5-2008

EVALUATION OF RED-COCKADED WOODPECKER HABITAT USING A RED-COCKADED WOODPECKER FORAGING MATRIX APPLICATION

Atul Kale
Clemson University, atulk@clemson.edu

EVALUATION OF RED-COCKADED WOODPECKER HABITAT USING A RED-COCKADED WOODPECKER FORAGING MATRIX APPLICATION

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Forest Resources

---

by
Atul Kale
May 2008

Accepted by:
Dr. Bo Song, Committee Chair
Dr. Tom M. Williams
Mr. Ralph Costa
Dr. Greg K.Yarrow
Dr. Christopher Post

ABSTRACT

The red-cockaded woodpecker (*Picoides borealis*) is a listed endangered species, endemic in the southeastern United States. It is a cooperatively breeding species preferring to live in an open, mature and old growth pine ecosystem. The restoration and management of red-cockaded woodpecker habitat is a difficult task within both public and private land. Forest management practices may have adverse effect on nesting and foraging habitat. To delist the red-cockaded woodpecker from the endangered species list, the U.S. Fish and Wildlife Service developed the 2003 Recovery Plan. The foraging matrix was developed to produce an index or scoring system to classify habitat based on criteria of the Recovery Plan. The foraging matrix scores are based on twelve criteria and four habitat criteria at the partition level. The RCW Foraging Matrix Application (FMA) is an automation of the forage matrix in GIS and is being used to evaluate the impact of various forest management practices on RCW habitat. In this study, the GIS foraging matrix was applied to 18-year (1989-2007) forest inventory and cavity tree position data on Hobcaw Barony. Stand and partition scores were developed for each RCW cluster for each of these 18 years. Historical RCW data included the number, position, and activity of all cavity trees for the 18-year period and the locations of all nests from 1994 through 2007. The number of clusters was determined by the method developed by Harlow et al. (1983) and those circles were used to locate individual clusters. Of 36 clusters located in this way from 1994-2007, 31 were found with at least one nest.

Stand scores ranged from 1-4.3 (1-5 possible range) and showed little year-to-year variation. Stand score is heavily weighted to the number and the basal area of large pines, which were not harvested during the period. Only mortality associated with Hurricane Hugo produced a noticeable change in stand scores. There was a qualitative correspondence between stand scores over 3 and success of RCW clusters as measured by persistence or rate of nesting.

Scores at the partition level only varied from 1-2.2 (1-5 possible range). Yearly average partition scores varied from 1.52-2.05 and reached the minimum when the number of clusters was the greatest, while they reached the maximum when the number of clusters was the least. In addition, partition scores rose from 1998-2004 while the numbers of both clusters and nests declined most steeply. Partition score also did not relate to nesting success, with clusters scoring minimum (1.0) and maximum (2.2) each nesting 13 of the 14 years.

The failure of the partition score to be correlated with any indicator of RCW success reveals flaws in the method of calculation of this score. The score is weighted heavily to the area of Good Quality Foraging Habitat, defined as stands that scored 5 (all 12 criteria perfectly met). No stand on Hobcaw met that score, and the partition score was unaffected by the scores of any stand within the partition. The other parameters also give higher scores based on partition area. Since RCW tend to have smaller home ranges in very good habitat an indicator based on area will tend to decline as the habitat improves.

Keywords: endangered species, foraging habitat, foraging matrix application, recovery plan.

ACKNOWLEDGMENTS

I would like to thank all people who have helped and inspired me during my master study. I especially want to thank my advisor, Dr. Bo Song, for her guidance during my research and study at Clemson University. Her perpetual energy and enthusiasm in research had motivated all her advisees, including me.

I would like to acknowledge my appreciation and special thanks to Dr. Tom Williams for his detailed and constructive comments, and for his important support throughout this research. I thank him for critiquing my thesis; without his encouraging words, I could have never finished this research. My deepest gratitude goes to Mr. Donald Lipscomb throughout my research; this thesis is simply impossible without him. Throughout my research, he provided encouragement, sound advice, good company, and many good ideas.

Mr. Ralph Costa, Dr. Chris Post, and Dr. Greg Yarrow deserve special thanks as my research committee members. They gave support and suggestions during my study and research. In particular, I would like to thank Mr. Ralph Costa for encouragement and suggestions during the research. He provided valuable information and literature about the Red-cockaded woodpecker.

I would like to thank Mr. Douglas Benson for his support and computer assistance in the research. I am especially indebted to Mrs. Barbara Ramirez spending many hours editing to my thesis. I am grateful to Mr. Brent Carey, for helping me during RCW data collection at Hobcaw Barony. I would also like to thank George Chastin, Jeffery Vernon, and Alreda Grate for the help and support during data collection. I would not finish this work without their help.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The red-cockaded woodpecker (*Picoides borealis*, RCW), one of 22 species of woodpeckers native to North America (Jackson, 1971; 1994), is an endangered species endemic to fire-maintained pine forest. The RCW population declined from late 1800's to 1980's due to extensive logging and short-rotation plantations and fire suppression in mature pine forests (Duncan et al., 2001). In 2000, 14,068 RCWs were estimated to be living in 5,627 known active clusters across eleven southeastern states. In, South Carolina there was 133 groups found on state-owned lands and another 524 groups on federal properties (USFWS, 2003). The decline in RCW populations led to management and restoration of habitat, a key to recovery.

The RCW population is managed under a distinct recovery unit system. Recovery units are geographic subunits (based on ecoregions) that are used to promote genetic variation and also adaptation to local environments. South Carolina contains sections of four recovery units, three of which are germane to this study: the Sandhills, Mid-Atlantic Coastal Plain, and South Atlantic Coastal Plain. In 1998, the US Fish and Wildlife Service (USFWS) signed the South Carolina Red-cockaded Woodpecker Safe Harbor agreement, a cooperative program with the South Carolina Department of Natural Resources. This is a voluntary program for private land owners designed to encourage conservation of RCW populations on private lands. This program was first implemented in the Sandhills physiographic province of North Carolina in an effort to maintain the RCW population and provide participating landowners with an incentive for increased management of the species (Kennedy and Costa, 1996). It has been very successful maintaining almost 300 groups of RCWs on 161,875 hectares (ha), represents nearly 75%

of RCWs on private lands in South Carolina. Hobcaw Barony, where the data for this study were collected, was one of the private lands that enrolled in the Safe Harbor program.

RCW habitat is considered good quality if it consists of open pines with little hardwood midstory, and a basal area of 50-80 square feet per acre with little or no hardwoods (Dickson, 2001). The primarily threats to RCWs, are: lack of suitable cavity trees (Costa and Escano, 1989; Hardesty et al., 1995), habitat fragmentation (Conner and Rudolph, 1991), lack of sufficient quantity of high quality foraging habitat (Walters et al., 2002; James et al., 2001) and hardwood midstory encroachment in the foraging habitat (Vabalean and Doerr, 1978; Locke et al., 1983; Conner and Rudolph, 1991; Costa and Escano, 1989; Loeb et al., 1992). The loss of old pine habitat with the increase in midstory vegetation was responsible for the decline of RCW populations (Jackson, 1971; Lennartz et al., 1983; Ligon et al., 1986; Conner and Rudolph, 1989) because it led to cluster abandonment (Conner and Rudolph, 1989). Thus, these adverse habitat conditions negatively affected the foraging habitat (Epting et al., 1995) and group fitness (Davenport et al., 2000), i.e., the group size and the number of fledglings. It has been also observed that the pine bole below the top of the midstory vegetation is generally disregarded by RCWs as foraging substrate (Skorupa, 1979; Franzreb, 1992).

Red-cockaded Woodpecker Life History

The RCW is monogamous and essentially single brooded, although rare instances of double brooding have been documented (Jackson, 1994; Schillaci and Smith, 1994). The breeding age for RCWs is approximately one year and as the age increases the success of reproduction improves (Walters, 1990). It is a cooperative breeder living in groups consisting of a breeding pair with or without male helpers (Ligon, 1970; Lennartz et al., 1987; Walters et al., 1988) that forage and roost in living pines (Hooper and Lennartz, 1981). It is a non-migratory and territorial bird and its territory ranges from 50 to 150 ha (Hooper et al., 1982; Porter and Labiskey, 1986; Walters, 1991).

The clutch size of RCW is normally two to four eggs (Ligon, 1970), and its incubation period is from 10 to 11 days, the shortest among birds (Ligon, 1970; Crosby, 1971). Incubation is done by parents and helpers (Jackson, 1994). The young fledge at 26 to 29 days of age (Ligon, 1970), although they are still dependent on their parents and helpers for two to five months thereafter (Jackson, 1994). Juvenile RCWs may serve as helpers in their territories or disperse in search of a breeding opportunity (Walters et al., 1988). RCWs have a long life span, with documented wild birds as old as 15 years (Jackson, 1994), and 18 years (R.Costa pers.comm.).

Red-cockaded Woodpecker Cavity Trees and Clusters

The group defends its territory, which includes foraging habitat and cavity trees; the aggregate of cavity trees used by a group referred to as a cluster (Walters et al., 1988). Cavity construction, which takes from 10 months (Baker, 1971) to several years (Jackson et al., 1979), begins with the selection of an old pine tree typically infected with red-heart fungus (*Phellinus pini*) because infected heartwood is soft and easy to excavate (Walters, 1990). RCWs prefer longleaf pines (*Pinus palustris)*, but the other southern species, such as loblolly pine (*Pinus taeda*), are also used for cavity excavation (Dickson, 2001). Old pine trees are preferable for excavation because they contain a larger heartwood diameter than young pines. The resulting cavity, situated within the heartwood, prevents resin flow from sapwood from entering the chamber (Jackson and Jackson, 1986; Clark, 1992).

High resin production is another factor that influences RCW's cavity tree selection. RCWs peck small holes, called resin wells, around the cavity causing resin to flow down the bole of the tree (Jackson, 1979). RCWs prefer cavity trees with high resin flow on the surface of the bole (Bowman and Huh, 1995; Conner et al., 1998a) to serve as a barrier against rat snakes (*Elaphe* spp), a major woodpecker predator (Jackson, 1974; Rudolph et al., 1990a), although it offers virtually no protection from other cavity competitors (Rudolph et al., 1990b).

Cavity trees with RCW activity are referred to as active cavity trees. The number of active cavity trees in clusters may be the good indicator of RCW group fitness. Active cavity trees on forest edges have the highest resin flow as compared to active cavity trees in the interior forest. Preference for active cavity trees may result in more excavation of new cavities near the edge even when interior basal area has been reduced and midstory has been controlled (Ross et al., 1997). Resin flow in active cavity trees varies greatly within pine species as a function of tree, site, stand density, and genetic factors (Mason, 1971; Hodges et al., 1979; Bowman and Huh, 1995; Ross et al., 1997).

Mature pine trees are preferred by RCWs for nesting and are usually more than 70 years old, while foraging habitat varies greatly in terms of species and age classes

(Lennartz and Henry, 1985). Foraging activity of RCWs occurs in the largest and tallest available pines (Jones and Hunt, 1996). RCWs select larger trees over small trees because: 1) bark flakes of larger trees detach easily and hide larger insect prey, and 2) larger insect populations can be associated with the greater structural diversity and surface area of trees (Hopper and Lennartz, 1981). RCWs save time and energy in their search for new foraging habitat in their selective preference for mature pine stands (Jones and Hunt, 1996). RCW foraging decreased in stands that had a greater basal area of hardwoods (Hooper and Harlow, 1986). During the breeding season, RCWs forage closer to their clusters and may include smaller pines and hardwoods as compared to the non-breeding season (Jones and Hunt, 1996). The overlap of RCW territories and varied composition of stands precluded the observation of RCW habitat preferences at Hobcaw.

Red-cockaded Woodpecker Foraging Habitat

Skorupa (1979) observed that RCW's foraging behavior is specialized and unique. RCWs require an open pine ecosystem for foraging (Jackson and Jackson, 1986). The foraging area mainly consists of large pines rather than hardwoods (Ramey, 1980; Bradshaw, 1995). They forage primarily on arthropods especially ants and roaches, beetles, spiders, centipedes, crickets and moths (Baker, 1971, Harlow and lennartz, 1977).

It takes several years to excavate cavities in pine trees. RCWs require the old growth living pines for their nesting/foraging habitat and new habitat becomes available only slowly over time. Therefore the need to conserve existing habitat is important (Loeb et al., 1992). To ensure the protection of RCW habitats, foraging habitat standards were developed to recover the RCW population on federal and state lands and conserve them on private lands.

Recovery Plan and Foraging Habitat Standards

The purpose of the Recovery Plan is to provide a strategy to remove RCWs from the endangered species list. It was assumed that size, distribution, and number of RCW populations would be sufficient for recovery if certain criteria were met (USFWS Recovery Plan, 2003). The most important among these is the population size measured as on the number of potential breeding groups; population trend is assessed using the number of active clusters. Improving a population's size and trend is dependent on active management and maintenance of RCW foraging habitat.

The first revision of the Recovery Plan was approved by the U.S. Fish and Wildlife Service (USFWS) in 1985, it recommended 51 hectare of foraging habitat be managed for each RCW group for recovery if other foraging criteria were also met. From this plan, foraging guidelines were established in 1989 to recover RCW populations on federal and other public lands. These guidelines, which are primarily based on the basal area and trees/hectare of pines include:

1. A minimum of 8,490 ft^2 basal area in pine.
2. Basal area of 60 – 90 ft^2 per acre
3. 50 percent or more pines in a pine stand.
4. Contiguous to the cluster and to other foraging habitat and not isolated by suitable habitat.
5. Pines of 30 years of age or older.

6. 6,350 pine stems ≥ 10" diameter at breast height (DBH).

These guidelines provided protection from over harvest of pines and helped maintain large areas for RCW foraging habitat. However these recommendations were based on one population and a small sample (n=18) (USFWS Recovery Plan, 2003). Furthermore, based on more recent research, the relationship between the total number and the total basal area of pines greater than or equal to 10 inches in DBH within the foraging area is unclear (USFWS Recovery Plan, 2003). As a result of new research on foraging habitat requirements and many other aspects of RCW ecology and management, the second revision of RCW Recovery Plan was approved by the USFWS in 2003. It includes two sets of foraging habitat guidelines: a recovery standard and a managed stability standard. These foraging habitat guidelines were also used to develop the matrix system.

Matrix System

After the establishment of RCW foraging guidelines in the second revision of the Recovery Plan, a matrix system was developed by USFWS to assess the quality of habitat and the impacts of projects e.g; timber sales, construction, etc. on that habitat (refer to the matrix in Appendix C). This matrix system evolved over several years.

Initially Fort Bragg, North Carolina, developed a matrix system to assess impacts of projects on RCW habitat on their lands. This first matrix system organized the foraging guidelines for implementation and evaluation of the habitat. However, it was not efficient for assessing habitat, because it was based on natural rather than managed RCW habitat. It classified habitat into five categories with 1 representing the least desired to 5, the ideal. There were no criteria established for RCW foraging habitat at the foraging habitat partition level in this matrix because it was assumed that this habitat was best managed at the stand level.

Later, this matrix system was modified to include a partition concept (which represents the RCW foraging area on a map), and additional stand standards, specifically hardwood midstory and fire return interval standards. Hardwood midstory has a negative impact on RCW habitat and it is also a key factor in determining the quality of the habitat The hardwood midstory standard was determined on the basis of two components, density and height, represented by the following categories (Source: USFWS website):

Height = low (L) <7', moderate (M) 7-15', tall (T) 15'+

Density = sparse (S), moderate (M), dense (D)

The height is listed first followed by density, e.g., T-D = a tall, dense midstory (refer to the matrix table in Appendix C).

In assessing midstory in the field, the height of the majority of the midstory stems is first determined. Then total midstory density of all stems is calculated; for example, if on average, 20% of the stems exceed 15 feet (tall), but 80% are 7-15 feet (moderate), the height category was found to be moderate.

The partition concept was first introduced in this matrix system to represent RCW foraging boundaries i.e., home ranges. This matrix had a There were total of sixteen foraging habitat characteristics. RCW habitat characteristics were classified into five categories: 1) Poor, 2) Fair, 3) Good, 4) Very Good, and 5) Excellent. RCW habitat was differentiated on the basis of the total score of all characteristics. For each characteristic a score from 1 to 5 was assigned and then the total score was calculated by adding all the scores for each characteristic.

Although this matrix included the requirements for RCW habitat in the scoring system, it lacked a weighting factor, i.e., it gave equal importance to all habitat characteristics. In addition, it did not have an automated, deployable format for evaluating RCW habitat at the stand level and the partition level. Because it had no automated deployable format, this matrix system was again modified based on the recommendations of the experts from Environmental Systems Research Institute (ESRI), Fort Bragg, the U.S. Army Environmental Center (USAEC), and the USFWS. They ranked the habitat characteristics, and the results were used to establish a preliminary weighting system for the recovery standard foraging habitat matrix. In addition it incorporated a deployable application using a geographic information system (GIS) to automate foraging habitat evaluation. In this matrix the characteristics are clearly differentiated at the stand and partition levels, twelve characteristics being identified at the former and four at the later. This matrix system was more efficient because it included all requirements of RCW habitat as well as classifying the habitat at both partition and stand levels; more importantly the characteristics were ranked using weighted factors. This matrix system became a part of the RCW Foraging Matrix Application (RCW FMA) used to evaluate and assess RCW foraging habitat at Fort Bragg. The RCW FMA was found to be a useful tool for managing longleaf pine forests and RCW habitat as both have similar management requirements. The forest inventory data from Fort Bragg was used as sample data in the RCW FMA. The result showed that the partition score was 2.2 out of the scale of five with the stand scores being higher than the partition scores.

Red-cockaded Woodpeckers and Vegetation Studies at Hobcaw Forest, SC

The RCW population has been studied on Hobcaw periodically since the 1960's (Dennis, 1968). In 1977, Grimes (1977) studied the relationship between vegetation characteristics and RCW clusters. Hobcaw stands varied widely in terms of density, basal area, and understory characteristics. Hobcaw RCW clusters primarily consist of loblolly pine, longleaf pine, and pond pine. In addition, cluster areas varied considerably in terms of structure and species composition. Grimes (1977) reported a low fledging rate (1.44/group) in 20 of the 28 clusters at Hobcaw.

Prescribed burning and different intensities of cutting, ranging from none to seed tree, were not been effective management strategies to improve the nestling productivity (Grimes, 1977). Wood et al., (1981) conducted both early home range and the only manipulative study of RCW habitat needs, finding that clearcutting had insignificant impact on the fledgling rate. A second reproductive study conducted by Nalley (1998) found a fledging rate of 1.0 fledgling per group. The 1993 private landowner guidelines (Costa, 1992) were used to assess foraging habitat conditions after Hurricane Hugo impacted Hobcaw in 1989 (Williams and Lipscomb, 1996). The guidelines basal area and stem requirements were used to predict the abandonment of individual clusters. The result showed that protection of the nesting areas since 1978 had not been effective, and protection of pines > 10" in foraging areas since 1990 was inadequate. Prescribed burning in the dormant season had occurred at 3-5 year intervals. To improve habitat conditions, several clusters have undergone understory hardwood removals and growing season prescribed fire from 2004-2007.

Partition Approach in the Matrix

Prior to approval of the second revision of the Recovery Plan, impacts to foraging habitat were assessed using for biological assessments and evaluations for federal lands (Henry, 1989), and the RCW manual for private lands (Costa, 1992). One goal of the matrix system was to allocate foraging habitat according to a group's territory.

The foraging partition approach incorporated GIS with the foraging habitat standards and evolved into a revised matrix system. Foraging partitions are used to define RCW territories. Foraging partitions create a 0.5 mile radius foraging circle around the center of each cluster. Stand data and characteristics are then applied to determine availability of foraging habitat within the newly created polygon. When 0.5 mile foraging circles overlap, equal portions of the foraging area are divided between adjacent clusters (USFWS, 2005).

Prior to this study RCW habitat at Hobcaw had never been evaluated by the RCW FMA. This study will focus on the relationship between habitat quality and the RCW population. Habitat quality can be used to assess RCW group fitness. For example, a basic assumption is that the nesting success of a specific group is affected by habitat conditions and that if nesting success is good then the territories fulfilled most of the requirements of good RCW habitat. This study is important because it not only evaluates RCW habitat at Hobcaw, but also the matrix system, an important component for implementing the Recovery Plan. Examining the matrix standards for stand and partition characteristics in RCW foraging habitat also illustrates the importance of individual characteristics and how they affect habitat quality. In this study, RCW habitat at Hobcaw was evaluated using the RCW FMA to predict the trend and success of RCW groups. This study evaluated and assessed the quality of the RCW habitat using the RCW FMA at Hobcaw Barony from 1989 to 2007. The resulting partition scores were used to correlate RCW habitat and the RCW population for three different years (1977, 1998, and 2007).

Specifically, this study focused on three areas: (a) the effectiveness of partition scores as an indicator of good RCW habitat; (b) the relationships among stands, partition scores, and the number of nests over a 14 year period, 1994-2007; and (c) the ability of the stand and partition scores to assess quality and quantity of habitat as measured by cluster status.

MATERIALS AND METHODS

Study Area

Hobcaw Barony is 17,500 acres, 7,600 of which are forest, 7,500 salt marsh, and 2,400 fresh water or brackish marshes and abandoned rice fields (Wood et al., 1985) located near Georgetown, South Carolina. The 7,600 acres of forest are comprised of 6,100 acres of pines, 800 acres of hardwood, and 300 acres of fields/marshes. Pine forests of Hobcaw mainly consist of longleaf pine, loblolly pine, and shortleaf pine with the hardwood species, mainly oak and sweetgum. Soils found on Hobcaw are entisols and spodosols (Lipscomb and Williams, 1983). Hobcaw is divided into six compartments: 1) Mud bay, 2) Hog pen, 3) Hobcaw, 4) Crabhaul, 5) Clambank, and 6) Bellefield, among which Hobcaw is the largest, and Crabhaul the smallest.

