, the ability to analyze a landscape to assess mean patch sizes, percent cover, and total area for a particular landcover type may be more important to a habitat ecologist than the ability to produce map products.

A feasibility study was done for reintroducing the bobcat to the Park. This is a realistic proposal, and a question raised by the Park staff. The cat is not present; an empirical study could be done (at high cost and over many years) and while the transplant might be successful for a few years, long term success is infeasible to be addressed in typical Master-of-Science projects. I sought to do a feasibility study to address: given the area and its surroundings and given knowledge of the bobcat, is it feasible to attempt a reintroduction? The question is one about a risk of failure for a decision maker who must allocate many funds and other resources in any typical reintroduction effort.

Of course, I cannot prove that a bobcat reintroduction will fail. My conclusion was that it is likely to and my confidence was raised by the extreme shortages or inadequate resources for the cat in not 1 but several areas. More study is not likely to change the results of the analyses. The thesis seemed to demonstrate a role of the GIS in feasibility studies for complex multi-factor managerial decision situations.

The bobcat study demonstrated an exclusionary approach to GIS use. Rather than making overlays of map layers to decide where some "optimal area" is, one where all criteria-related factors overlap, the approach demonstrated absence of appropriate resources. I progressively excluded inappropriate or non-habitat areas, narrowing the area that might be used by a bobcat population. After several such exclusions, it became clear that there was no longer available, even in this 142 square kilometer (35,100 acre) study area, sufficient habitat for the cat. This is an example of a type of study in which no field work was needed, no tests necessary. Of course, if new information becomes available which relaxes the known species requirements, the analyses can be repeated given the already existing data.

The accuracy of the results of the analysis depends upon the accuracy of the original map coverages and the reliability of information on species requirements in the literature. No information was available to me regarding the accuracy of the map coverages provided by Park personnel. If such information had been available (e.g., estimated percent error for identifying each cell with its true landcover type), then quantitative estimates of the accuracy of the results could have been made. I assumed that species requirements given in the literature were reliable. However, the requirements were given only in terms of the amount and percentage of high quality area needed. Juxtaposition of habitat patches was not addressed. It is also possible that relatively narrow habitat patches may not be usable for bobcat, since a unit of bobcat home range would not "fit" within the area. However, since the cats can disperse over great distances, and, since they are not precluded from making some use of sub-optimal habitat (i.e., prey may be available at a lesser density in sub-optimal habitat and the chance of success will be lower), I assumed that patch size and shape would not significantly affect the results.

The bobcat example shows the potentials for using GIS in doing historical ecology (Carmel Kelley, personal communication). Retrospective views suggest the cat could have been present.

GIS could be used to map and model landscape change over time. If reliable maps are available to show the condition of a landscape at different points in time, GIS could be used to model trends and predict future landscape conditions. Such analyses could be a useful management tool, especially in those areas undergoing rapid change as a result of development and agricultural land use.

The work described above addresses a notable interest in biodiversity, namely that of bird species richness. This part of the thesis demonstrates a multi-species approach to likely presence over a long period (bird species observed in any 1 year would not equal those included in the mapped numbers). Within this demonstration of applications, I showed total species, then habitat-related species (those near streams), then user-related species (those near trails). No field data of bird counts were used in these analyses. I used only data which indicate the likely presence or absence of each species. The avian species richness maps were produced by assigning species to the appropriate habitat types. Thus, the accuracy of these maps is dependent upon the accuracy of the original landuse/landcover coverage.

I did not explore all of the potential landscape relationships that might affect bird species richness. For example, an examination of the relationship between riparian areas and forest interior patches might provide useful insights. Riparian areas are important sources of invertebrates, and a cartographic overlay of riparian zones of influence with forest interior patches could identify areas of high ecological value for bird species. I also did not identify actual riparian zones. This could have been accomplished by using DEM data and the vegetation coverage to map the actual riparian zone which would be significantly narrower than the riparian zone of influence. Other boundaries between differing habitat types could have been mapped if time and resources had permitted. Ecotones could be mapped in a GIS using data on soil type, elevation, and vegetation.

Certain bird species (e.g., red-shouldered hawk (*Buteo lineatus*), blue-gray gnatcatcher (*Polioptila caerulea*)) require a minimum tract size (Hamel 1992). The bird species richness maps could be further improved if patch sizes were calculated and these species were no longer predicted to occur within patches of insufficient size.

If time, funds, and personnel were available to collect field data on a fine scale, further management applications for GIS are possible. Bird counts could have been made to test the validity of predictions such as those demonstrated here relating bird species richness to habitat type. Vertical diversity in the landscape could have been mapped and used as another layer for predictive models (e.g., bird species diversity vs. foliage height diversity). Point habitats (rocky outcrops, caves, crevices, earthen banks, snags) could be mapped to show the areas where certain species were most likely to be found.