Collection of Forest Inventory Data

The stand data collected for the RCW FMA can be classified broadly into three periods:

1. Pre –Hugo period.
2. Hugo period in which data were collected on tree mortality and damage.
3. Post –Hugo period.

These data include the basal area and stems per acre for six size classes: pine 4-10”, 10-14”, and 14”+, and hardwoods 4-10”, 10-14”, and 14”+. These data were generated from four sources:

1. A 5% inventory of the forest in 1986.
2. Growth data from 1979-1984 continuous forest inventories.

3. A 1% inventory of Hugo wind damage.
4. An aerial photo based estimation of areas of salt mortality.

Pre-Hugo stand data were developed based on the stand inventory of 1986 (Williams and Lipscomb, 2002). This inventory represented a 5% stratified sample of the forest. Point samples were allocated to 361 stands on the basis of area. All trees in the plots were measured for species group, DBH, and merchantable height using codes of the TVA Inventory Processor Program (Bean and Ellis, 1984). Since the Inventory Processor program was developed to classify forest products size classes, the original point data were reanalyzed to divide them into the six classes required by the matrix program. An Excel workbook was designed to import the species and the DBH data and organize them based on stems per acre and basal area of pines and hardwoods in the three required diameter classes. Each page of the workbook corresponded to a stand, and data from each page was then imported into an ARC-GIS shape file of the stands of 1986. Attributes of the shape file, developed for forest management (Lipscomb and Williams, 1983; 1998) were added to include trees per acre and basal area of pines with DBH of 4-10", 10-14", and 14"+, respectively, plus the hardwoods of the same size classes.

To ensure relevant data for each year, growth was estimated from the Continuous Forest Inventory system (Lipscomb and Williams, 1987). Since data collected from 1979-1984 represented a period of normal growth and mortality, they were used for periods of 1986-1989 and 1992-2007. The 1979-84 data were used to calculate net growth up to 2007 in the three diameter classes for pines and hardwoods (Table 1). This net growth estimation was then used to calculate annual changes in each class for the 1986-1989 and 1992-2007 periods.

Hurricane Hugo struck Hobcaw in September 1989 and had two primary impacts. Winds caused significant mortality across species and diameter classes. Wind damage was assessed by a 1% inventory in 1989-1990. Line transects were used to determine damage and mortality by species and size class in each stand (Gresham et al., 1991). These data were used to determine the percentage loss of pines and hardwoods in each stand. Since the mortality increased with increasing DBH the average stand mortality was halved for the 4-10" diameter class and doubled for the 14"+ diameter class. These wind mortality percentages became the basis for the mortality statistics from 1989 to 1990.

In addition to wind damage, approximately 1000 acres of the forest were covered with salt water during the storm. Within this area salt stress killed a large number of trees. The mortality was mapped from aerial photographs to identify areas of at least five dead trees or more throughout the affected area (Gardner et al., 1991). The percentage of each stand mapped as dead was calculated. Stand TPA and BA were reduced by the percentage of the stand area that was mapped as dead. These reductions were then applied to stand data for 1991. Data for 1992 -2007 were then calculated by applying the net growth estimated in Table 1.

Stand data were categorized into pine and non-pine data (in Appendix E: tree species list). Basal area and trees per acre of pine and hardwood were tabulated in the Excel datasheet separately on the basis of three classes of DBH, i.e., 4-9, 10-14, and > 14 inches. These results, in addition to the basal area, were calculated in the excel spread sheet and then loaded into the attribute columns of the stand feature class of the RCW FMA geodatabase. Among 59 attributes in the stand feature class, 23 represent the basal area, tree per acres, hardwood midstory, prescribed fire, stand age, herbaceous groundcover, site index, and stand type. The remaining 36 attribute columns remain empty and the values for these attributes are calculated by the RCW FMA. The calculated values of these attributes represent the recovery and manage and stability foraging habitat as presented in the Recovery Plan standards.

Cavity Tree Data, Red-cockaded Woodpecker Population, and Nest Counts

In April from 1989-2007 all cavity trees were assessed and recorded as being active or inactive based on the condition of the cavity. All new cavity trees were mapped using GPS and assessed for cavity condition. All cavity trees with fresh resin flow on the bole were identified as possible nest sites. In May, the RCW breeding season, all active cavity trees were tapped or scrapped in an attempt to flush adult an RCW incubating eggs. This tapping method conducted at 2-7 day intervals proved to be an efficient method for the identification of nest trees (Nalley, 1998). The nest search was conducted every year in April from 1994-2007. An adult RCW census was conducted during the nesting seasons of 1977, 1998, and 2007. The first two census were conducted in April, and the last one from May to June. The existing database was used to verify the location of each cluster. It is easy to count RCWs during the nesting season because post-hatching adults begin feeding the chicks in the morning and throughout the day. If adult birds were not found in a cluster, a second visit to that cluster was done to verify the presence/absence of birds in the cluster.

Number of Clusters at Hobcaw Barony

Harlow's cluster numbering system (Harlow et al., 1983) was adapted specifically for Hobcaw. In this numbering system cluster location is based on the location and presence of active cavity trees. The number of clusters pre-Hugo was used as a benchmark for this numbering system. There were 28 clusters present at Hobcaw during the pre Hugo period. These clusters were numbered from 1 to 28, starting in the north and moving to the south. These numbers remained the same for the 18-year period.

If a new cavity tree was found ¼ mile or greater from the center of an existing cluster, a new cluster number was assigned to it. The same cluster number was assigned to cavity trees that were not located more then ¼ mile from the "original" cluster center. Using this system, the number of clusters varied from 29 to 40 from 1991 -2007 (see Table 3).

Cluster numbers in the RCW FMA were assigned by the red-cockaded woodpecker forage analysis tool (RCWFAT) (Lipscomb and Williams, 1998). The RCWFAT program was used to generate cluster centers at Hobcaw during the 18-year period. These cluster centers were used in the RCW FMA to create the ½ and ¼ mile partitions. After creating the partitions the cluster number was assigned to relevant cavity tree numbers. Once each cavity tree was assigned to a cluster, the application was run from the beginning for each 18-year period.

Red-cockaded woodpecker Foraging Matrix Application

The RCW FMA is an efficient application that evaluates RCW foraging area at stand and partition levels. It is based on ArcGIS, Geographic Informaiton Systems (Redlands, CA) software and contains various features. There are a total of 19 feature classes and four tables in two geodatabases: sample geodatabase and blank geodatabase. To run the application two feature classes in the geodatabase are required:

1. Cavity_Tree_Points – The data were collected on the basis of the cavity tree locations (X, Y coordinates) and the clusters to which each tree was been assigned.
2. Stands – The data for this feature class were collected and loaded to relevant attributes or fields.

   All attributes or fields of these feature classes are required to run RCW FMA but some of the attributes are calculated by RCW FMA. The remaining 17 feature classes are empty at the beginning and are populated by the RCW FMA (refer to Appendix D). All fields present in these feature classes are required and will be calculated by the RCW FMA.

Before running the application the scale ranges were set for all the feature classes (Max and Min ranges for X: 2600000, 2400000, Y: 600000, 400000), and all data were projected into South Carolina state plane coordinates measured in feet in ArcGIS. The names of each attribute in the feature classes were matched to the attributes in the corresponding sample feature classes (e.g., "Cavity_Tree_Points").

Matrix Standards in the Red-cockaded Woodpecker Foraging Matrix Application

The application includes two types of foraging habitat matrix standards: recovery standard and standard for managed stability. The value of each habitat characteristic was modified based on the management requirements for the two foraging habitat standards.

1. Recovery Standard: All criteria are required for this analysis except the number of GQFH within ¼ mile of cluster center.
2. Standard for Managed Stability: This standard includes both requirements and recommendations. At the stand level, % herbaceous groundcover, fire return interval, and season of last prescribed burn have recommended values. At the partition level, the total acres of foraging habitat within ¼ mile and the number of contiguous foraging acres have recommended values.
   (USFWS: http://www.fws.gov/rcwrecovery/matrix.html).

Foraging Habitat Calculation

Data loading procedures and the attributes required for running RCW FMA can be found in the Appendix D. The application assessed RCW foraging habitat at the Hobcaw through the steps below:

1. Cluster centers: The RCW FMA creates the cluster centers on the basis of mean location of the cavity trees for each partition or cluster. The Cavity_Tree_Point feature class contains the cavity tree locations and assigned cluster numbers.
2. ¼ mile partitions: The RCW FMA outlines a quarter mile partition around the cluster center. The RCW activities primarily occur in the quarter mile partition. At Hobcaw the ¼ mile partitions are assumed to represent the territories of RCW rather than ½ miles partitions because the clusters are so close to one another, they overlap frequently.
3. ½ mile partitions: These partitions normally represent the territories of RCW groups and are determined based on the cluster centers. The reason for the this ½

mile partition is that RCWs forage over a maximum distance of not more than ½ mile radius. It is necessary to run the RCW FMA for all clusters at the same time to delineate the boundaries between adjacent clusters.

4. Stand scoring: After creating the partitions, the RCW FMA calculates each of Hobcaw 361 stand values for all characteristics present in the matrix standards. Then it compares these values with the table in the geodatabase. A score is assigned to all stands corresponding to the table values (see the matrix table for recovery standards in Appendix C).
5. Partition scoring: Next the partition score is generated. The RCW FMA simultaneously calculates the 361 stand scores on Hobcaw after delineating ½ mile partitions. This partition scoring is based on four standards in the matrix. These columns in the stand feature class which are blank during uploading of the data are populated during the stand score calculation.
6. During the calculation of partition scores, the RCW FMA also assigns a score for contiguity status; score of 1 meaning contiguous and 0, not contiguous. There is an option in the RCW FMA to choose the contiguity status either automatically or manually. For this study, the contiguity was calculated automatically by the RCW FMA. To be contiguous, the stand must be within 200 feet of another foraging stand that is also contiguous with the stand containing the cluster center.
7. Report: Finally, the RCW FMA generates the report based on the stand and partition score calculation. For Hobcaw the report focused on the partition scores of the recovery standards.

Table 1. Average net growth estimates for six classes of trees on Hobcaw Forest during the period of normal growth and mortality for 1979-1984. These net growth percentages were applied to inventory data for 1986-1989 and 1992-2007.

	1979-1984	**1979-1984**
	TPA Change **(Tree per acres)**	**Basal Area Change**
	Average % **Per Year**	**Average %** **Per Year**
Pines (4-10)	1.42	2.63
Pines (10-14)	4.75	4.36
Pines (14 and Up)	2.69	2.48
Hardwood (4-10)	2.99	2.98
Hardwood (10-14)	1.46	1.58
Hardwood (14 and Up)	1.39	3.36

RESULTS

Data collected at Hobcaw suggested that the number of active cavity trees and the number of clusters and nest trees are correlated with each other. Although the RCW population data were available for only three years, it was found that the number of active cavity trees and the number of clusters are highly interrelated. At Hobcaw, the effect of Hurricane Hugo i.e.; loss of active cavity trees, can be clearly seen in the graphs of active cavity trees and clusters (Figure 1 and 2).

Relationship between Red-cockaded Woodpecker Population and Cavity Trees in Hobcaw

RCW population assessment taken in 1977 (Grimes, 1977), 1998 (Nalley, 1998), and 2007 at Hobcaw Barony represent both pre and post Hurricane Hugo periods (Table 2). The number of active cavity trees and the number of adults showed that the proportion of active cavity trees to adult birds was similar, between 1.4 and 1.7, for all three years (see fourth column in Table 2). This relationship suggests that data collected from 1989 to 2007 on active cavity trees can be used as a reasonable estimate of the number of adult RCWs during this period.

Table 2. Data collected for the Hobcaw RCW population in 1977, 1998, and 2007

Year	No. of Active Cavity Trees	No. of Adult Birds	Active Cavity Tree per RCW Adults	No. of Nests	No. of Fledglings
1977	71	42	1.7	NA	30
1998	111	75	1.5	20	20
2007	65	47	1.4	16	NA

The number of active cavity trees varied from 51 (the lowest, 2004) to 135 (the highest, 1996) during the 18-year period (Figure 1). More than 40 active cavity trees were lost due to Hugo. However, the number of active trees post-Hugo increased rapidly peaking in 1996 at 130, followed by a decline to 51 in 2004. The number of active cavity trees fluctuated from 50-65 from 2005-2007 (Figure 1).

Active cavity trees were distributed over 18 to 30 clusters that contained 12 to 26 nests during the study period (Figure 2). The maximum number of clusters and nests occurred in 1995 and 1996 respectively, while the minimum number of both clusters and nests occurred in 2006. However, since 1996 there has been a slow, steady decline in the RCW population at Hobcaw. The cavity tree dynamics over the 18-year period showed a wave-like shape as a result of cluster budding and status change (e.g., active to inactive) of clusters (Figure 1 & 2).

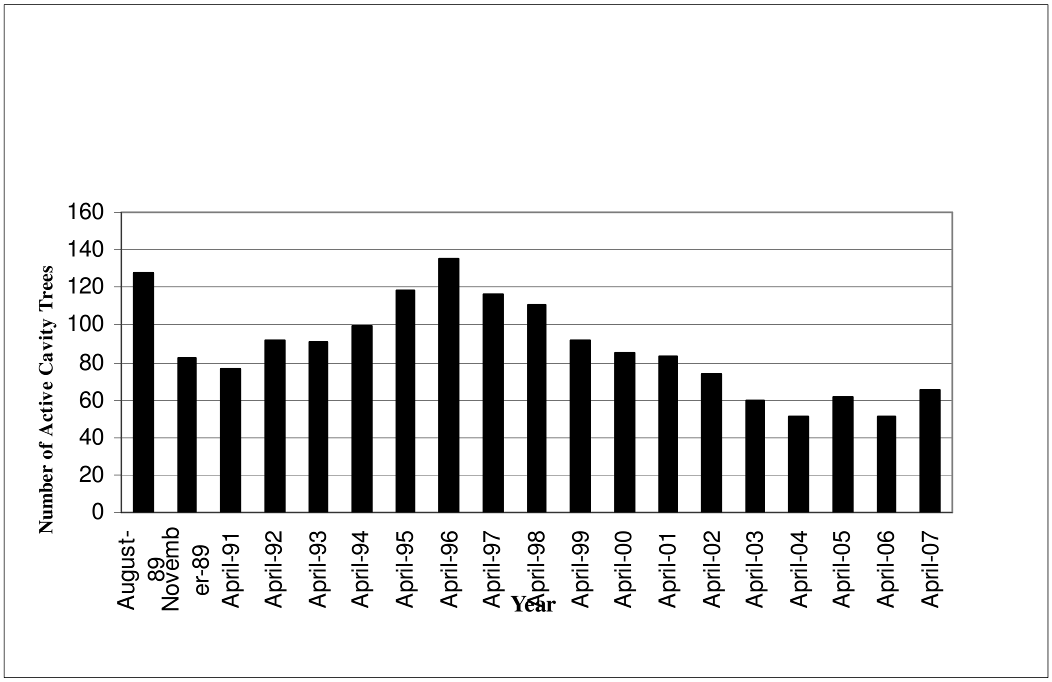


Figure 1. Active cavity tree over 18 years at Hobcaw Barony.

The initial loss of cavity trees post-Hugo was due to wind damage and salt water intrusion of the near the coastal area, followed by beetle infestations that thrived in stressed trees. The number of active cavity trees increased after Hugo during the period 1991 to 1996. RCW on Hobcaw were very active in this period, creating new cavity trees, forming new clusters, and showing increased nesting (observed from 1994-1996).

Relationship between Cluster Status and the Red-cockaded Woodpecker Population

Budding and loss of clusters after the Hugo indicated that budding increased while at the same time several of the older clusters became inactive. Specifically, the clusters near the eastern edge of the forest, where salt induced mortality was the greatest, were slowly abandoned while cluster density in the inland area of Hobcaw increased dense. This change is supported by data on the number of nest trees documented between

1994 and 2007. The ratio of nesting attempts to the number of active clusters varied from near 90% in 1997 and 2007 to a low near 56 % in 2001 (Figure 2).

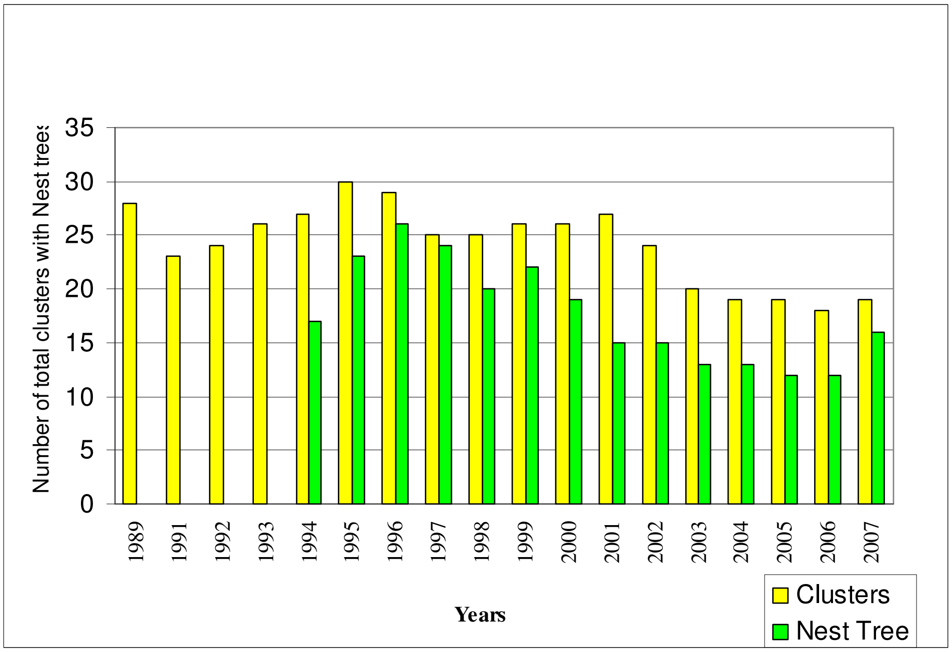


Figure 2. Relationship between the numbers of clusters with nests at Hobcaw Barony

In 1995, the number of active clusters was the highest. In 1996, the number of active cavity trees peaked while the number of clusters decreased. The number of nest attempts increased from 1994 to 1996 and then gradually decreased until 2006 (Figure 2, the green bars). The number of clusters increased gradually after Hugo until 1995, and remained stable until 2001, then decreased through 2006 (Figure 2). The number of nest attempts peaked in 1996 (coinciding with the peak number of active cavity trees) and declined thereafter until 2006, with only one small increase in 1999.

Relationship between Matrix Scores and Population Indicators

Stand scores indicate that the model seems to be a good indicator of RCW habitat conditions (Appendix B: Stand score maps for 18-year period). Stand scores ranged from 1 to 4.3, and remained relatively stable throughout the 18-year period. The impact of Hugo is best indicated by the reduction of stand scores in the southeastern section of Hobcaw (Cluster No. 22-28). The mortality in this area had a significant impact on the number of large pines, which are highly weighted in the stand scoring system. This same area showed a marked decline in clusters from 1996-2006. Conversely, in the south central portion of the Forest (Cluster No. 12-20), continuously higher stand scores were associated with budding during the 1991-96 period and the persistence of a high density of clusters.

The average partition scores for Hobcaw, which did not change significantly over the 18-year period, ranged from 1.0 to 2.2 with a mean of 1.76 (Figure 3). The average partition scores showed a limited decrease for several years (1991-1996) after Hugo and then a detectable increase from 2000-2005. However, there was no strong correlation between the partition scores and the presence of RCW groups. The number of active cavity trees increased sharply from 1991 to 1996 then gradually decreased until 2006. Likewise, the number of clusters increased until 1995, and subsequently decreased quite sharply from 2000-2004. The number of nesting attempts declined sharply during the increase in partition scores from 2000-2005. While the number of clusters with nests peaked in 1995, with nests and active cavity trees peaking in 1996, the lowest average partition score of the period occurred in 1995, with 1996 being only slightly better.

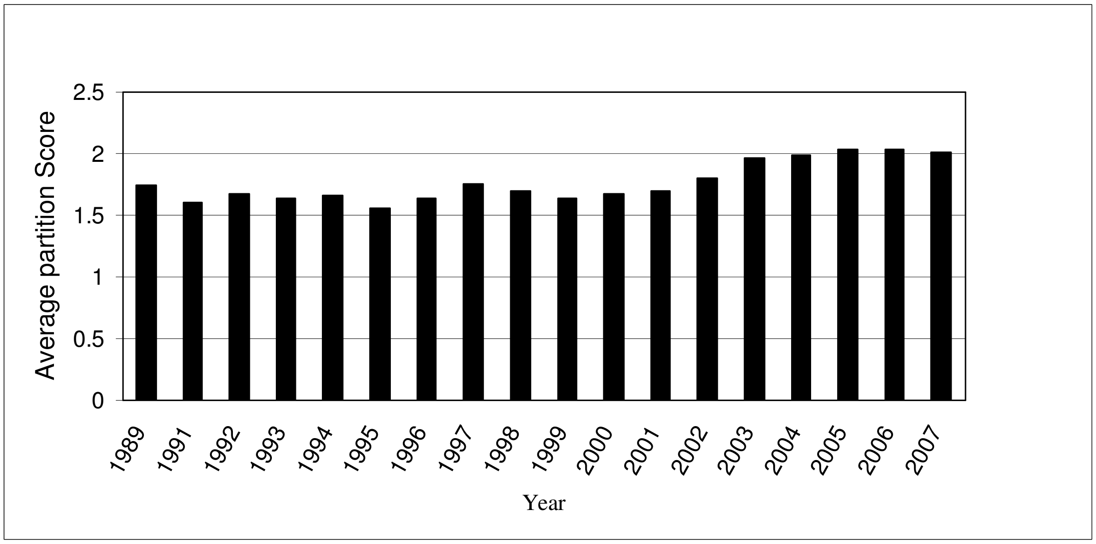


Figure 3. Average partition scores calculated by the RCW Foraging Matrix Application

Partition scores were not indicative of the overall success (i.e., status) of a particular cluster (Table 3). Abandoned clusters scored from 1.0-2.2, while budded clusters generally scored between 1.0 and 1.9, although cluster 39 scored 2.2 after 5 years. Partition scores of clusters that nested 13 or more years varied from 1.0-2.2. However, cluster 15 nested 13 years but never had a score above 1.2. Conversely, cluster 24 which never had a score below 2.1 except in 1991 scoring only 1.4, nested only nine years before being abandoned in 2005 with a score of 2.2. Based on observations of RCW population response at Hobcaw post-Hugo (i.e., rapid replacement of natural cavities) and the positive post-Hugo response of RCW on the Francis Marion National Forest to artificial cavities (Watson et al., 1995), in spite of foraging habitat limitations, foraging habitat may not be a significant limiting factor for RCW population Both cases indicate that suitable cavities are the primary limiting factor for RCW population.

Table 3. Partition scores (Recovery Standard) of each cluster from 1989-2000. The y or n in years after 1993 indicates if that cluster had a nest in that year or not.

Cluster Number	1989	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	2.2	2.2	2.2	2.2	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,n
2	2.0	-	-	-	-	-	-	-	-		
3	1.4	-	-	-	-	-	-	-	-		
4	2.2	2.2	2.2	2.2	2.2,y	2.2,y	2.2.y	2.2,y	2.2,y	2.2,y	2.2,y
5	2.2	1.4	2.2	2.2	2.2,n	2.2,y	1.2,y	1.2,y	1.2,n	1.2,y	2.2,n
6	2.2	2.2	2.2	2.2	2.2,n	2.2,n	2.2,n	2.1,n	-	-	-
7	2.2	-	-	-	2.2,y	2.2,y	2.2,y	2.2,y	2.2,n	2.2,n	2.2,y
8	2.2	-	-	-	-	-	-	-	-	-	-
9	2.1	-	-	2.2	2.1,y	2.0,y	2.0,y	2.2,y	2.2,y	2.2,y	2.2,y
10	1.2	2.2	2.2	1.0	1.0,n	1.0,n	1.0,y	-	-	-	-
11	1.7	2.2	2.2	2.2	2.2,n	2.2,y	2.2,y	2.2,y	2.1,y	2.1,y	2.1,y
12	1.0	1.1	1.0	1.4	1.0,y	1.0,y	1.0,y	1.3,y	1.3,y	1.3,y	1.3,y
13	2.0	-	-	-	2.2,n	2.2,y	2.2,y	2.2,n	2.1,n	2.1,n	2.1,y
14	2.1	1.9	1.9	1.9	1.9,y	1.9,y	1.9,y	1.9,y	1.6,y	1.6,y	1.6,y
15	1.0	1.0	1.0	1.0	1.0,y	1.0,n	1.0,y	1.0,y	1.0,y	1.0,y	1.0,y
16	1.0	1.0	1.0	1.0	1.2,y	1.0,y	1.2,y	1.4,y	1.4,y	1.4,y	1.4,y
17	2.2	2.2	2.2	2.2	2.1,y	2.2,y	2.2,y	2.2,y	2.1,y	2.1,y	2.0,y
18	2.0	1.2	1.0	1.9	1.7,n	-	-	-	-	1.6,y	1.6,n
19	2.1	2.2	1.9	1.9	1.9,n	1.2,n	1.4,n	2.2,y	2.2,y	2.2,y	2.2,y
20	1.9	1.9	1.6	1.4	1.4,y	1.9,y	2.0,y	2.0,y	2.0,y	1.2,y	1.2,y
21	2.0	2.1	2.0	1.9	1.9,n	1.6.y	1.7,y	1.9,y	1.9,y	1.9,y	1.9,n
22	2.2	2.2	2.2	2.0	2.0,y	2.2,y	2.0,y	2.2,y	2.2,y	2.2,y	2.1,y
23	1.4	1.1	2.0	1.9	1.6,y	1.6,y	1.6,y	1.6,y	1.4,y	1.4,y	1.6,y
24	2.2	1.4	2.2	2.2	2.2,y	2.1,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y
25	1.0	1.0	-	-	-	-	-	-	-	-	-
26	1.0	1.2	1.5	1.0	1.0,y	1.0,y	1.0,y	1.0,y	1.0,y	1.0,y	1.0,y
27	1.0	-	-	1.0	1.0,y	1.0,y	1.0,y	1.0,y	1.0,n	1.0,n	1.0,n
28	1.0	1.0	1.6	1.4	1.4,y	1.4,y	1.4,y	1.6,y	1.6,y	1.6,y	1.7,y
29	-	1.0	1.0	1.4	-	-	-	-	-	-	-
30	-	1.0	1.0	-	-	-	-	-	-	-	-
31	-	-	1.0	1.0	1.0,n	1.0,y	1.0,y	-	-	-	-
32	-	-	1.0	1.0	1.0,n	1.0,n	1.3,y	-	-	-	-
33	-	-	-	1.0	1.0,n	1.0,n	1.4,y	1.4,y	1.4,n	1.0,n	1.0,n
34	-	-	-	-	-	1.2	1.6,y	1.2,y	1.2,y	1.2,y	1.2,y
35	-	-	-	-	-	1.0	-	-	-	-	-
36	-	-	-	-	-	1.0	-	-	-	-	-
37	-	-	-	-	-	1.1	2.0	-	-	-	2.0
38	-	-	-	-	-	-	1.4	1.4	1.4	1.4	-
39	-	-	-	-	-	-	-	-	1.4,y	1.2,y	1.1,n
40	-	-	-	-	-	-	-	-	-	-	1.2,y

Table 3 (Contd.). Partition scores of each cluster from 2001-2007.

.

Cluster Number	2001	2002	2003	2004	2005	2006	2007
1	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y
2	-	-	-	-	-		-
3	-	-	-	-	-		-
4	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y
5	2.2,n	2.2,n	-	2.2,n	2.2,n	2.2,n	2.2,n
6	-	-	-	-	-	-	2.2,y
7	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y	2.2,y
8	-	-	-	-	-		-
9	2.2,y	2.2,n	2.2,n	-	2.2,n	2.2,n	2.2,y
10	-	-	-	-	-		-
11	2.1,y	2.1,y	2.2,n	2.2,y	2.2,y	2.2,y	2.2,y
12	1.3,y	1.7,n	1.9,y	2.2,y	2.0,y	2.1,y	2.0,y
13	2.1,n	-	-	-	-	-	-
14	1.4,y	1.2,y	1.2,y	1.2,n	1.4,n	-	1.4,y
15	1.0,y	1.0,y	1.0,y	1.0,y	1.0,y	1.2,y	1.0,y
16	1.6,y	-	-	-	-	-	-
17	2.0,y	2.1,n	2.2,y	2.2,y	2.2,y	2.1,y	2.2,y
18	1.9,n	1.6,y	2.0,y	2.0,y	2.0,n	2.0,n	1.9,y
19	2.1,y	2.2,y	2.2,y	2.2,n	2.2,y	2.2,y	2.2,y
20	1.0,y	1.6,n	1.6,n	1.6,n	1.6,n	1.6,n	1.6,n
21	1.9,y	2.1,y	2.0,y	2.1,y	2.0,y	1.9,y	2.0,y
22	2.1,y	2.2,n	2.2,y	2.2,y	2.2,y	2.2,y	2.2,n
23	1.4,y	1.4,y	-	-	-	-	-
24	2.2,y	2.2,y	2.2,n	2.2,n	2.2,n	-	-
25	-	-	-	-	-	-	-
26	1.0,n	1.0,n	2.1,n	2.1,n	2.2,y	2.2,y	2.2,y
27	1.0,n	1.0,n	-	-	-	-	-
28	1.7,n	1.6,n	1.7,n	-	-	-	-
29	-	1.9,y	1.7,y	1.7,n	1.9,y	2.0,y	1.9,y
30	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-
33	1.4,n	-	-	-	-	-	-
34	1.2,n	1.2,n	-	-	-	-	-
35	-	-	-	-	-	-	-
36	-	-	-	-	-	-	-
37	2.0,n	-	-	-	-	-	-
38	-	-	-	-	-	-	-
39	1.1,n	2.2,y	2.2,y	2.2,y	2.2,n	2.2,n	2.2,y
40	1.4,n	2.0,n	2.0,n	2.0,n	1.9,n	1.9,n	-

Table 4. RCW Population in Clusters in 2007

Cluster ID Number	Number of Adults	Nests	Number of Active Cavity Trees
1	2	1	3
4	3	1	6
5	2	0	2
6	3	1	2
7	2	0	2
9	5	1	6
11	6	1	5
12	3	1	5
14	1*	1	2
15	2	1	3
17	2	1	3
18	2	1	4
19	3	1	3
20	0	0	3
21	1*	1	4
22	2	1	4
26	2	1	3
29	6	2	3
39	0	0	2
Total	**47**	**16**	**65**

*Only one bird was found without knowing if it was a male or female, while the presence of a nest suggests at least two birds in these clusters.

Relationship between Active Cavity Trees, Nests, and Trees/Cluster

From 1994-2007, the number of natural active cavity trees present per cluster were sufficient to support the RCW population at Hobcaw Barony (Table 5). The average number of active cavity trees/cluster was above three for the 18-year period except in 2004 and 2006. The Recovery Plan recommends that at least 4 active cavity trees be present in RCW clusters. Table 5 shows that the number of active cavity trees/cluster is correlated with nesting attempts. For example in 2005, the number of active trees/cluster was 3.26, while there were a minimum number of nests (12); conversely, in 1996, the number of nests was 26 with 4.66 trees/cluster.

Table 5. The relationship between active cavity trees, nests, trees/clusters, and trees/nest.

Year	No. of active cavity trees	Number of nests	Number of clusters	Trees/nest	Trees/cluster
1994	99	17	27	5.82	3.67
1995	118	23	30	5.13	3.93
1996	135	26	29	5.19	4.66
1997	116	24	25	4.83	4.64
1998	111	20	25	5.55	4.44
1999	92	22	26	4.18	3.54
2000	85	19	26	4.47	3.27
2001	83	15	27	5.53	3.07
2002	74	15	24	4.93	3.08
2003	60	13	20	4.62	3.00
2004	51	13	19	3.92	2.68
2005	62	12	19	5.17	3.26
2006	51	12	18	4.25	2.83
2007	65	16	19	3.42	3.42

DISCUSSION

Stand and Partition Scores of Red-cockaded Woodpecker Foraging Habitat at Hobcaw

The matrix scoring system provides a means to assess foraging habitat at two levels, the recovery standard and the managed stability standard. The recovery standard rather than the managed stability standards was the focus of this research. Maps for Hobcaw were generated for both partitions and stands using the recovery standard. RCW FMA provides scores for each stand in the partition as well as an overall score for the partition. Using RCW FMA, the stand scores of all 361 stands at Hobcaw were calculated for the 18 year period, from 1989 to 2007.

Generally, individual stand scores changed little over the 18 year period as shown in the five color scheme representations (see stand maps in Appendix B). The effect of the management activities, which were primarily winter prescribed burns, can not be readily seen in stand score analyse for two reasons: 1) the weighting factors for stand characteristics are weighted heavily towards the number of large trees (see matrix table for recovery standard in Appendix C); and 2) in those partitions in which Hurricane Hugo salt surge caused widespread mortality, the number of large trees decreased significantly. Except for the hurricane, the differences at Hobcaw seen in the map are related only to regular prescribed burning and the relative slow growth of large trees.

Group success in both persistence and the number of nests was related to stand scores, which varied from 1 to 4.38 across Hobcaw. For example, partitions 1, 4, and 15 had stand scores above 4 over the entire period. These three clusters persisted throughout the period recording 40 nests in 14 years of nest observation. Conversely, of clusters 26, 27, and 28, located in areas impacted by the Hugo, only 26 persisted until 2007, and these three clusters had only 21 nests in the 14 years of nest observation.

For the partition scoring system, four characteristics were also scored from 1 to 5. These four factors were then multiplied by a weighting factor and totaled to produce a partition score that should reflect the actual habitat conditions for RCWs. After running the RCW FMA for the 18 year period, overall partition scores were low, although many important stand criteria met the standards. The matrix scoring system indicates the condition of RCW habitat in the field. That is, high scoring characteristics should produce both a high partition score and high stand scores. Although stand scores ranged as high as 4.38 there were no partition scores above 2.2. The primary reason for the low partition scores was due to the lack of GQFH in the partitions (recovery standards for matrix table in Appendix C). The partition score primarily depends on the total acres of GQFH as described in the following standards:

1. Total acreages in GQFH, a weighting factor of 0.4
2. Total acreages in GQFH within a ¼ mile, weighting factor of 0.3
3. Total acres of pine in partition, weighting factor of 0.2
4. Number of contiguous foraging acres, weighting factor of 0.1

Factors involved in the GQFH account for 70% of the partition score. GQFH will be assigned to the stand only if all stand characteristics have a score of five. If the score is less than 5, even if it is 4.99, the stand will be not identified as a GQFH. In the partition scoring system the RCW FMA checks the total area or acreage of GQFH; any stand not meeting the GQFH standard will not contribute in the calculation of the partition score. Under current habitat conditions at Hobcaw, and likely throughout the RCW range, it is very difficult to achieve a score of 5 for all 12 criteria. For Hobcaw the model produced stand scores ranging from 1 to 4.3, but none of them contributed to acreages designated as GQFH. As a result, there is discrepancy between the stand and the partition scores when evaluating RCW habitat. Partition scores are dependent on total pine acres and areas of contiguous foraging.

Contiguity

Contiguous forage acreage is one of the partition parameters in the matrix system. To be contiguous, a stand must score greater than 3 and be separated by no more than 200 ft from the stand containing the cluster center. The purpose of a contiguity parameter is to minimize habitat fragmentation. According to the Recovery Plan, to protect cavity trees a 61m (200 ft) buffer zone of continuous forest should be established around the minimum convex polygon containing an RCW group's active and inactive cavity trees i.e., the cluster (USFWS Recovery Plan, 2003). In order to calculate the partition score, the total acreage of contiguous area plays an important role. The RCW FMA looks for the stand scores greater than three and contiguous stands. If a stand has a score greater than three but is not contiguous it is not included in the calculation of the partition score. The kind of barrier e.g., non-forest, hardwood bottom or young pine plantation has no effect in determining the contiguity or non-contiguity as long as it is over 200 ft wide. In RCW FMA, stands that have a score of less than three but are contiguous, are not included in the determination of the partition score. In many cases on Hobcaw, the total contiguous foraging acres have a score of 5 (range 200-500 acres). In determining quality and quantity of habitat, contiguity is an important factor in the case of young pine plantations. In RCW FMA young pine plantations are considered a barrier because stands <30 years old are considered non- foraging habitat.

In sample data from Fort Bragg that was examined, stands were noted to be very large; e.g., a stand covering 2 or 3 partitions. If stands are large enough to be in several partitions they are also more likely to contain cluster center. Hobcaw is a research forest with small areas of open or young trees that are less likely to be lumped into a single stand, i.e., barriers at 200 ft wide are more likely to have been mapped as a separate stand on a small research forest than on a large military base. Determining contiguity is more complex at Hobcaw as compared to Fort Bragg (T.M.Williams pers. comm., 2007).

Partition Scores and Red-cockaded Woodpecker Population at Hobcaw

The number of clusters at Hobcaw does not correspond to partition score trends (Figure 2 and 3). Assessing RCW population trends depends on three parameters: the numbers of active clusters, the proportion of solitary males in the population, and the proportion of captured clusters (USFWS Recovery Plan, 2003). In 1998, the adult RCW population was 72 birds; there were 111 active cavity trees. Over the three observation periods (1977, 1998, 2007), the number of adults equaled 80% of the number of active cavity trees (Table 2). This observation suggests that active cavity trees can be used to indicate trends in RCW populations. The number of active trees peaked in 1995 while the number of active clusters peaked in 1996. The number of nests can be viewed as both an indicator of habitat quality and a predictor of the population size. The number of nests peaked simultaneous to the peak in active clusters and declined before the decline in active clusters. These trends are not reflected in the average partition scores.

The minimum average partition score corresponds to the maximum number of active cavity trees, while the most significant increase in partition scores corresponds to the most significant decline in the number of active cavity trees. Individual cluster results followed a similar pattern. For example, a cluster consistently having a minimum score nested all but one year of observation (Cluster 15 in Table 3), and a cluster with consistent scores of 2.2 was eventually abandoned (Cluster 24 in Table 3). In an already dense population, an increase in the number of clusters will reduce the size of each territory, simultaneously reducing the foraging area of individual groups as the number of clusters increase. Since the partition score depends on the total acres of habitat whether it is total pine or total GQFH, the overall partition score will decline as the density of clusters increases.

Positive and Negative Effect of Stand Standards

The stand parameters are broadly classified into two categories on the basis of their effect. Some characteristics have a positive effect on the habitat such as basal area of pines >14'', the number of pine stems/acres, stand age, and the number of prescribed burns per unit time. On the other hand, the presence of midstory and basal area of pines <9" DBH have a negative impact on habitat. Therefore, in the matrix system, the total weighted factor for seven characteristics that have a positive effect on RCW habitat is 0.747 and the total weighted factor for the six characteristics that have a negative effect on RCW habitat is 0.253.

In the matrix there are more characteristics in the recovery standards at the stand level as compared to the partition level. The presence of too many standards in the matrix for the recovery standard may make it difficult to judge important characteristics in the field (D.Lipscomb pers. comm., 2007).

Related Stand Characteristics of Red-cockaded Woodpecker Foraging Habitat

The matrix parameters, their associated ranges of values, and the scoring system were determined by the USFWS for recovering and managing RCW populations. One factor that was included in the matrix standard was percent herbaceous groundcover. Its weighting factor contributes 0.101 out of the total 1.000. Herbaceous groundcover is closely related to prescribed burning (fire interval and season of fire). If these parameters were treated as single parameter their total weighting factor would be 0.266 (0.165 +0.101). Likewise stand age >60 and the basal area of pines > 14 inches in DBH could be treated as a single parameter. They have the same weighted factors (0.139+0.139) and as a single parameter the weighted factor would be 0.266. There are a total of twelve parameters in the matrix table and thirteen parameters in the RCW FMA. If the above mentioned related stand standards can be combined and weighting factors were redistributed, it may improve the assessment of RCW habitat at the stand level. (R. Costa pers. comm., 2007).

Recommendations for Matrix System:

Weighting factors at the stand level and partition level were not evenly distributed in terms of importance. Previous research has already shown midstory vegetation has a profound effect on RCW habitat, RCWs preferring little or no midstory (Rudolph, 2002). However, in the matrix system the weighting factor given to midstory vegetation is quite low as compared to other stand characteristics. Giving more "weight" to hardwood midstory may increase the accuracy of evaluating foraging habitat. Likewise combining related stand characteristics discussed above would also increase the weighting of other important stand characteristics.

In Fort Bragg's sample data and Hobcaw stand data, even with 70-80% pine in the partition (with score more than 3, and weighted factor 0.1), the partition score is essentially because the unaffected score solely depends on GQFH standards (weighted factors 0.4 and 0.3 for ½ and ¼ mile partition, respectively). A more equivalent distribution of weighting in the partition parameters may solve this problem, for example, all partition parameters could have a 0.25 weighting factor. The adjustment of the weighted factor also indirectly improves the weighted factor of the number of pine/acres in the stand standards. This is important because those stands are includes cavity trees which are most critical factor for the RCW.

The total acres of GQFH in ½ and ¼ mile partitions affect the evaluation of RCW habitat to a greater extent. Based on 18 years of Hobcaw data, RCW FMA can only judge the difference between ideal and non-ideal RCW habitat. Furthermore, the RCW FMA calculates habitat quality at the stand level but makes the final determinations (i.e., an overall score) at the partition level. By considering the percentage of stand acreage that scored greater than 3 in a partition the partition score may be more meaningful. That is, the score could be calculated by dividing stand acreage (scoring greater than 3) by the total partition acreage. This would eliminate the total acreage in GQFH to some extent in the scoring system. Another possibility would be to use the percentage of total acres with a "good score". For example, if 20% of acres meet the GQFH criteria, and the other 80%

does not, but it has "high" stand scores, then this 80% could be considered good habitat based on the stand score. The partition score should be based on stand scores but because of GQFH acreage standards it is not (R. Costa pers. comm., 2007).

Theoretically, these recommendations may be applicable without considering the GQFH acreage factor. The basic flaw in the matrix system was determined to be acreage factor present in the partition standard. Essentially, the matrix identifies habitat quantity as more important than habitat quality. If all stands have a uniform value for GQFH standards, i.e., score of 5, then expected evaluation of RCW habitat should also be uniform. However, in reality, due to the GQFH acreage factor in all the partition standards, partitions with poor quality habitat but with large the number of acres had a higher partition score when compared to partitions that had high quality acres, but fewer of them.

On Hobcaw budding of clusters frequently occurred. As RCW clusters budded, partition scores decreased. For example, in 1994 -1995, cluster 32 budded and formed two new clusters 35 and 36 and cluster 24 budded to form new cluster 37. Clusters budding indicated that habitat quality was sufficient for additional RCW groups, net decreases in the partition score resulted. Although formations of new RCW groups indicate an increase in the RCW population resulting decrease in partition score suggests degradation of habitat quality.

In evaluating RCW foraging habitat, each stand characteristic should contribute to the partition score. In the RCW FMA, the partition score is primarily determined by the number of larger pine trees (>14" and 10"), while the remainder of the stand standards contribute collectively, rather than individually, to the partitions score. For example, the hardwood midstory, % canopy hardwoods, and fire characteristics significantly affect RCW habitat in the field. However, in RCW FMA all of these characteristics contribute in the partition scoring via an overall stand score. If a stand has greater number of pines trees >14" and 10" than an adjacent stand, it likely has more basal area/acre than the adjacent stand. However, if in the adjacent stand with less basal area, other habitat characteristics are better than the first stand, such as low midstory, growing season fire, and high percentage of herbaceous ground cover, then the partition score calculation will be affected in a negative way because the number of pines in the partition is weighted higher than other characteristics. Although both stands will contribute to the partition score, but RCW FMA will assign a better stand score to the stand containing more pines.

If stands do not have to meet all GQFH criteria to score a 5, and GQFH criteria can be excluded from the partition characteristics, then the scoring system will be more effective because all scores from 1 to 5 of the stand standards will contribute to the RCW FMA analysis and foraging evaluation. This system would also give a fair score to partitions even if the acreage factor is included in the matrix standards. This system would improve the correlation between partitions and stand score.