GIS can be used alone, or in conjunction with field studies, to address virtually any management concern that has historically been addressed by field work alone (Chandler et al. 1993; Haines-Young et al. 1993; Johnston et al. 1988).

I also addressed, in the more conventional manner, a specific use of GIS: the probable locations of a rare orchid, the small whorled pogonia. The use of such maps is fairly clear: for identifying areas to protect; areas to monitor; areas needing management (since rare plants are often related strongly to forest type, age, and sunlight through the canopy); areas where reintroductions, movements, even intensive cultivations may be attempted; areas where guided tours may be conducted for photographers and amateur botanists; and areas for carefully planned research.

The approach demonstrated (as well as that for the bobcat) is highly relevant to each species in the state (about 1000 large fauna and over 2000 plants) and elsewhere. An overlay of them all should produce a faunal or floral richness map not unlike the one shown only for birds (Figure 8).

There are several uses of GIS that may contribute to conservation efforts at PWFP (and other national parks) in the future. GPS units could be used to determine the "ground truth" of map coverages. These units can help both to update current coverages as well as to collect fine scale data in those areas of the Park that are particularly valuable ecologically. If time and resources had permitted, GPS validation would have been useful to this thesis project, since no information on the "ground truth" of the data was available.

A large-scale analysis of the role of PWFP in providing stopover space along migratory routes of neotropical migrants may be useful. GIS analysis on a large-scale could include a study of the relationship between the Park and nearby wildland areas such as Shenandoah National Park. Detailed habitat use of bird species and other faunal groups within the Park may allow precise maps of habitats to be made where species occurrence is very probable (Agee et al. 1989, Bildstein et al. 1990, Sperduto 1993).

Since development pressures on the Park boundary will have potential effects on edge-sensitive species, the relationship between development and edge permeability could be studied at PWFP. In particular, the dynamics of nest parasitism and predation on forest interior bird species within the Park could be studied as the development continues along the boundary. The juxtaposition of protected versus threatened interior patches within the Park presents a convenient scenario for a comparison and contrast of effects. The current lack of consensus among researchers makes this a particularly important subject in conservation biology.

Invalidation (Holling 1978) of none of the projects was possible. The work reported herein is entirely deductive and procedural. The bobcat was not "stocked" and failure to survive over 10 years not reported. The bird species were not studied. A species list was used that was accumulated by staff and others over an excess of 30 years. Hamel's (1992) extensive 10 year effort to relate birds to habitat types was not done within the PWFP. The occurrence of the 4 rare bird species was not confirmed or denied. We did not do a bird baseline study, wait for development of structures at the Park boundary, then re-study populations. The sites of the pogonia were not visited. Staff were highly protective of the plant. They did confirm that the mapped area did contain some plants: a small step toward failing to invalidate the results.

SUMMARY AND CONCLUSIONS

A study was conducted to create procedures within a GIS that could be used by staff of a U.S. National Park. That use was limited to gaining information about managerially important wild animals and a wild plant. The study was restricted to a National Park of the US NPS, namely the PWFP located 60 km. south of Washington, D.C. The GRASS GIS system was selected. Data were acquired from the Virginia Department of Soil and Water Conservation, the College of Forestry and Wildlife Resources at Virginia Tech, and from PWFP staff. No new data were collected or digitized. At the conclusion of the study, assembled data were delivered to the PWFP staff. Seven procedures were studied and judged to be of managerial interest to the PWFP staff and others within the US NPS and elsewhere.

A procedure was developed to determine whether the area of about 142 square kilometers (~35,000 acres) in and around the PWFP was suitable for reintroducing the bobcat. Once present, the animal no longer occurs in the park. The procedure evaluates animal needs, evaluates whether the area can meet these needs (of feeding, denning, seclusion from human disturbance), and reports the results. It was concluded that the bobcat should not be reintroduced because the mix of area-support functions was not present in sufficient numbers to support a minimum population of 20 animals every year in perpetuity.

The procedure is relevant to restoration ecology, for preventing unwarranted or high-risk, high-cost reintroduction efforts, and for justifying efforts that may be successful.

The emphasis within the bird-watcher community is on number of bird species present, rarely numbers within a species. The count of species is called species richness. Six procedures related to avian richness were studied. Parkwide richness was mapped based on birds typically associated with each habitat type found within the area. The resulting map displays those areas where richness is greatest (the darker the richer.) Such maps may have relevance in suggesting a display mechanism for total biodiversity (called for in some wildland agency policy and regulations). They raise questions as well. For example, 2 areas with 10 species are mapped the same, even though there may be no species in common between the 2.