Importance of Red-cockaded Woodpecker Active Cavity Trees and Population Density in Budded Clusters

During the development of the matrix, two important factors, the number of active cavity trees and RCW population density were not considered. Because they were not included in the matrix standards evaluating RCW foraging habitat is not affected by them. The recovery plan assumes that meeting the foraging habitat standards would assist in RCW recovery. However, if all of the foraging habitat standards are not met in a partition, but there is an increase in the number of active cavity trees in a partition, this could indicate good habitat quality. This relationship was observed in partition maps in 1994-1995 and 1996, and is illustrated in the graph of active cavity trees (Figure 1). During budding (splitting of partition), active cavity trees are formed in the new partition.

Another factor that may affect evaluation of RCW habitat is RCW population density. An understanding of the relationship between RCW population density and habitat quality may help solve the problem of habitat evaluation by estimating the population density required by the RCW. Testing RCW FMA at Fort Bragg which has a healthy and expanding RCW population, also failed to correctly judge RCW habitat conditions.

It is a difficult task to judge foraging habitat on the basis of sparse and dense RCW populations because matrix standards excluded the number of active cavity trees and population density while quantifying habitat structure. Also, as noted earlier, recent research has been unable to establish a relationship between RCW group fitness, e.g., group size, and total basal area of pines greater than or equal to 25.4 cm (10”) DBH, within a group’s foraging area. Other research found that sparse populations were more affected by habitat removal and fragmentation compared to dense populations. Previous foraging habitat guidelines stressed quantity of foraging habitat, as defined by the number of medium and large trees. Recent research has shown that habitat selection and group fitness is influenced by the structure of foraging habitat which includes (USFWS Recovery Plan, 2003):

1. Healthy groundcover of bunchgrasses and forbs,

2. Minimal hardwood midstory,
3. Minimal pine midstory,
4. Minimal hardwood overstory,
5. A low to intermediate density of small and medium sized pines, and
6. A substantial presence of mature or old pines.

RCW habitat requirements can be maintained through effective management practices, such as prescribed burning and thinning. These practices are important because RCWs require foraging habitat suitable in both quantity and quality. In addition, the quality of foraging habitat affects the size of home ranges, the area supporting the daily activities of an RCW group (USFWS Recovery Plan, 2003). Generally, as habitat quality improves, the area of foraging habitat used is reduced.

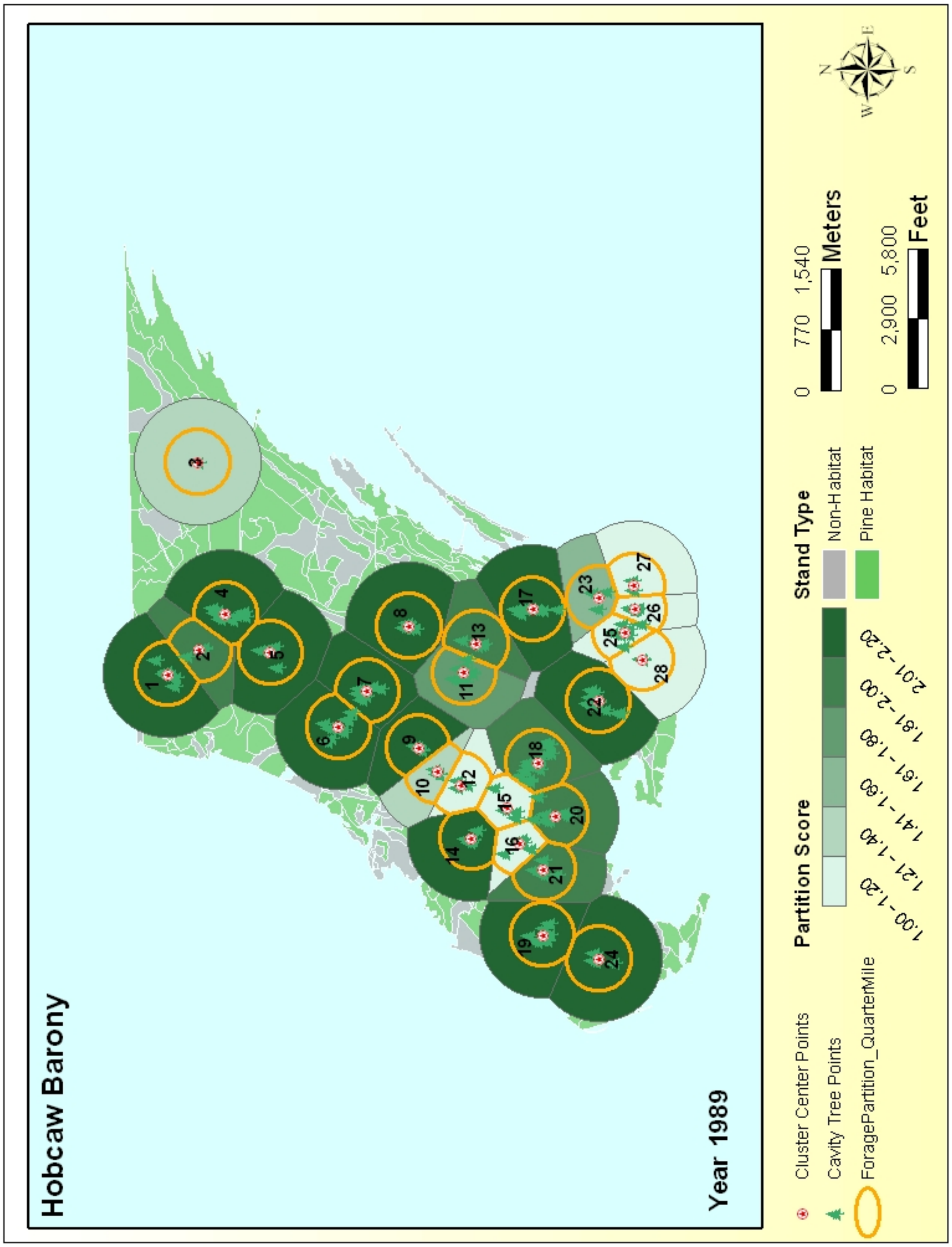
For GQFH, a minimum of 75 acres is required in a partition to earn a score of 1 and more than 120 acres is needed to score a 5 i.e., ideal habitat. However, on Hobcaw if a foraging partition had less than 75 acres, it did not necessarily mean that it was poor quality. In addition, the presence of RCW groups does not indicate that the partition has met all the matrix standards.

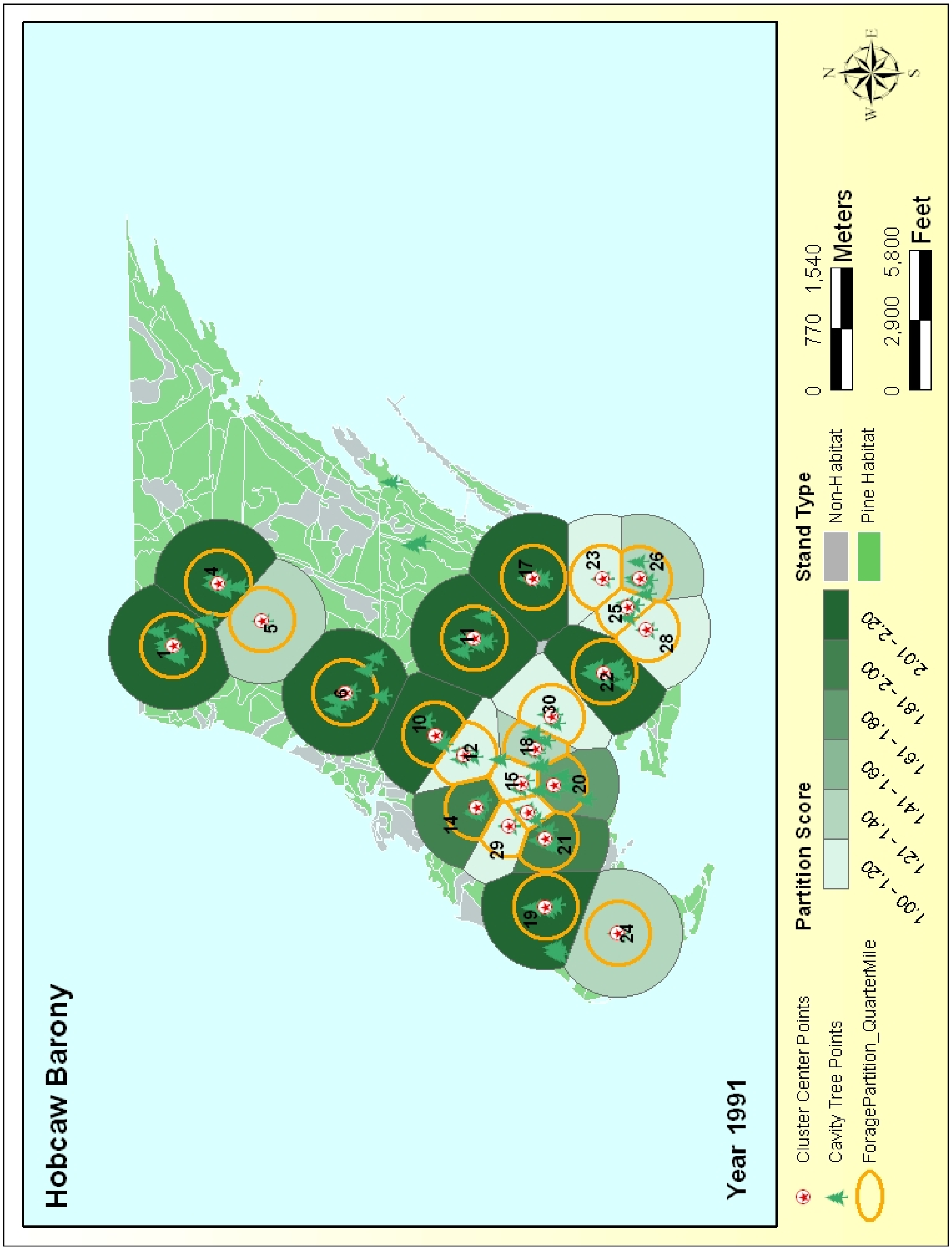
In good quality RCW habitat, home range size may be smaller than the size in average quality habitat. A possible reason for this difference is that the RCW clusters tend to bud in good quality habitat, increasing group density while simultaneously decreases territory size/home range. At Hobcaw, partition maps indicated that budding of clusters typically occurred in the same areas over the 18-year period. The number of clusters range from 18 in 2006 to 30 in 1995, with an average number of 24 over the 18-year period. Where population data was available, they indicated that the incremental increase in the RCW population occurred in a specific area over a given period of time. Typically, density is greater in areas with budded clusters than in other areas. Evaluating these budded group's partitions may help categorize the standards of GQFH for the total foraging area. On this basis, other foraging partitions may be able to be categorized from poor to ideal. This process may reduce the habitat requirements listed in matrix standards as well as help establish the relationship between RCW population density and the quality of foraging habitat. Additionally, a better understanding about the relationship between foraging habitat characteristics and RCW group fitness may be achieved.

By analyzing GQFH criteria in healthy RCW populations with quality habitat such as the Francis Marion National Forest and Fort Bragg (where the RCW population is dense) over a specific time period, estimates regarding requirements for both RCW fitness and habitat quality may be determined. RCW response e.g., budding, to habitat quality can vary from region to region, and be influenced by population demography and other factors, however, assessing such responses and their result on population health, e.g., increase in density, may still be helpful in establishing GQFH standards (R. Costa pers. comm., 2008).

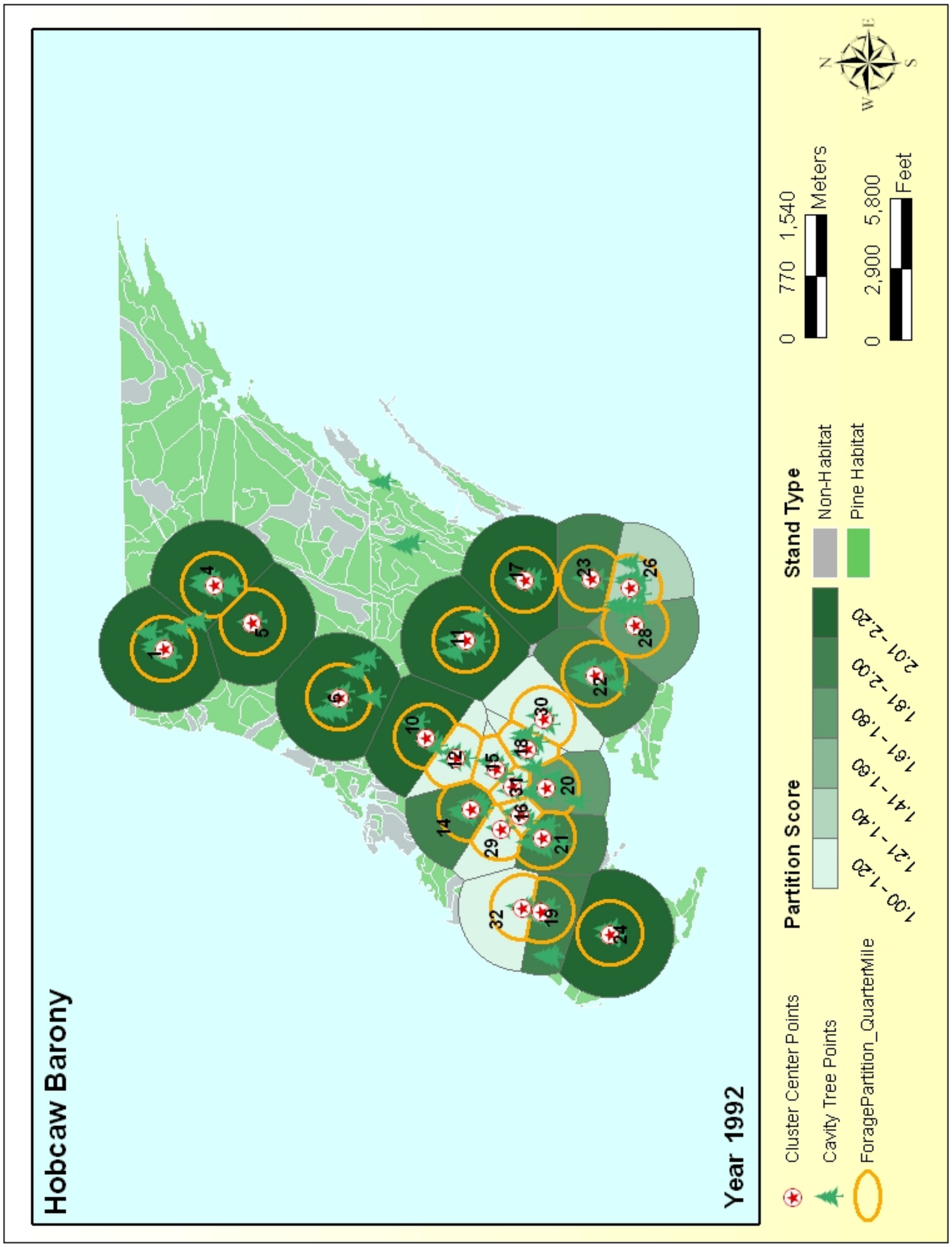
Appendix A

Partition maps of the Hobcaw Barony from year 1989 to 2007.

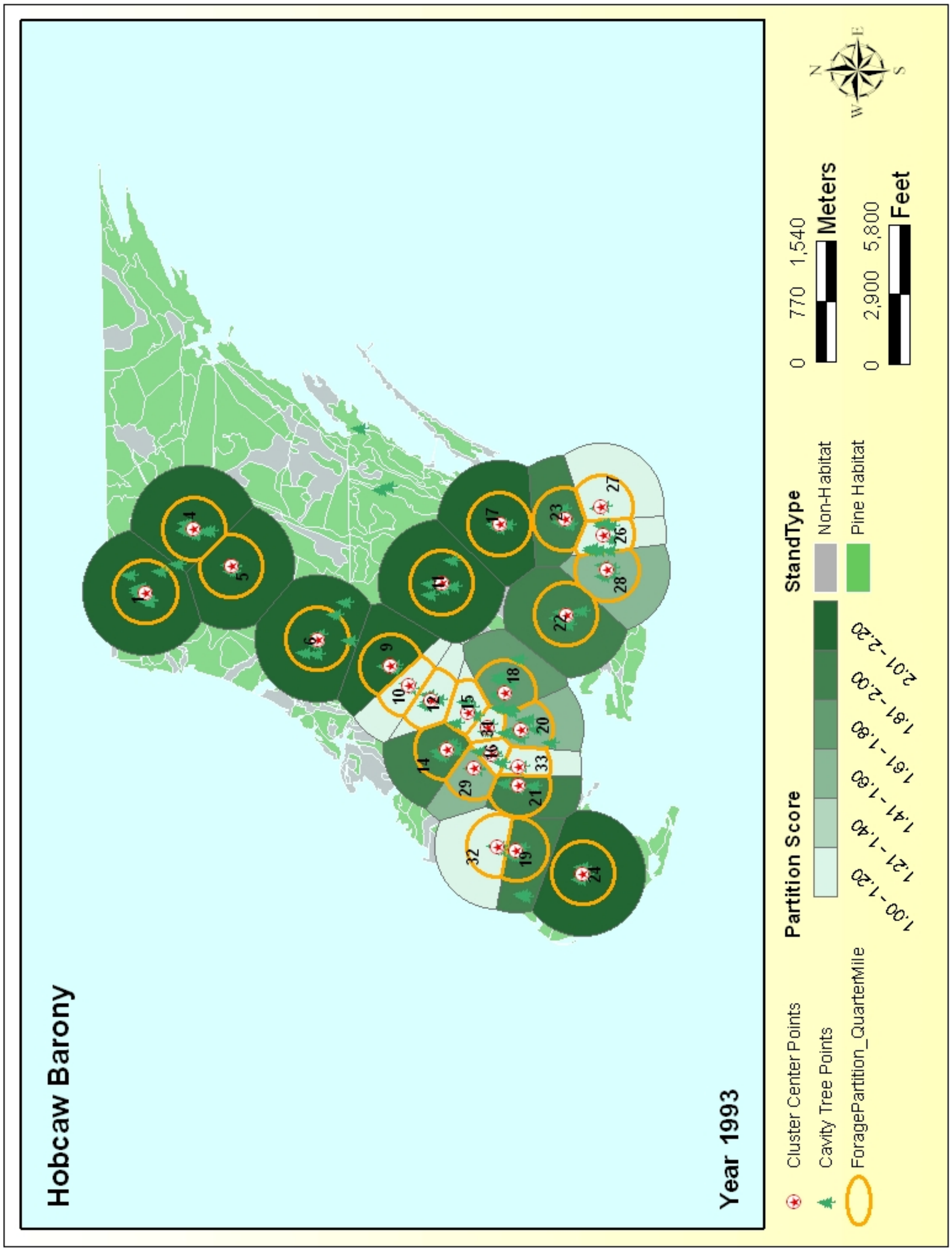

Hobcaw Barony
Year 1989
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W



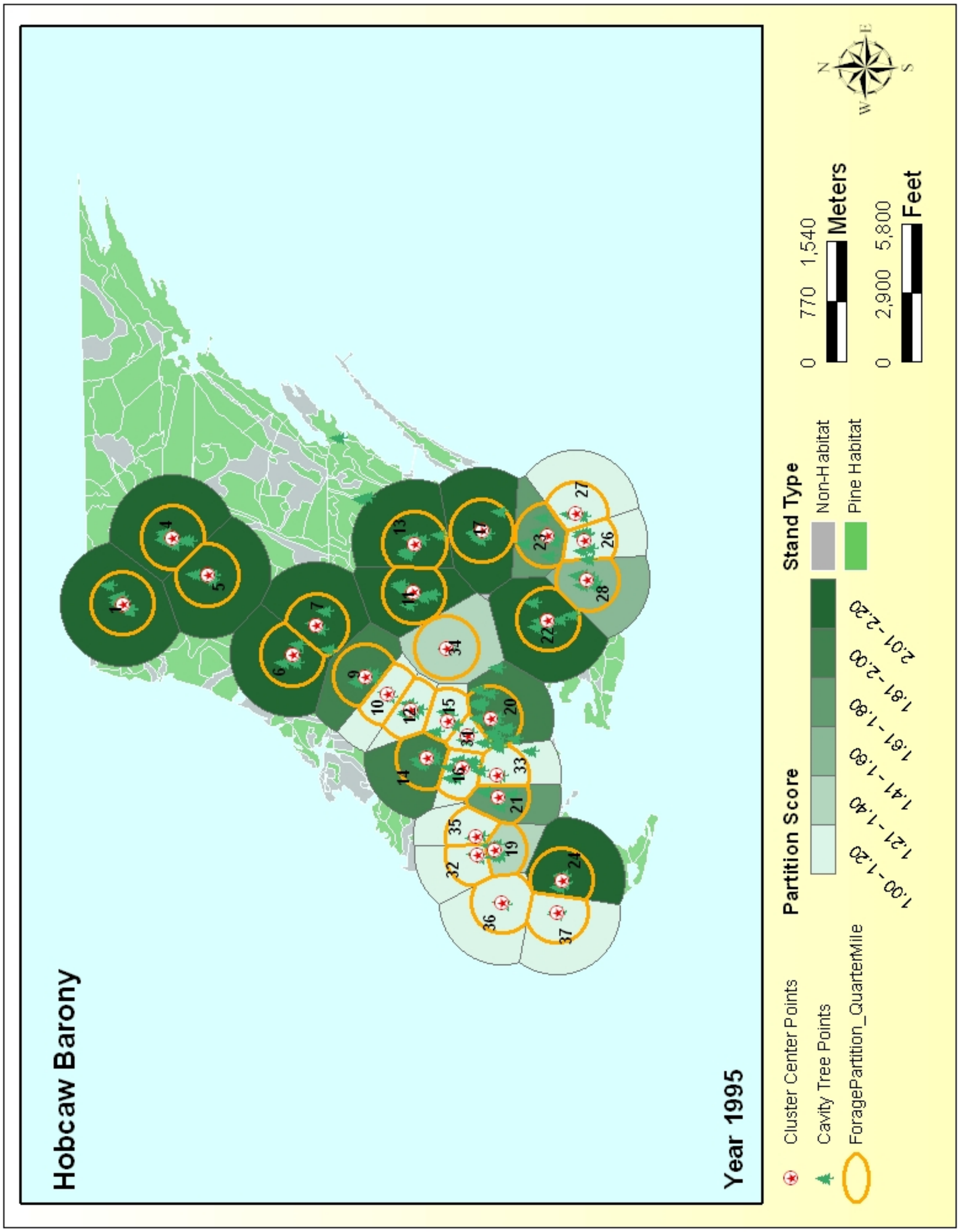
Hobcaw Barony
Year 1991
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet

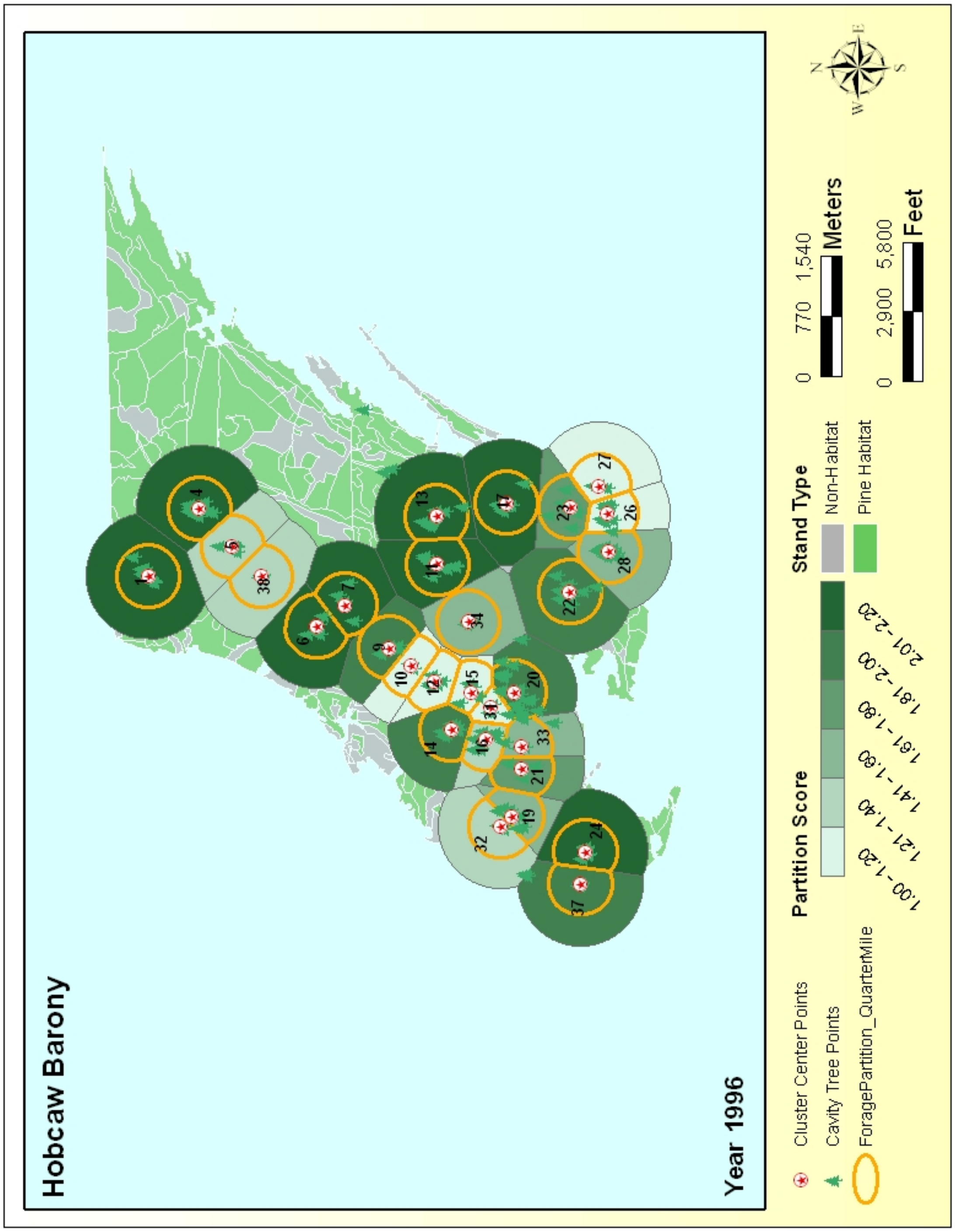


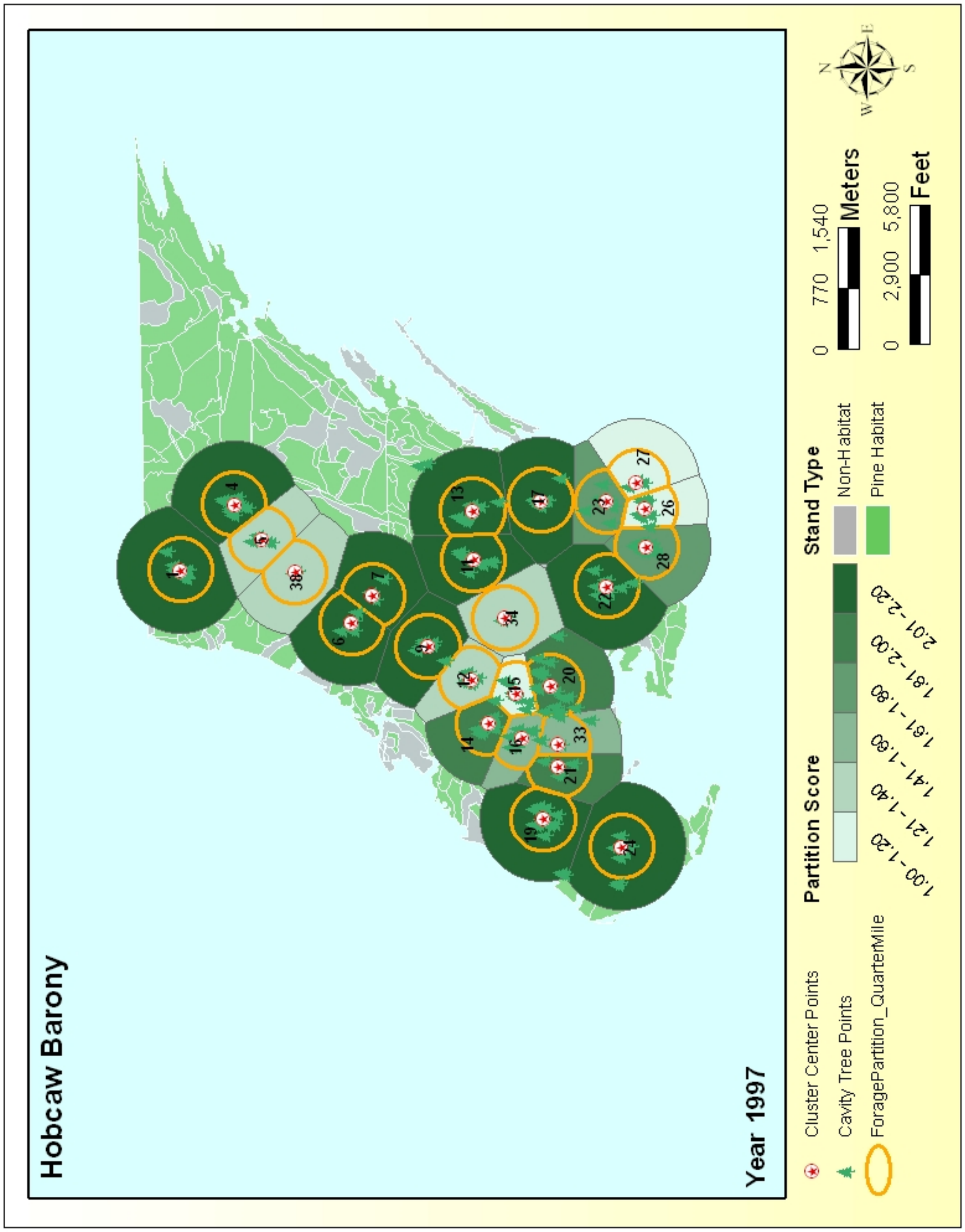
Hobcaw Barony
Year 1992
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

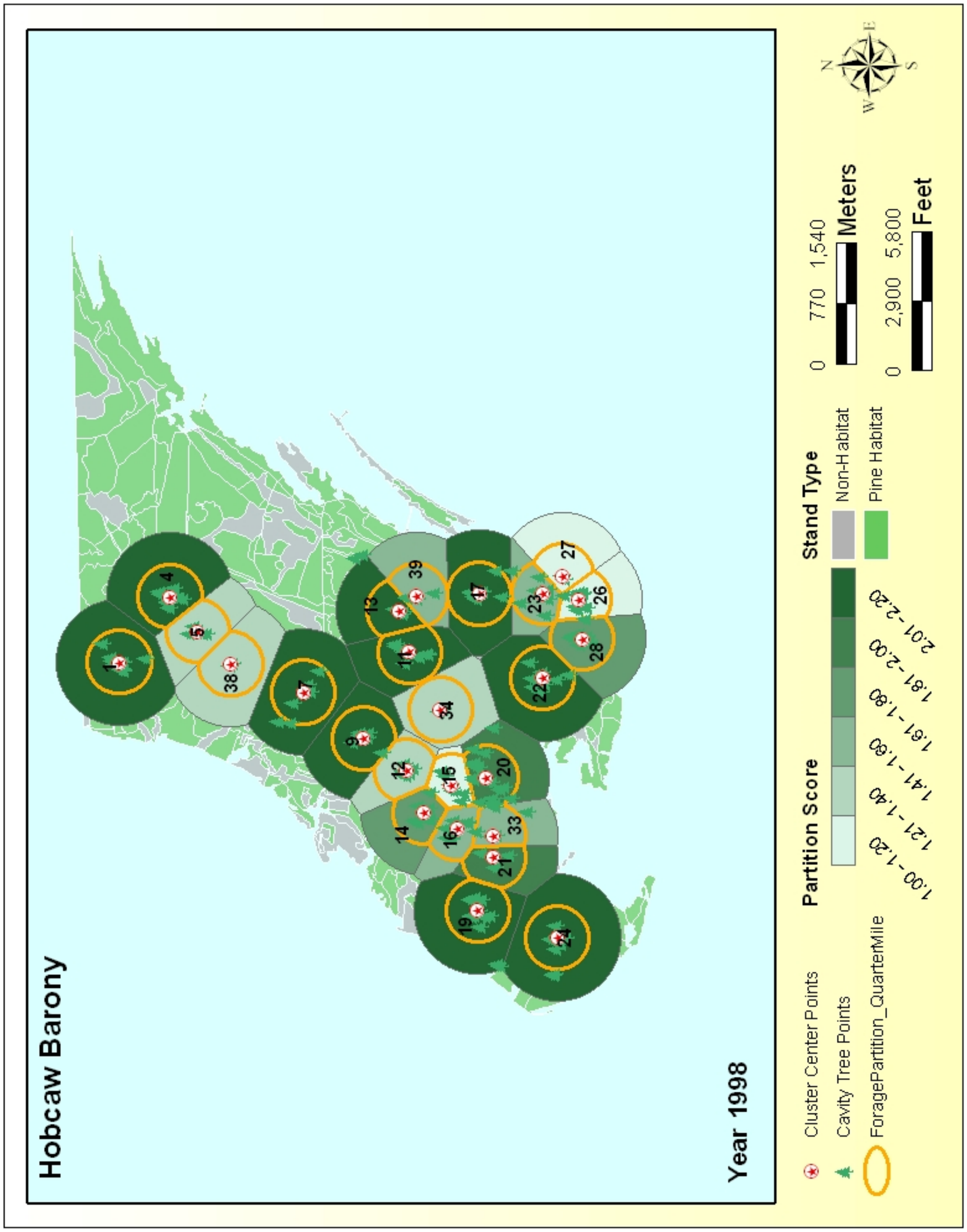

Hobcaw Barony
Year 1993
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
StandType
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

Hobcaw Barony
Year 1994
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet
N
S
E
W

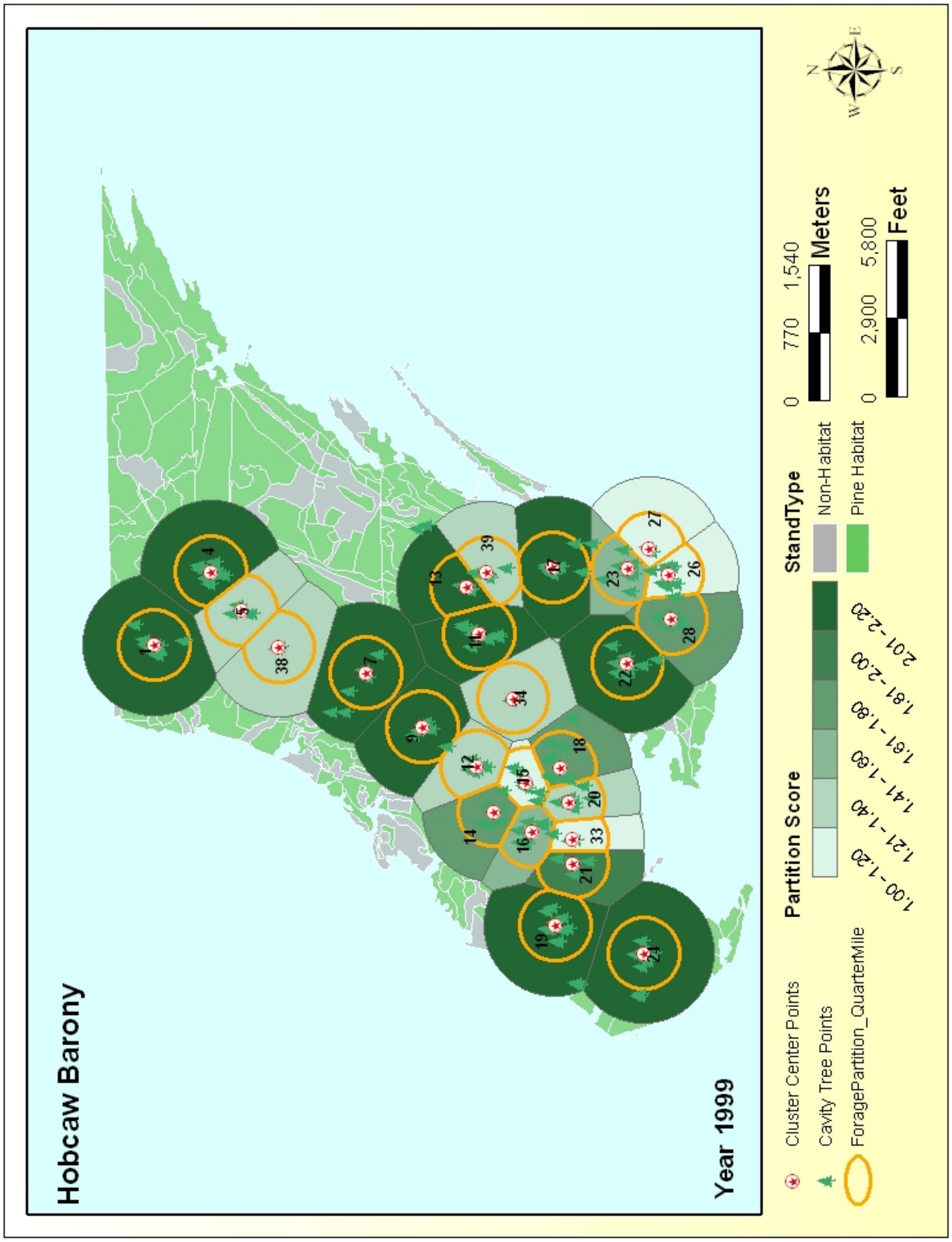

Hobcaw Barony
Year 1995
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00-1.20
1.21-1.40
1.41-1.60
1.61-1.80
1.81-2.00
2.01-2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