Interest in riparian areas stimulated a procedure to study and map the species richness in a riparian zone. Bird species richness was greater in the zone than that throughout the non-zone, but this was a vegetation cover-type relation only. Local studies may allow a precise riparian avifaunal zone to be described.

Because of bird watcher interest, a map of trails was developed to accompany species richness. The procedure allows users to locate good birding areas, areas where they can expect to see the greatest number of birds (a function relating to the quality of recreational user hours).

Only 4 threatened and endangered bird species occur on the PWFP. Two are ubiquitous, the other 2 related to water. The procedure suggests that maps can be made but may not provide information for decision making. When refined information on a species is available, the species is limited in its habitat use, or the species is of very high value, the GIS procedure is likely to be useful.

From the project inception, interest was high in having an ability to use maps as the basis for commenting on a development outside of a park and on things inside. A procedure was presented to show an hypothetical development at the park boundary and to show the area within zones around the development within which birds might be influenced. Effects on birds associated with the interior of forests were studied. "Non-forest" areas were identified and excluded from the total area under consideration. The procedure showed how much interior area really exists and how small the areas in which interior species richness is high.

A procedure for studying a rare plant, part of the wild *life* of the PWFP, was developed. As with the bobcat, many known characteristics of the plants' environment were selected. The areas where it should not occur (an exclusionary mapping and area selection strategy) and areas where it may occur were delimited based on the habitat conditions in which it is normally found. The procedure provides a means for recovery teams to summarize their work, to concentrate sampling, to protect and manage plant populations, and to allow more directed studies to prevent further species loss.

There are limitations of most data sets, most analytic procedures, most conclusions. I did not collect 50 layers of information over ~35,000 acres. I used what was available. The data I used was of comparable quality to that which would ordinarily be used by Park staff. Decisions <u>must be</u> made; information for doing so <u>is</u> limited and presumably will always be so. Caution in using any data, any analyses, any conclusions seems reasonable. However, it is not always possible to obtain: more data, better quality data, more recent data, better analyzed data. In many cases, there is a lack of time, resources, expertise, money, or synthetic ability. Risk is inherent in all decisions. The reasonable person will reduce the risk. Not deciding is rarely an option; not deciding, by definition (Giles 1978) is not doing wildlife management.

The GIS, along with data and its active, rational, use can result in procedures to aid parkland resource managers in making difficult decisions, such as limiting visitor access, conducting silvicultural or pesticide treatments, reintroducing species, or placing nest boxes. GIS work is not a substitute for intensive field study, but can help to make the best possible use of already existing data.

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APPENDIX . Landuse / landcover category types associated with each bird species. The category numbers correspond to those given in Table 1.

Species	Landuse/landcover types
Cooper's Hawk, *Accipiter cooperii*	all areas except 29-31.
Sharp-Shinned Hawk, *Accipiter striatus*	all areas except 29-31
Red-Winged Blackbird, *Agelaius phoeniceus*	16-25, 27-28
Wood Duck, *Aix sponsa*	28-29
Mallard, *Anas platyrhynchos*	28-29
Ruby-Throated Hummingbird, *Archilochus colubris*	18-20, 28
Great Blue Heron, *Ardea herodias*	28-29
Ruffed Grouse, *Bonasa umbellus*	12-20
Canada Goose, *Branta canadensis*	28-29
Great Horned Owl, *Bubo virginianus*	1-11, 21-23, 26-28
Red-tailed Hawk, *Buteo jamaicensis*	5-15, 27
Red-Shouldered Hawk, *Buteo lineatus*	18-20, 28
Broad-Winged Hawk, *Buteo platypterus*	12-15
Green-Backed Heron, *Butorides striatus*	28-29
Whip-Poor-Will, *Caprimulgus vociferus*	13-15, 27
Northern Cardinal, *Cardinalis cardinalis*	21-25, 27, 30
American Goldfinch, *Carduelis tristis*	18-20, 27-28
House Finch, *Carpodacus mexicanus*	27, 30
Turkey Vulture, *Cathartes aura*	all areas except 29-31
Yellow-Billed Cuckoo, *Coccyzus americanus*	16-20
Northern Or Yellow-Shafted Flicker, *Colaptes auratus*	13-15, 20
Northern Bobwhite, *Colinus virginianus*	2, 10, 21, 26-27
Rock Dove/Pigeon, *Columba livia*	30
Eastern Wood-Pewee, *Contopus virens*	2, 6, 9-10, 13-15, 26
Black Vulture, *Coragyps atratus*	all areas except 29-31
American Crow, *Corvus brachyrhychos*	1-11, 21-27, 30
Blue Jay, *Cyanocitta cristata*	9-10, 13-15, 27, 30
Black-Throated Blue Warbler, *Dendroica caerulescens*	9-10, 13-15, 17, 19-20,25
Yellow Warbler, *Dendroica petechia*	2, 6, 9, 10, 21, 23
Pine Warbler, *Dendroica pinus*	1-11
Pileated Woodpecker, *Dryocopus pileatus*	18-20
Acadian Flycatcher, *Empidonax virescens*	18-20
Bald Eagle, *Haliaeetus leucocephalus*	18-20, 28
Worm-Eating Warbler, *Helmitheros vermivorus*	17, 19-20
Barn Swallow, *Hirundo rustica*	30
Wood Thrush, *Hylocichla mustelina*	6, 9-10, 18-20
Belted Kingfisher, *Megaceryle alcyon*	28-29
Red-Bellied Woodpecker, *Melanerpes carolinus*	18-20
Red-Headed Woodpecker, *Melanerpes erythrocephalus*	18-20