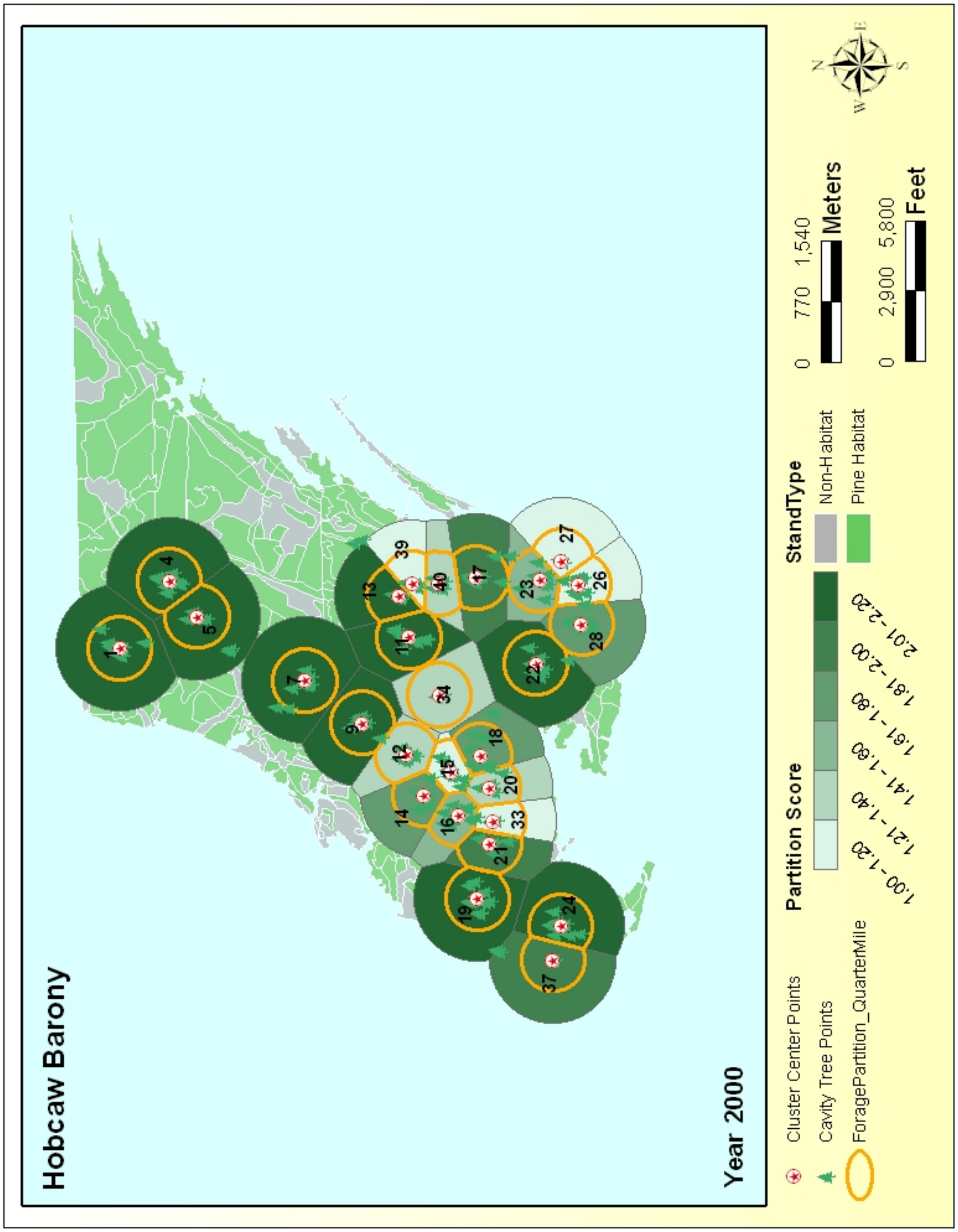

Hobcaw Barony
Year 1996
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

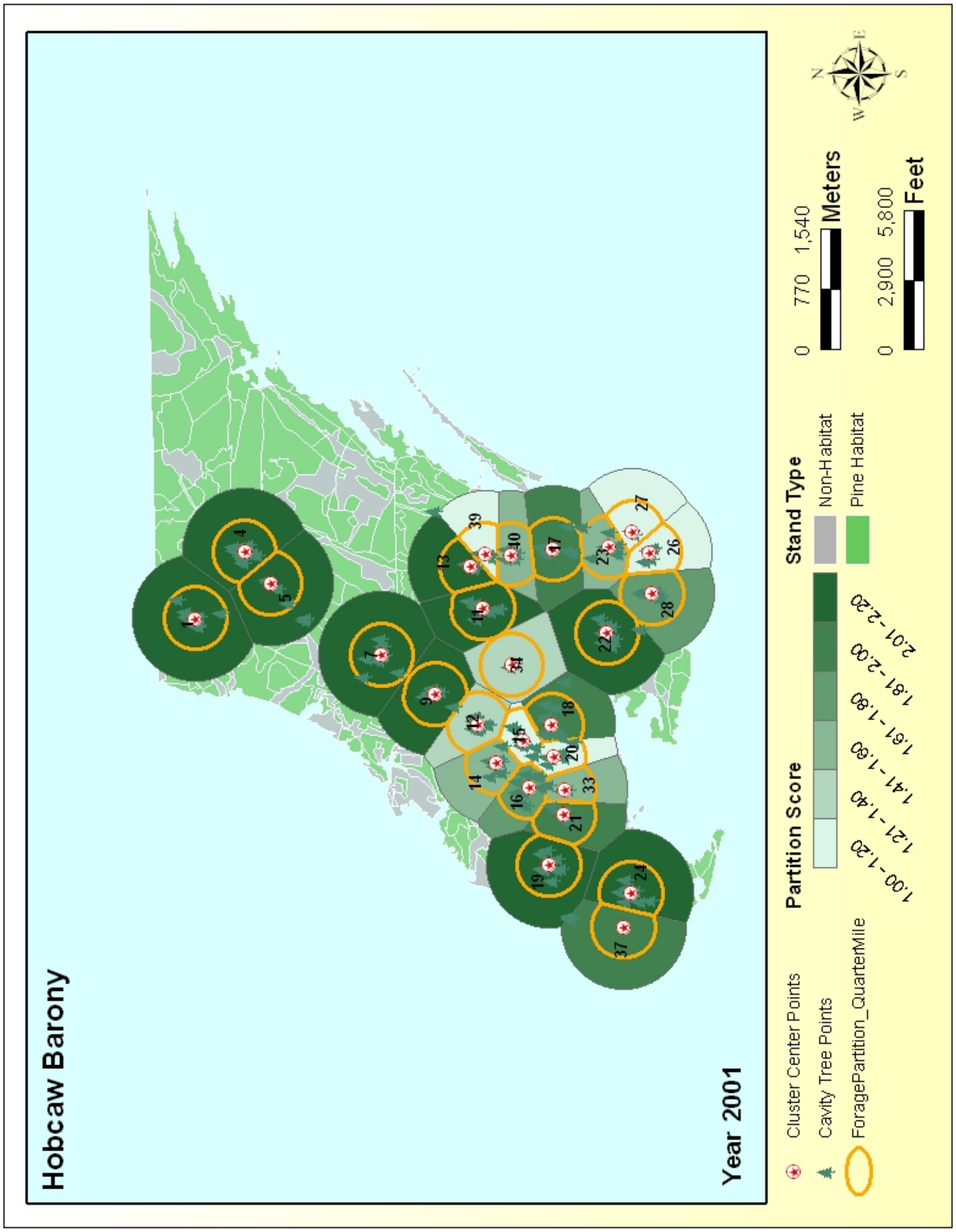

Hobcaw Barony
Year 1997
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W



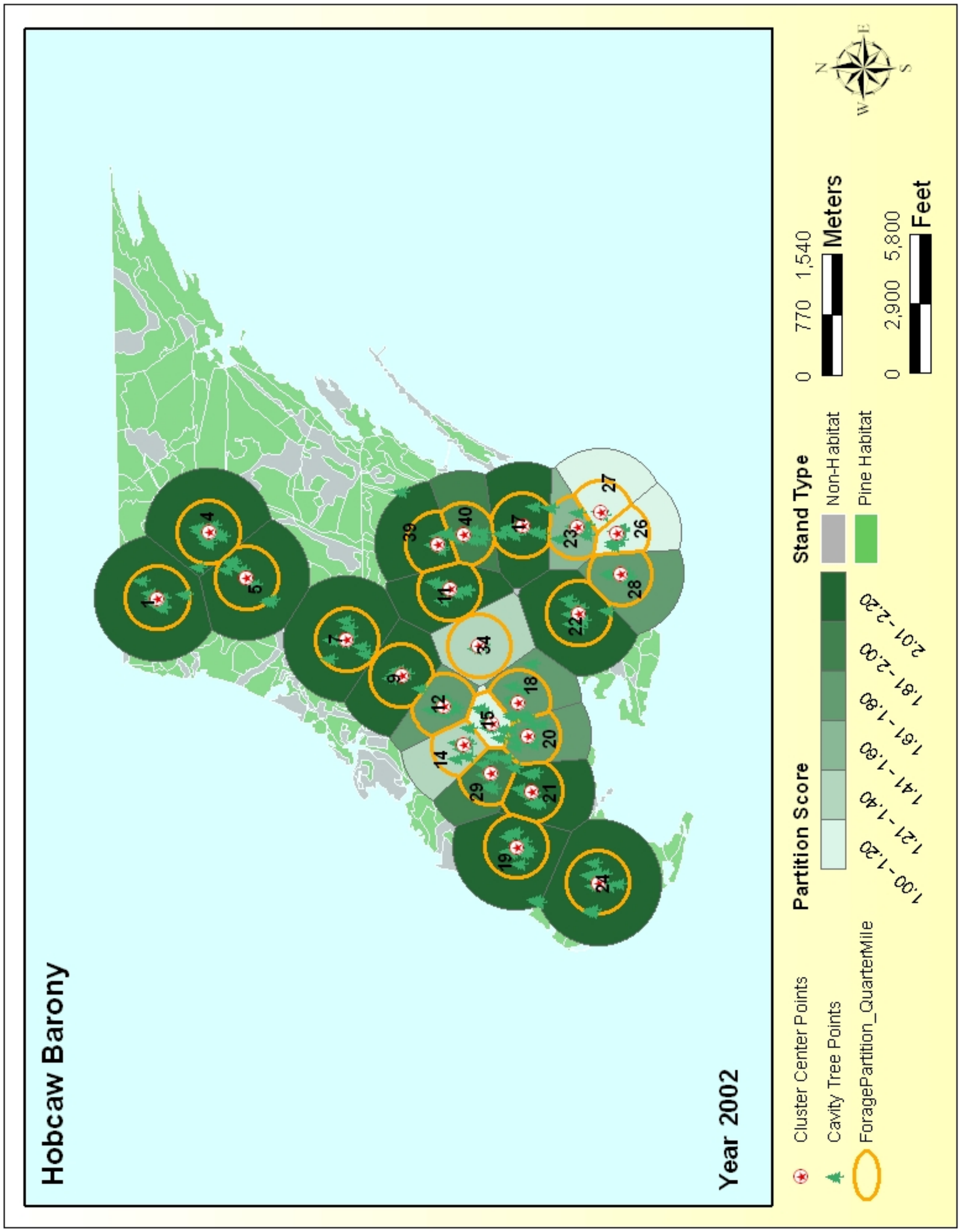
Hobcaw Barony
Year 1998
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet

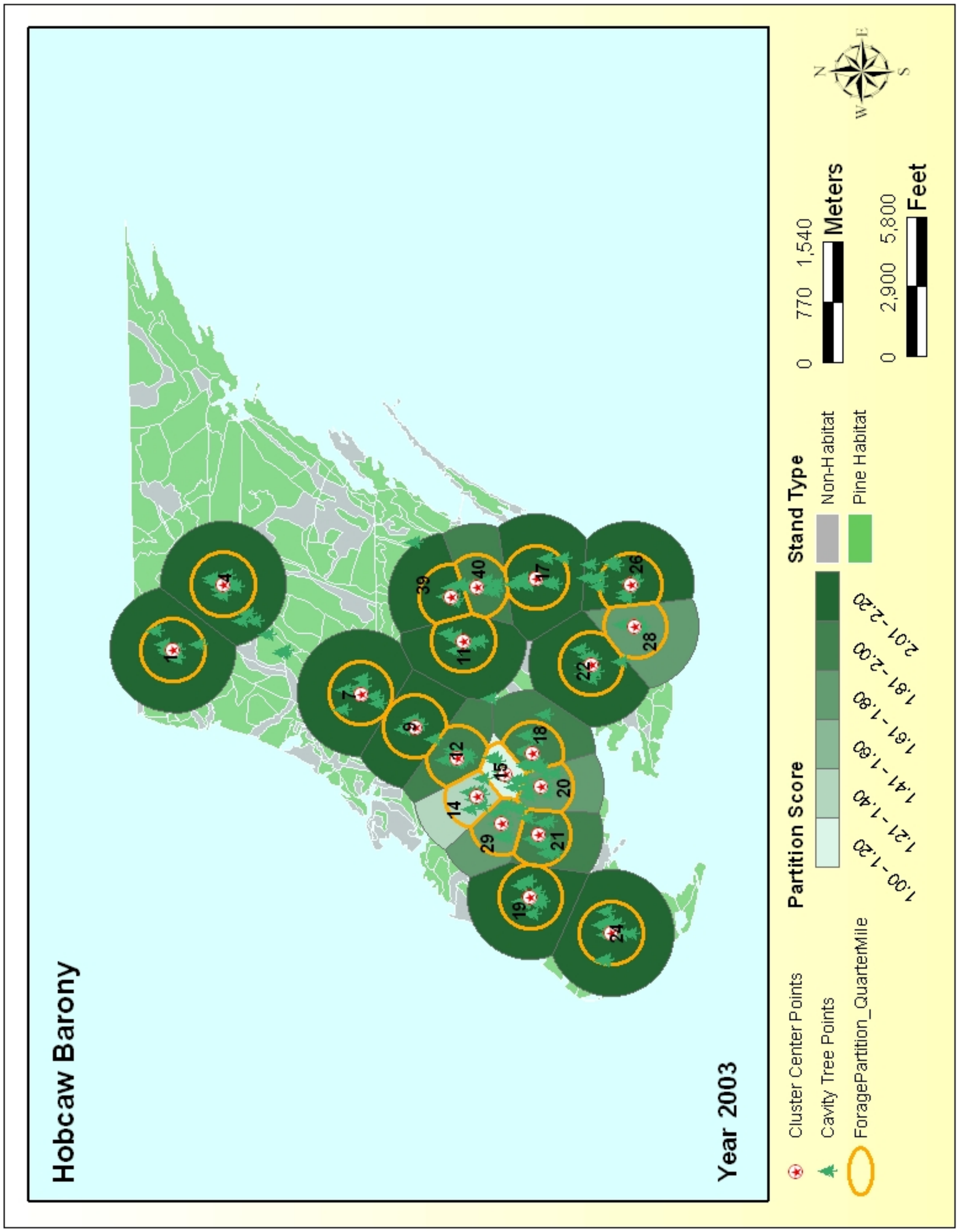

Hobcaw Barony
Year 1999
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
StandType
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

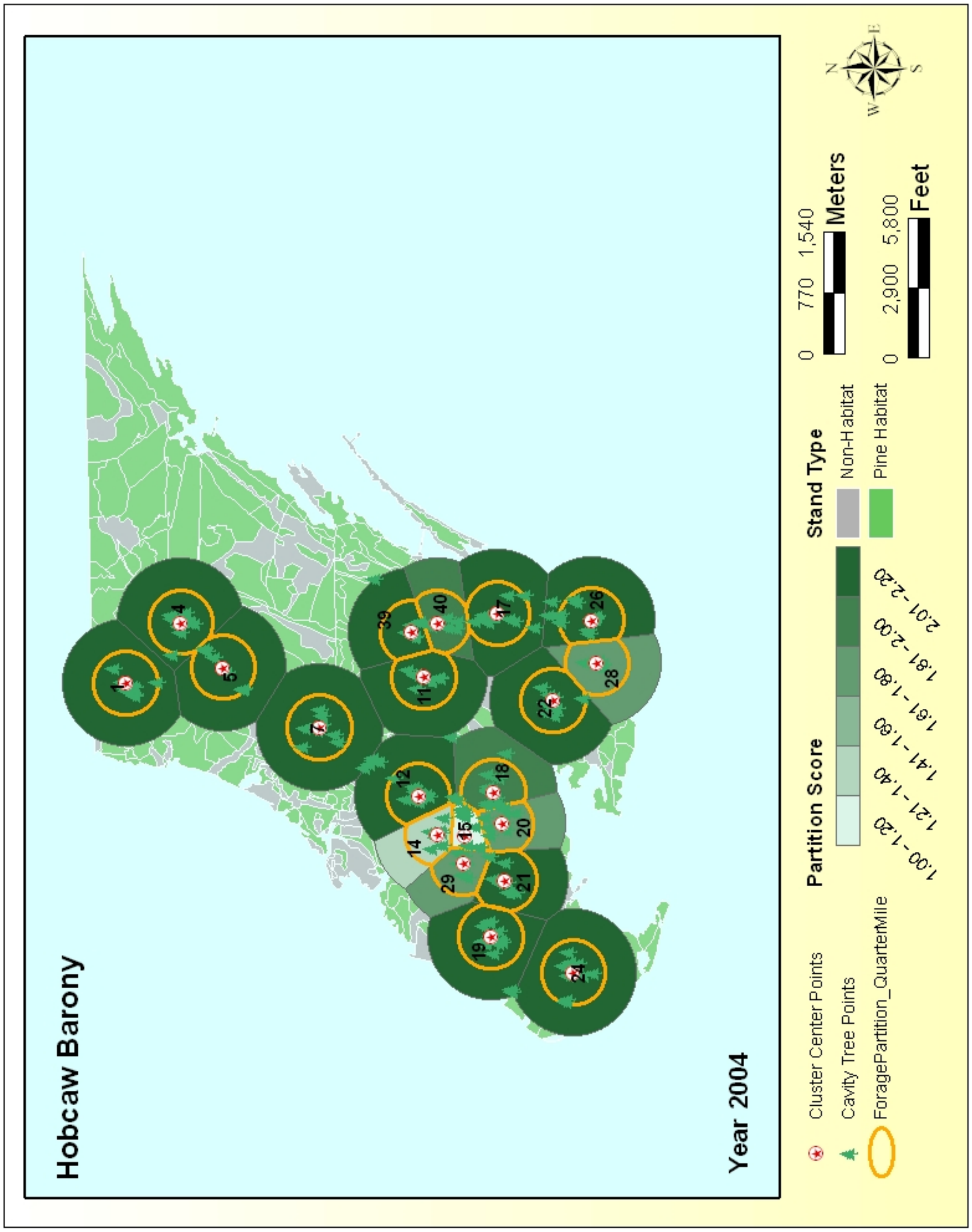

Hobcaw Barony
Year 2000
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
StandType
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet
N
S
E
W

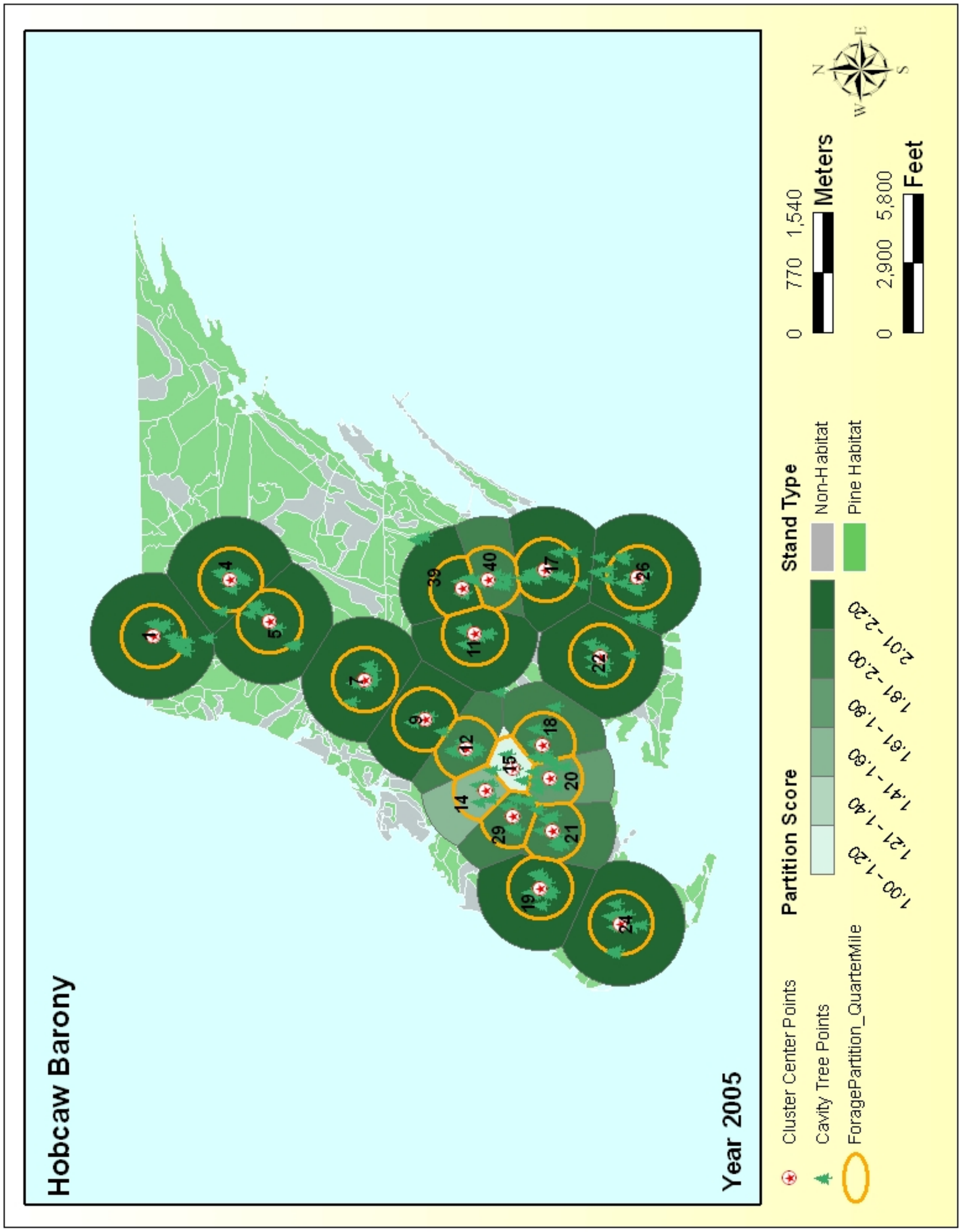


Hobcaw Barony
Year 2001
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet

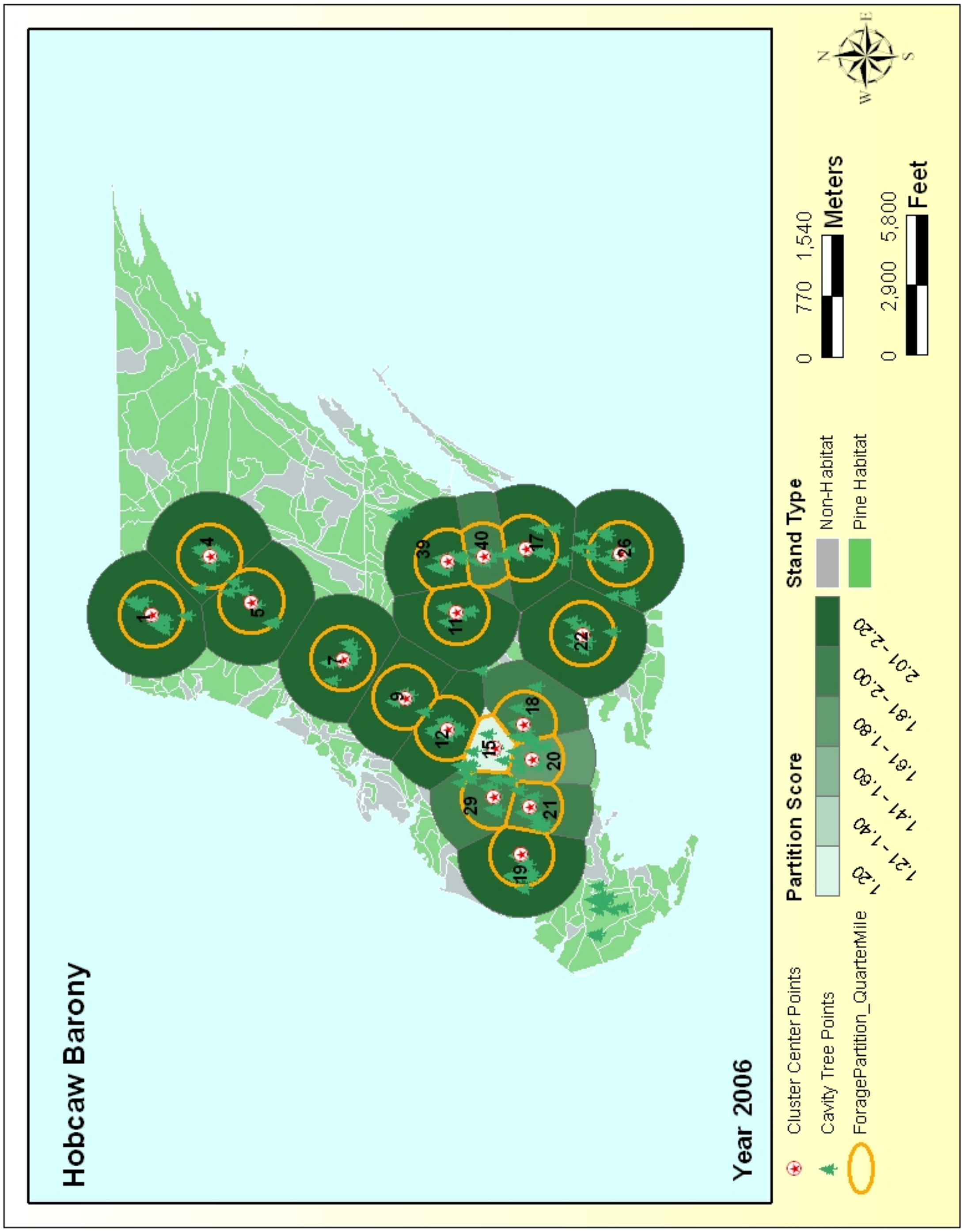

Hobcaw Barony
Year 2002
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00-1.20
1.21-1.40
1.41-1.60
1.61-1.80
1.81-2.00
2.01-2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet


Hobcaw Barony
Year 2003
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W
1
4
7
9
11
12
14
15
17
18
19
20
21
22
24
26
28
29
39
40

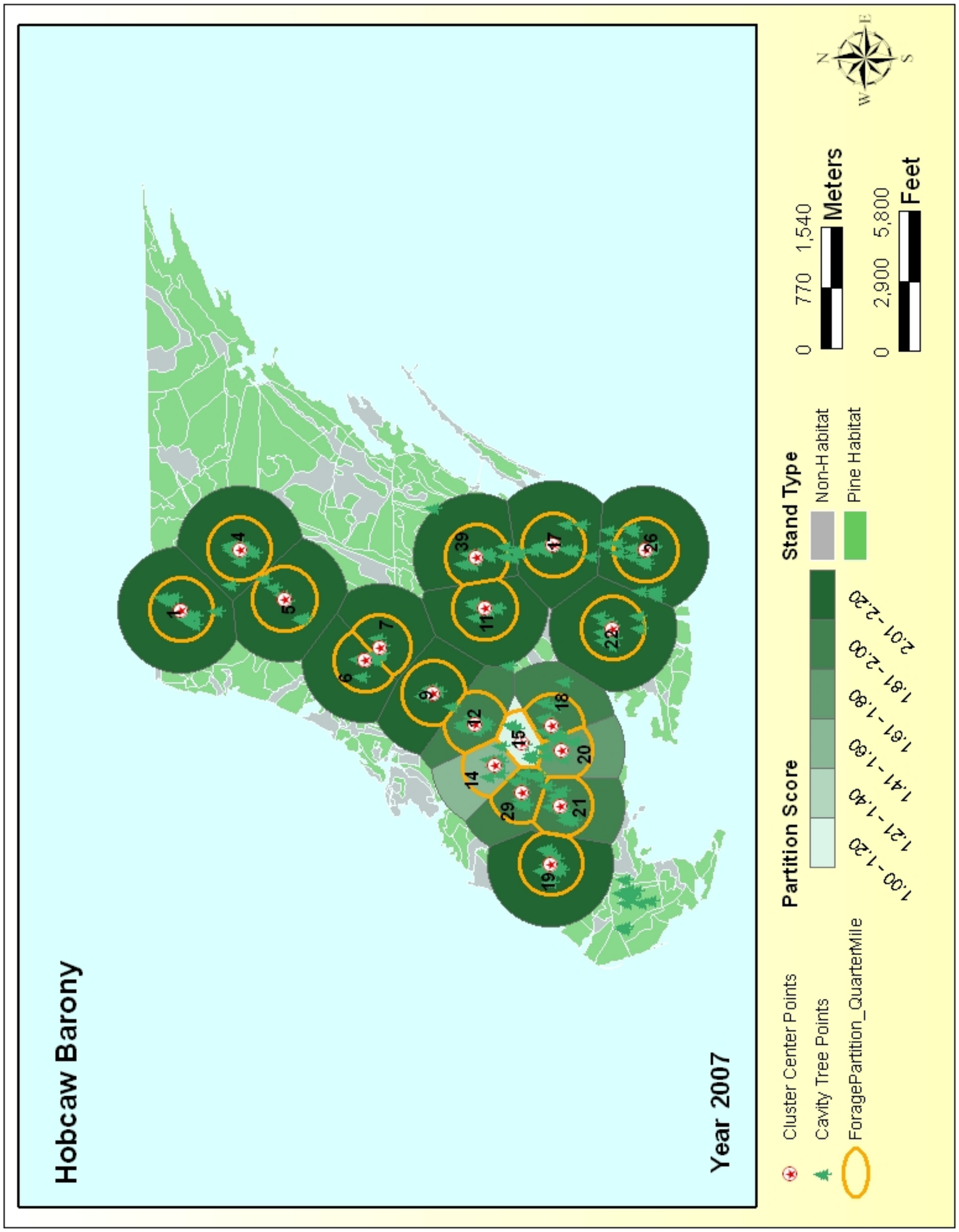

Hobcaw Barony
Year 2004
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W



Hobcaw Barony
Year 2005
1
4
5
7
9
11
12
14
15
17
18
19
20
21
22
24
26
29
39
40
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

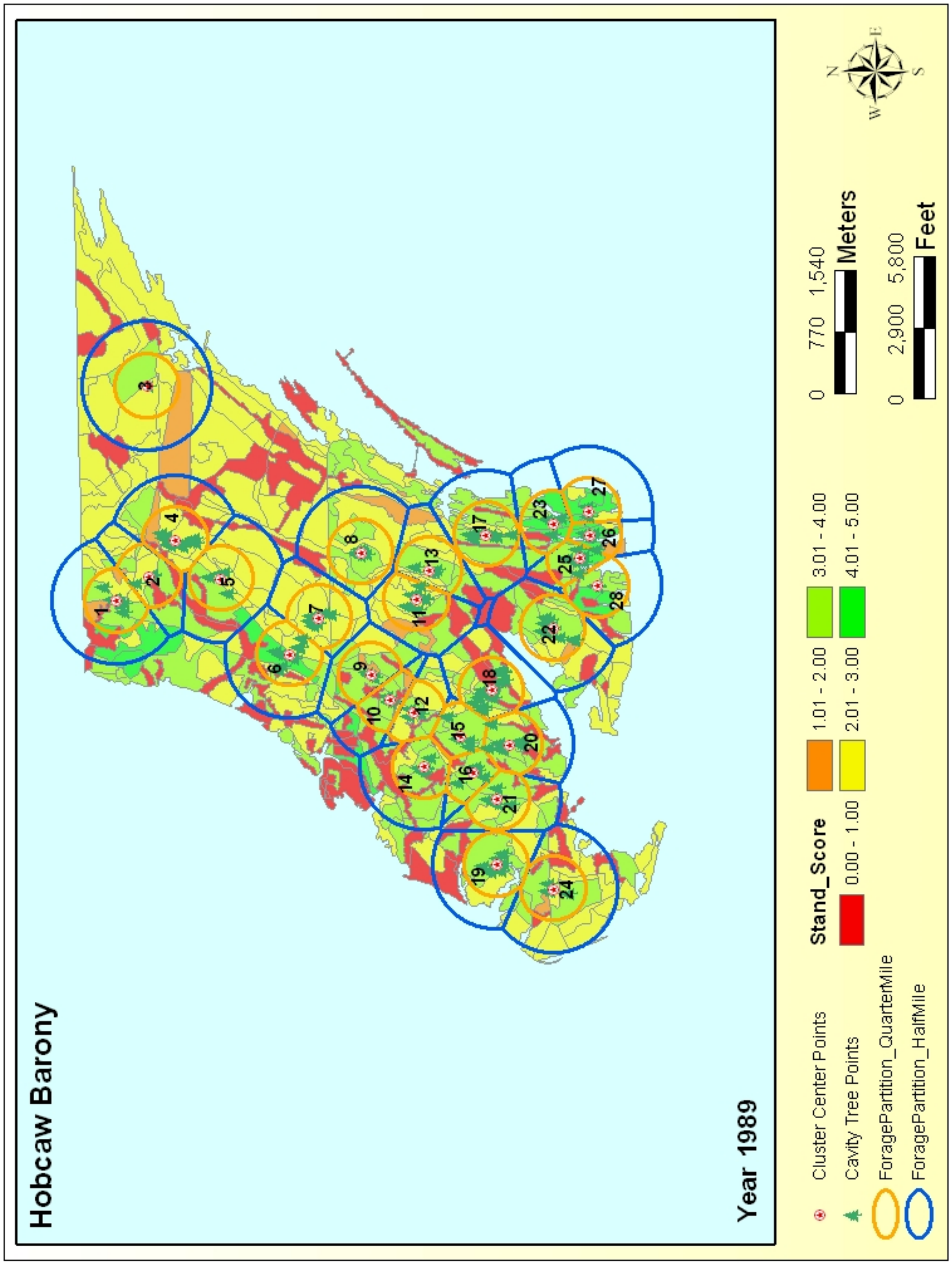


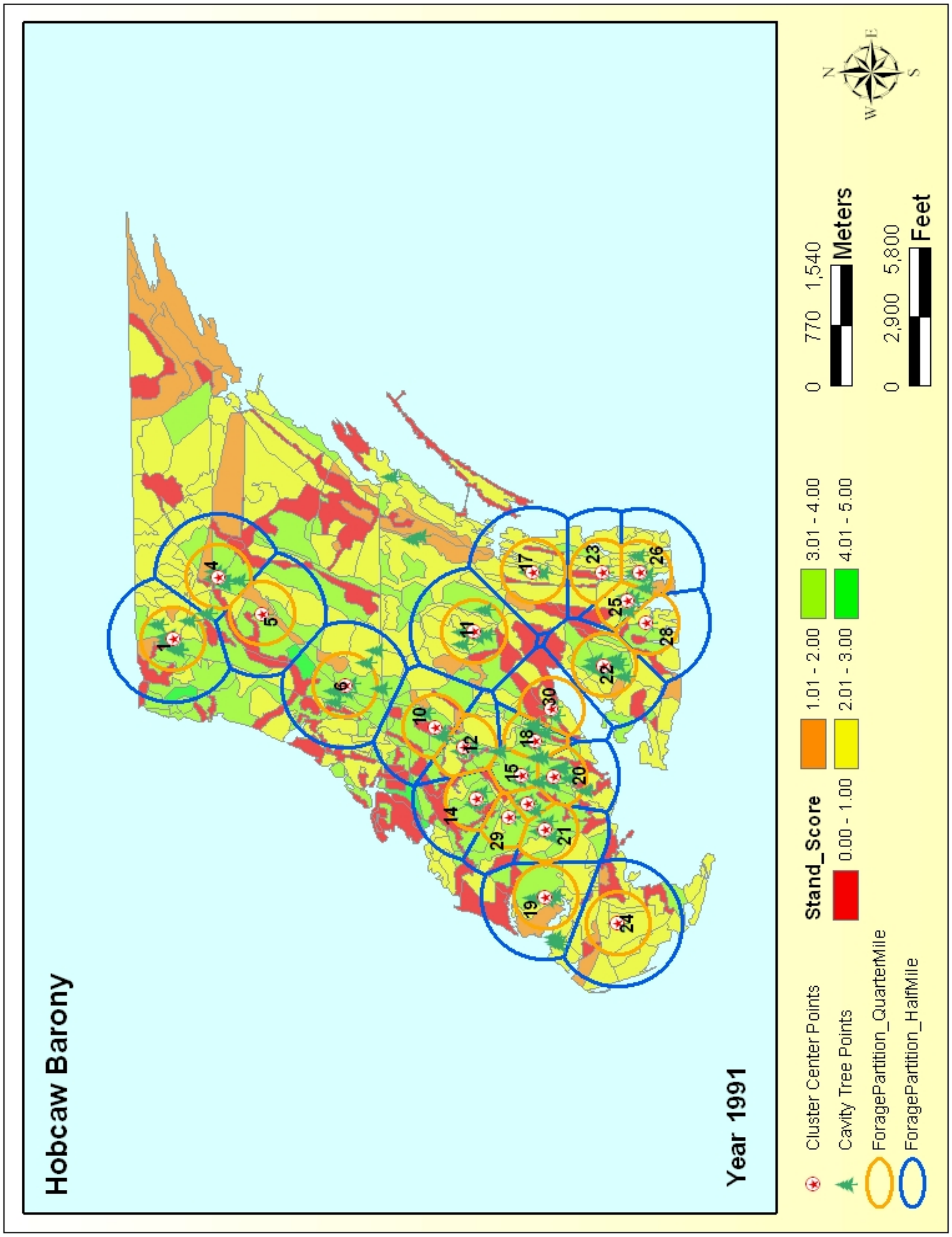
Hobcaw Barony
Year 2006
1
4
5
7
9
12
15
18
20
29
21
19
39
40
17
26
11
22
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

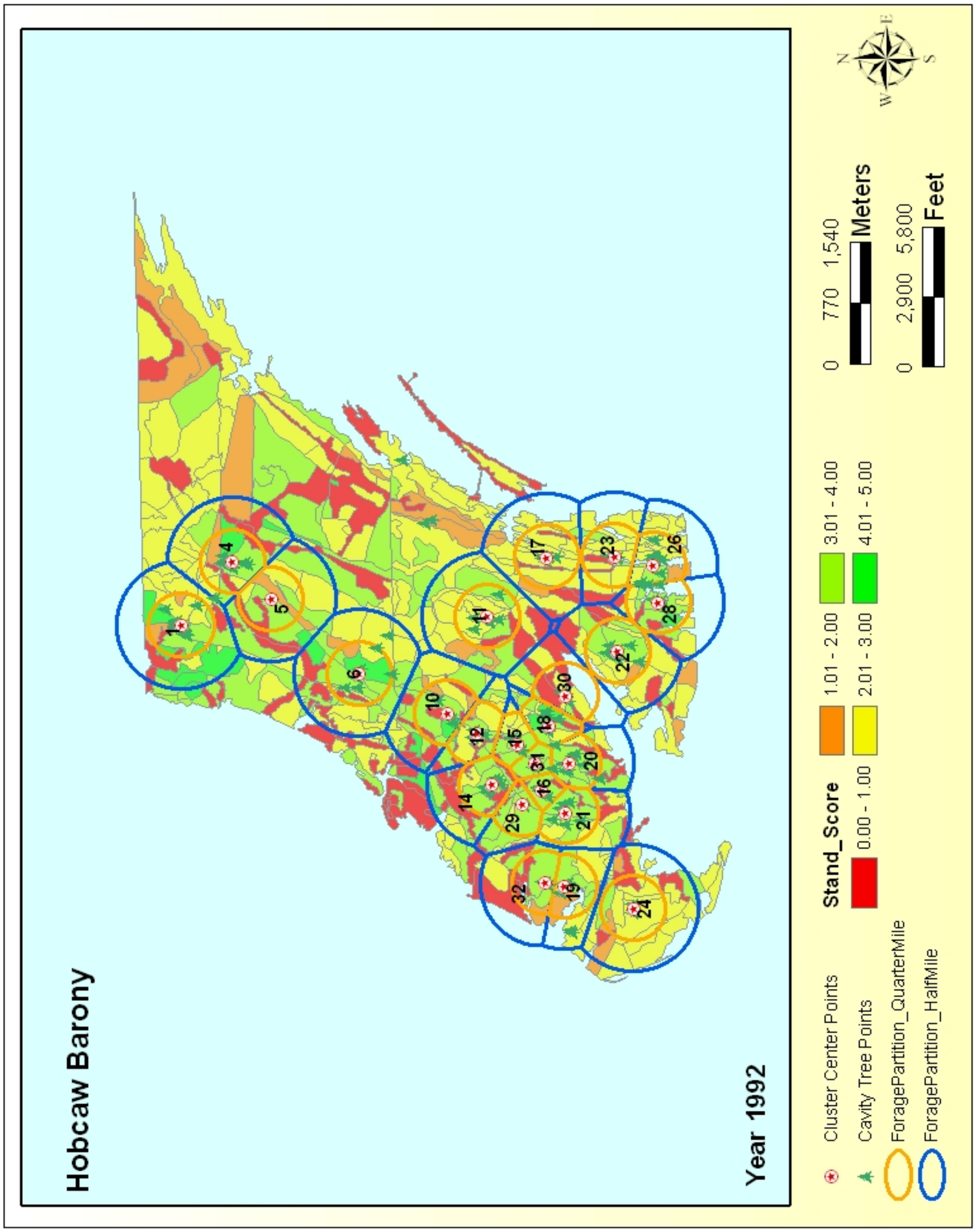

Hobcaw Barony
Year 2007
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
Partition Score
1.00 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
1.81 - 2.00
2.01 - 2.20
Stand Type
Non-Habitat
Pine Habitat
0 770 1,540
Meters
0 2,900 5,800
Feet

Appendix B

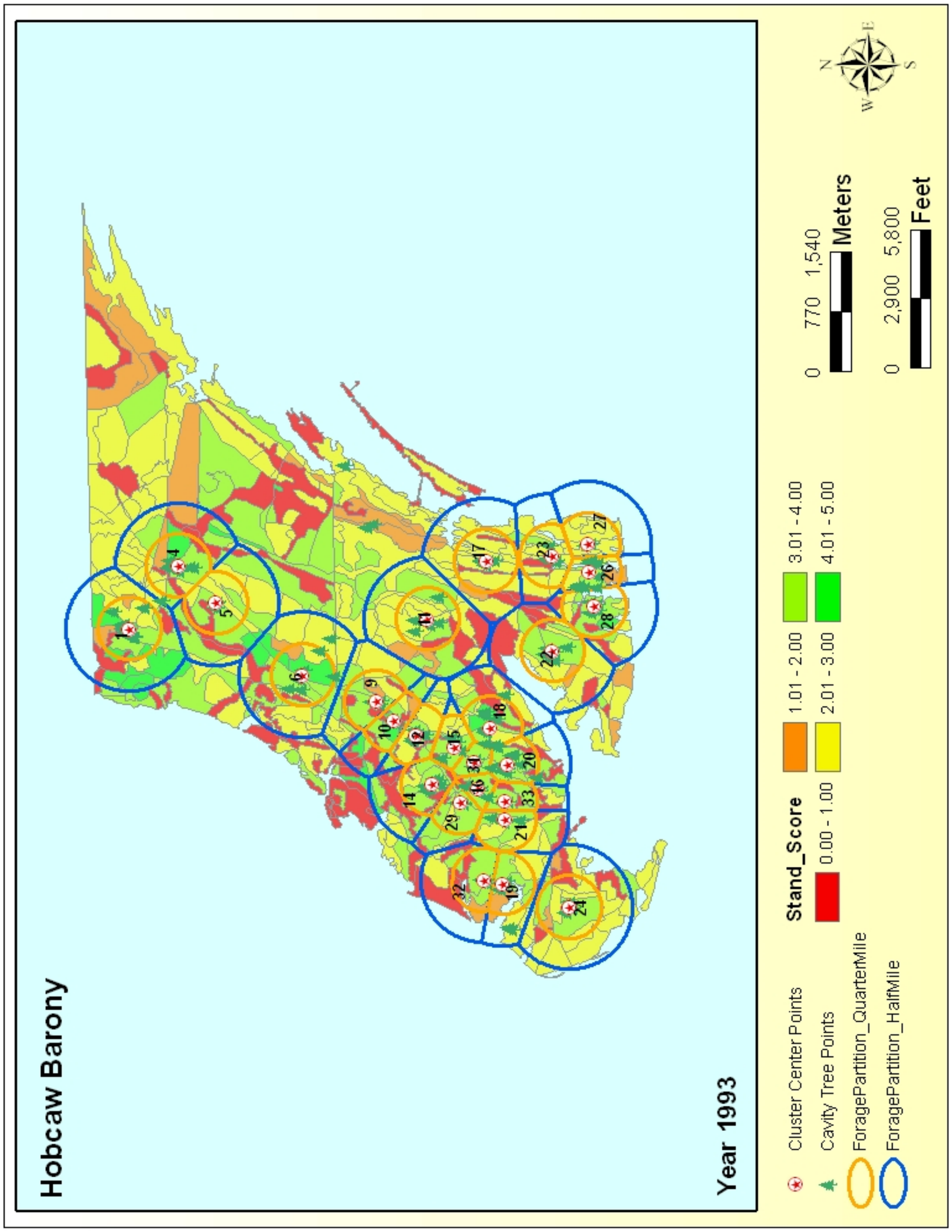
Stand maps of the Hobcaw Barony from year 1989 to 2007.