APPENDIX . (continued)

Landuse / landcover category types associated with each bird species. The category numbers correspond to those given in Table 1.

Species	Landuse/landcover types
Wild Turkey, *Meleagris gallopavo*	8, 9, 11-13, 16-18
Song Sparrow, *Melospiza melodia*	27-28
Northern Mockingbird, *Mimus polyglottos*	27, 30
Black-And-White Warbler, *Mniotilta varia*	18
Brown-Headed Cowbird, *Molothrus ater*	2,10,14,15,20,27,30
Great Crested Flycatcher, *Myiarchus crinitus*	2,10,14,15,20
Kentucky Warbler, *Oporornis formosus*	18-20
Tufted Titmouse, *Parus bicolor*	12-20, 24-25, 30
Carolina Chickadee, *Parus carolinensis*	5-11
House Sparrow, *Passer domesticus*	30
Indigo Bunting, *Passerina cyanea*	14-15, 27
Rufous-Sided Towhee, *Pipilo erythrophalmus*	2,10,14-15,22,27
Scarlet Tanager, *Piranga olivacea*	12-13
Summer Tanager, *Piranga rubra*	6,9-10,13-15,25
Blue-Gray Gnatcatcher, *Polioptila caerulea*	5-9,11-13,18-19
Common Grackle, *Quiscalus quiscula*	1-7,18-20,21,26,30
Eastern Phoebe, *Sayornis phoebe*	18-20
American Woodcock, *Scolopax minor*	16-20,27
Ovenbird, *Seiurus aurocapillus*	12-13
Louisiana Waterthrush, *Seiurus motacilla*	18-20
American Redstart, *Setophaga ruticilla*	18-19
Eastern Bluebird, *Sialia sialis*	2,10,15,20-25,27,30
White-Breasted Nuthatch, *Sitta carolinensis*	13-15,17
Field Sparrow, *Spizella pusilla*	2,10,15,21-24,27
Barred Owl, *Strix varia*	16-20,27-28
European Starling, *Sturnus vulgaris*	18-20,27,30
Carolina Wren, *Thryothorus ludovicianus*	16-25,27
Brown Thrasher, *Toxostoma rufum*	2,10,14-15,27
American Robin, *Turdus migratorius*	18-20,30
Red-Eyed Vireo, *Vireo olivaceus*	12-13,16-19
Hooded Warbler, *Wilsonia citrina*	16-20
Mourning Dove, *Zenaida macroura*	27,30,31

VITA

Gary Casabona was born on November 26, 1959, in Clifton, New Jersey. During his youth, he could often be found catching crayfish and salamanders in the Alphonso F. Bonzo bird sanctuary which was located just a few hundred meters from his home. It was this early love of nature which would lead him to pursue a career in wildlife study. He graduated from Clifton High School in June of 1977 and began pre-veterinary studies at Cook College, Rutgers University.

After 2 years, he left school to pursue interests in music and theatre. For 8 years, he worked by day as a laboratory technician in the environmental and pharmaceutical fields, while at night he acted in theatre productions and played in a band. In 1987, he returned to Cook College where he received a Bachelor of Science degree in Environmental Science in May of 1989. During the following year, he worked as an analytical chemist for the Department of Environmental Science at Rutgers studying the effects of organophosphate pesticide exposure on citrus workers in Orange County, Florida. In January of 1992, he became a candidate for a Master's degree in the School of Forestry and Wildlife

Resources at Virginia Tech. During his graduate career at Virginia Tech, Gary studied resource economics for a year before choosing to explore the applications of geographic information systems in wildlife management.