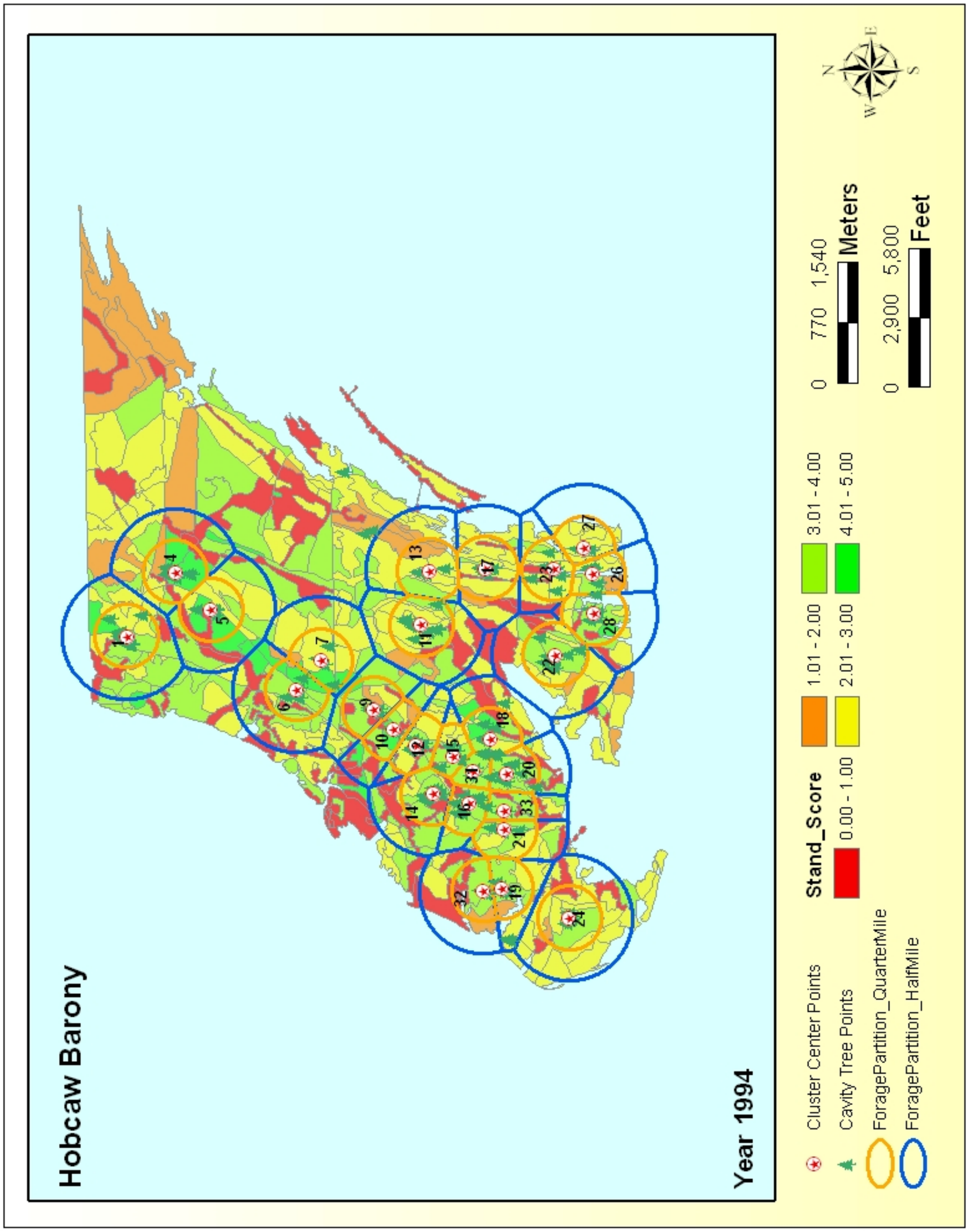

Hobcaw Barony
Year 1989
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

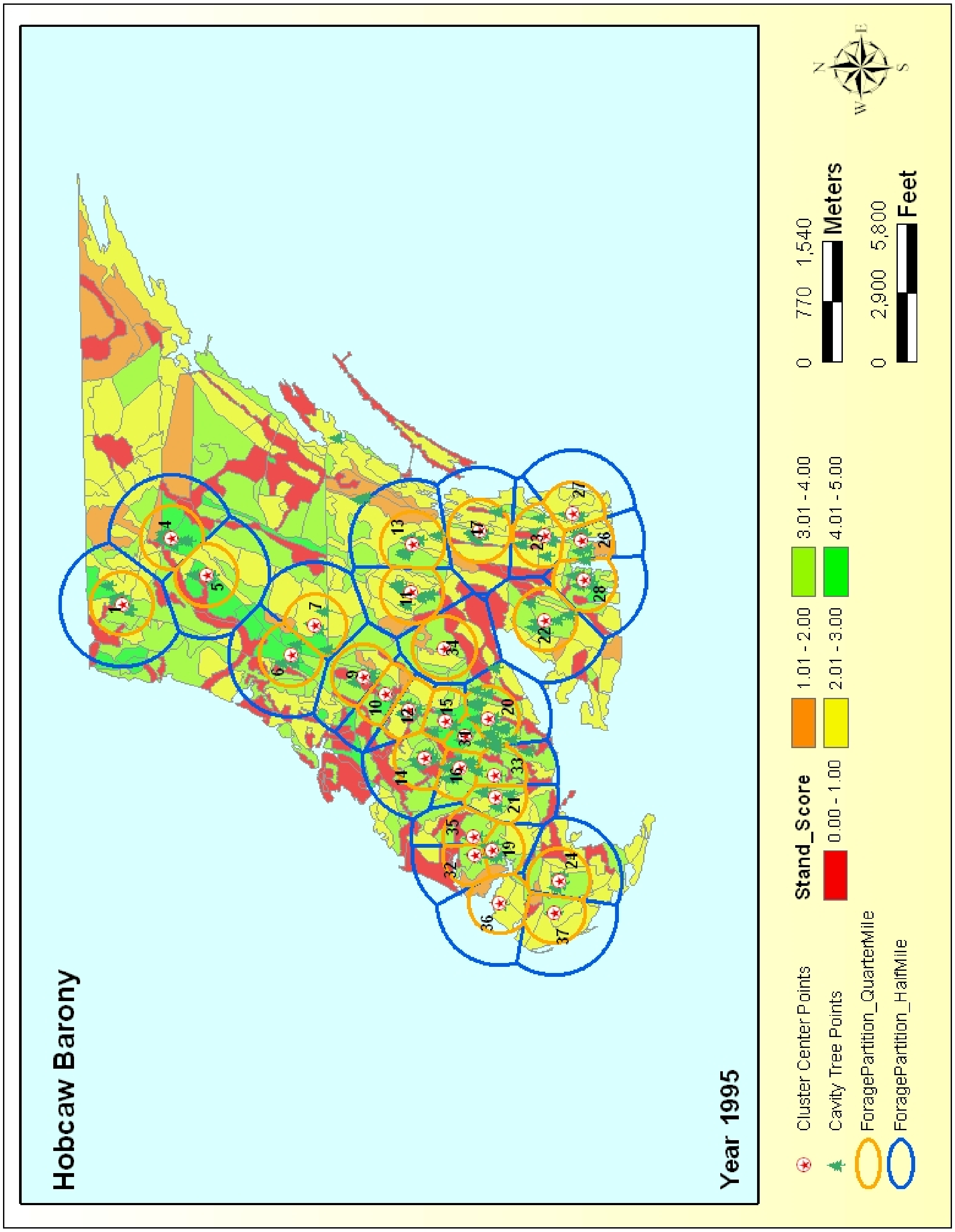

Hobcaw Barony
Year 1991
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

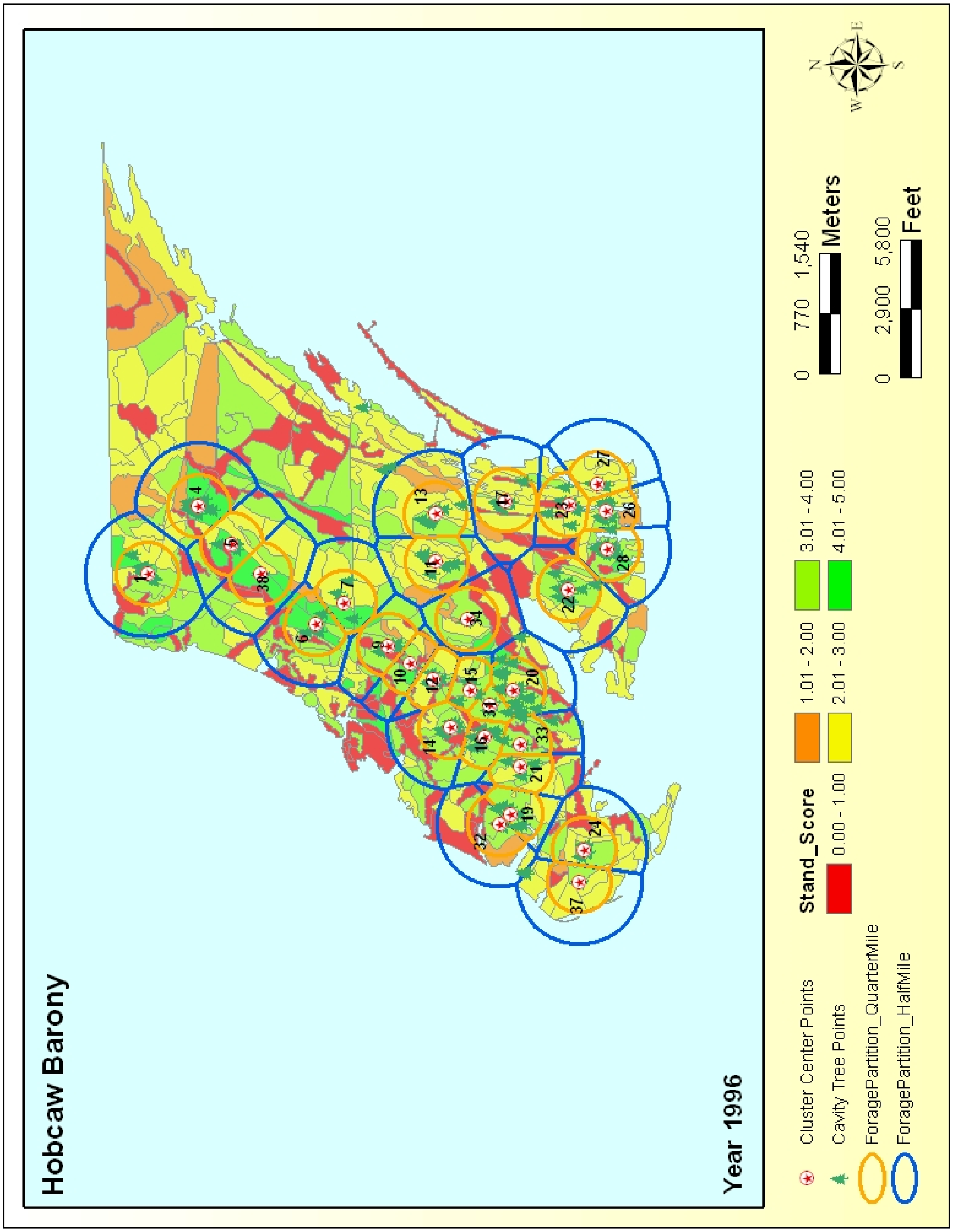


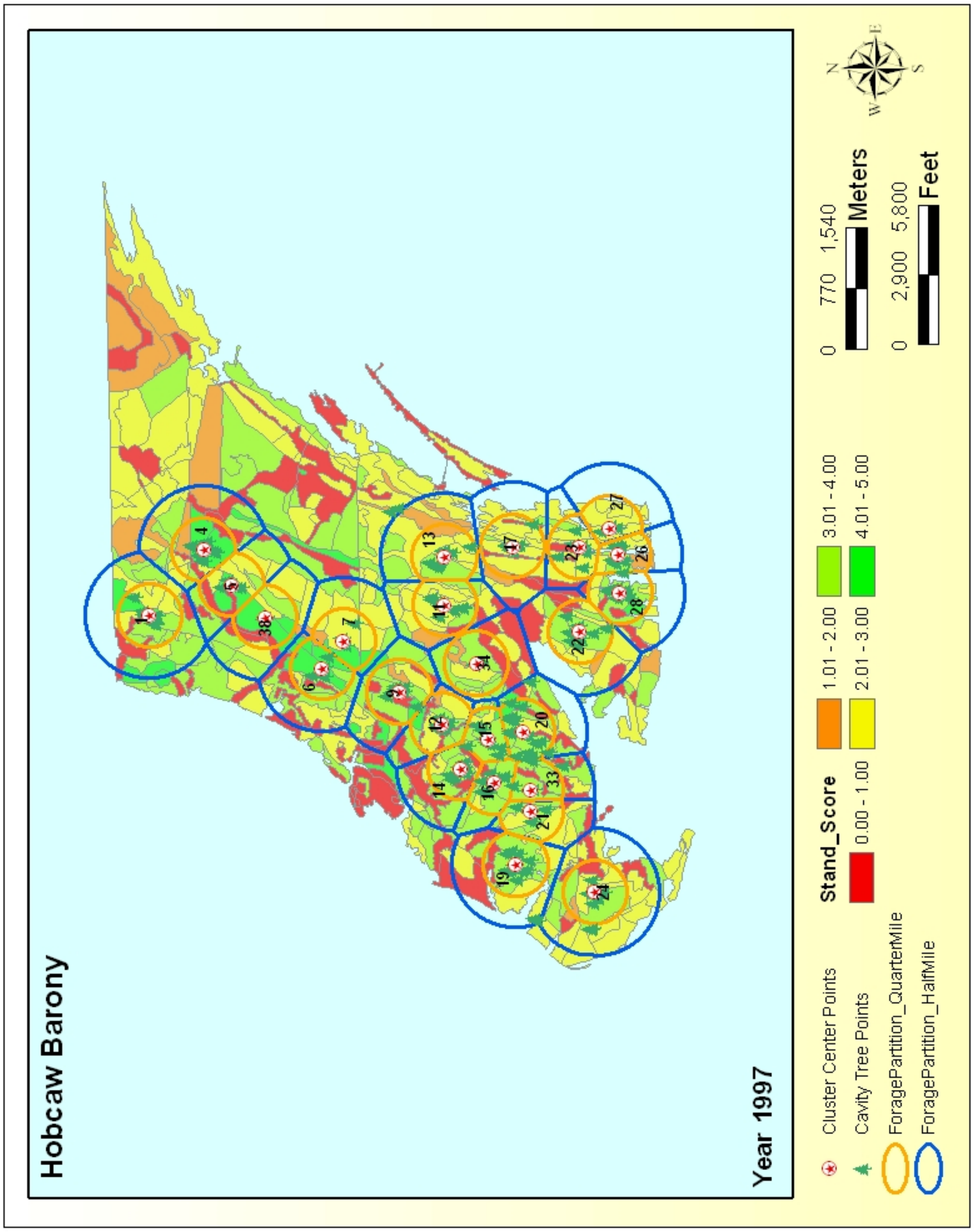
Hobcaw Barony
Year 1992
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet


Hobcaw Barony
Year 1993
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

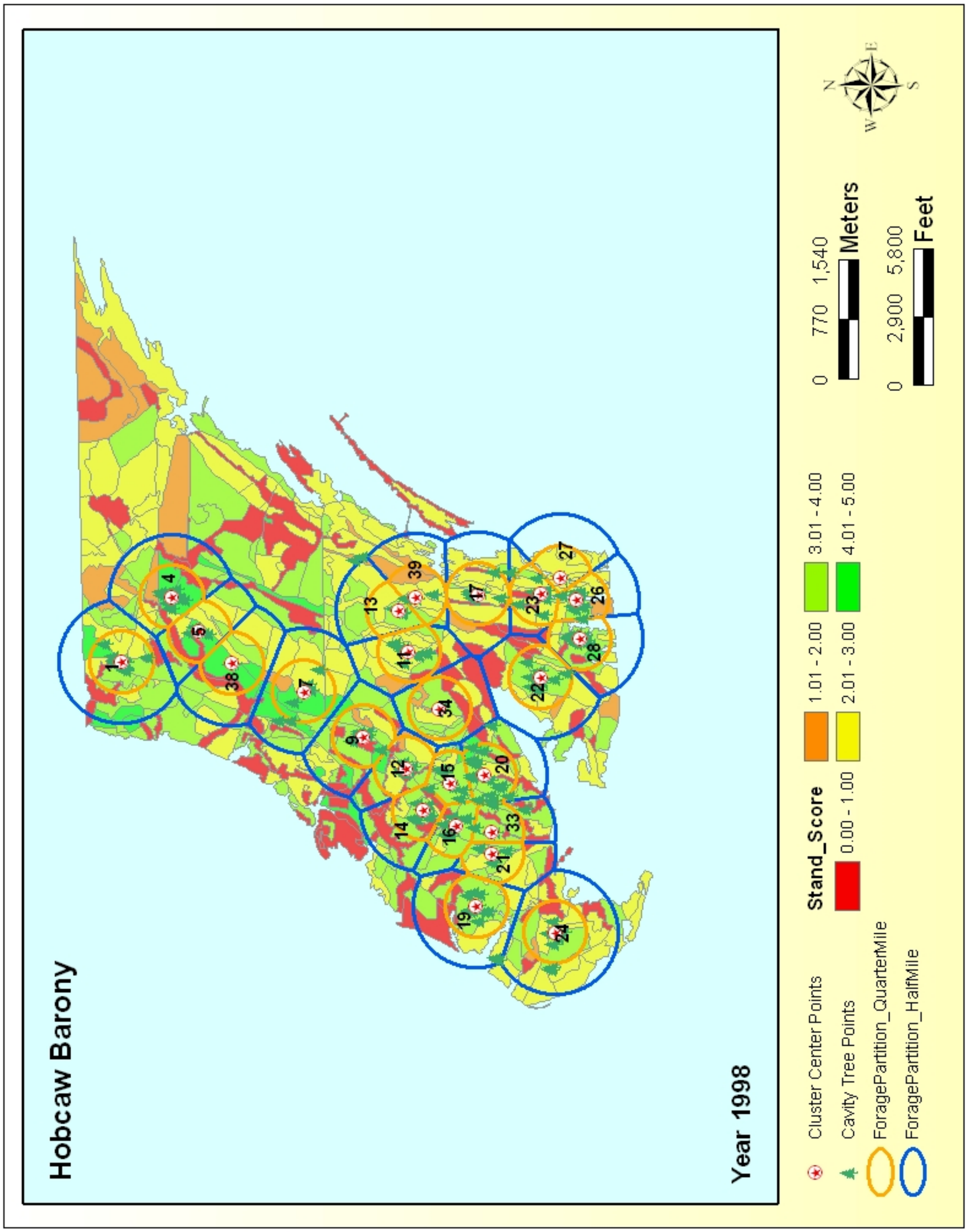

Hobcaw Barony
Year 1994
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

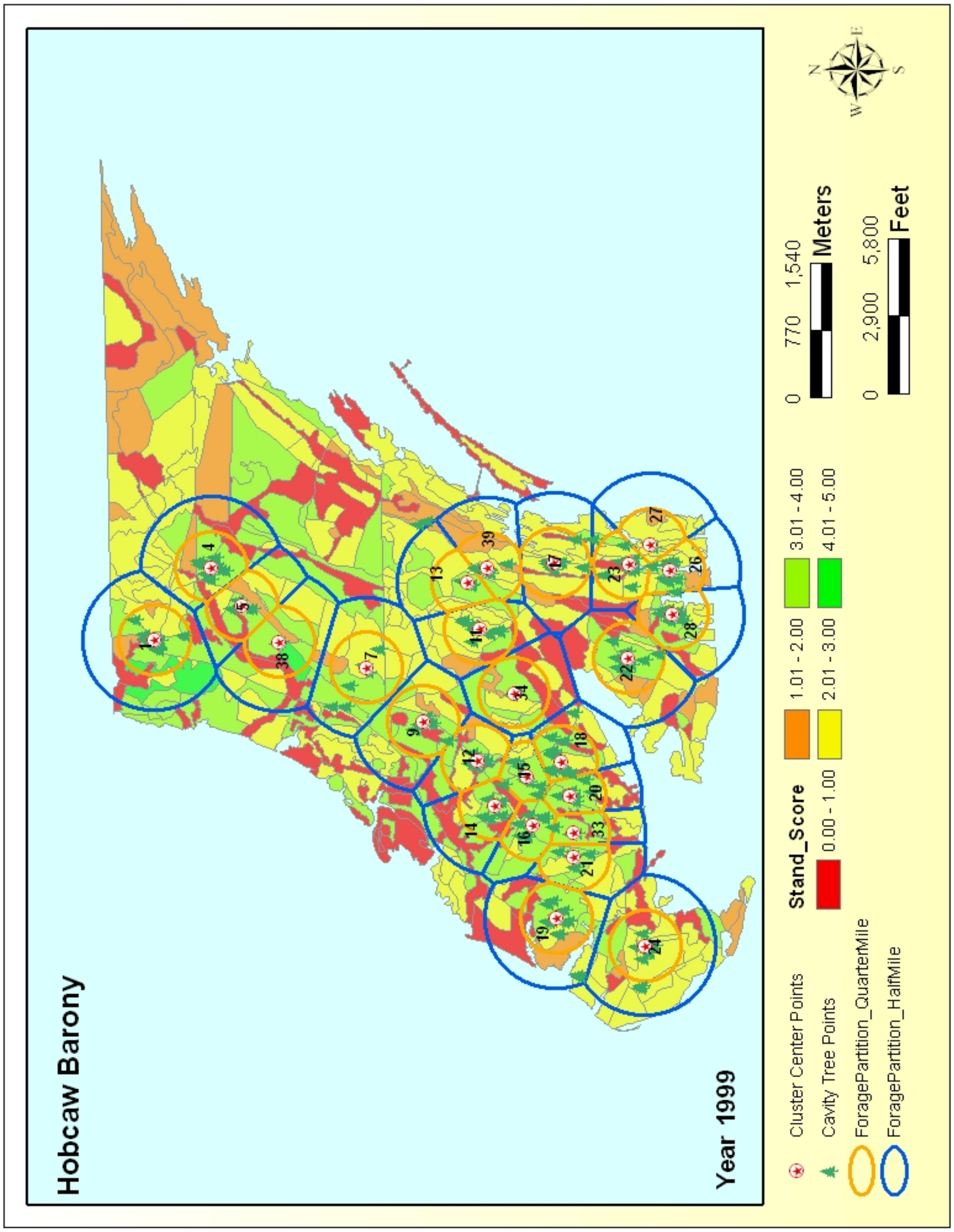

Hobcaw Barony
Year 1995
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

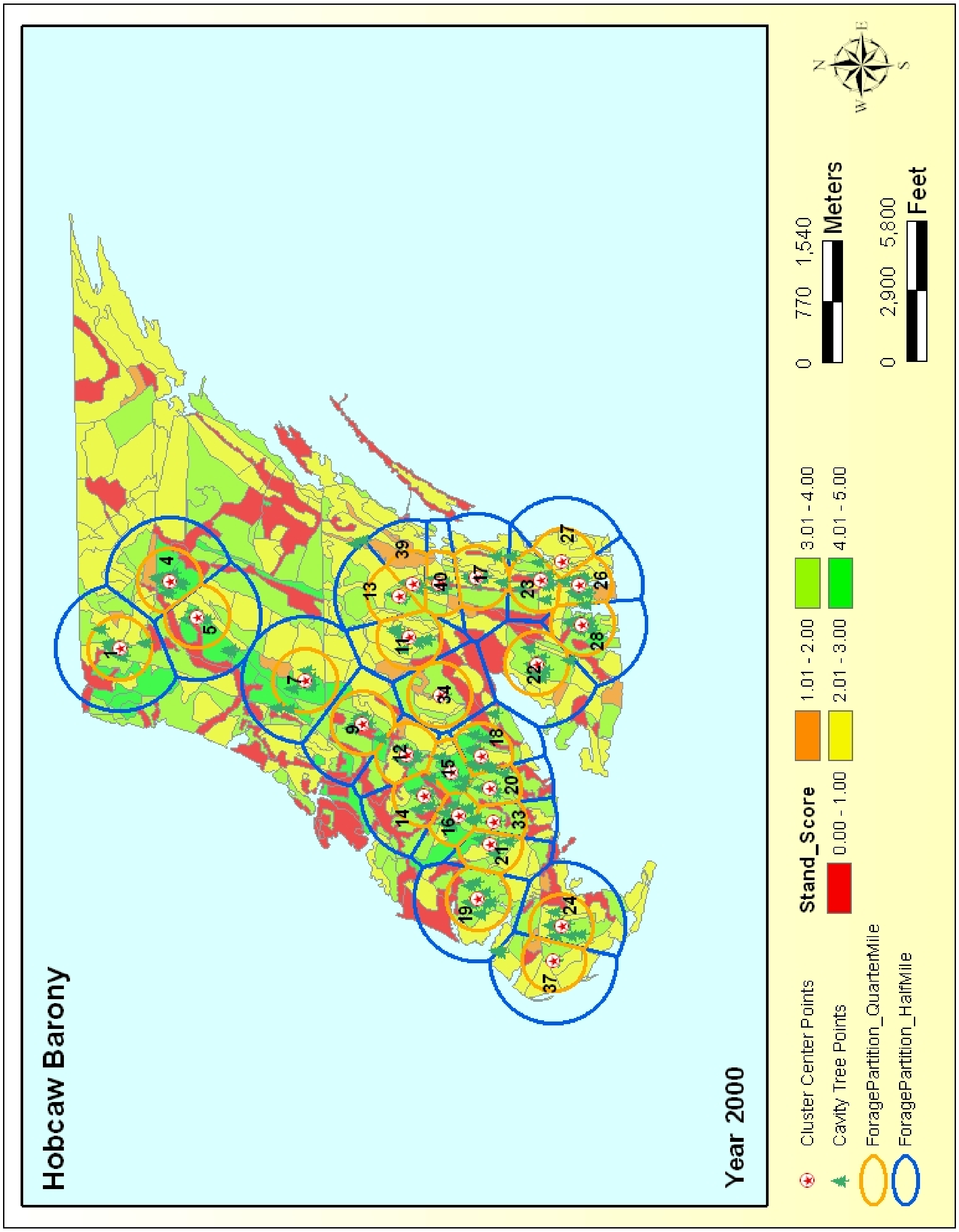

Hobcaw Barony
Year 1996
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet

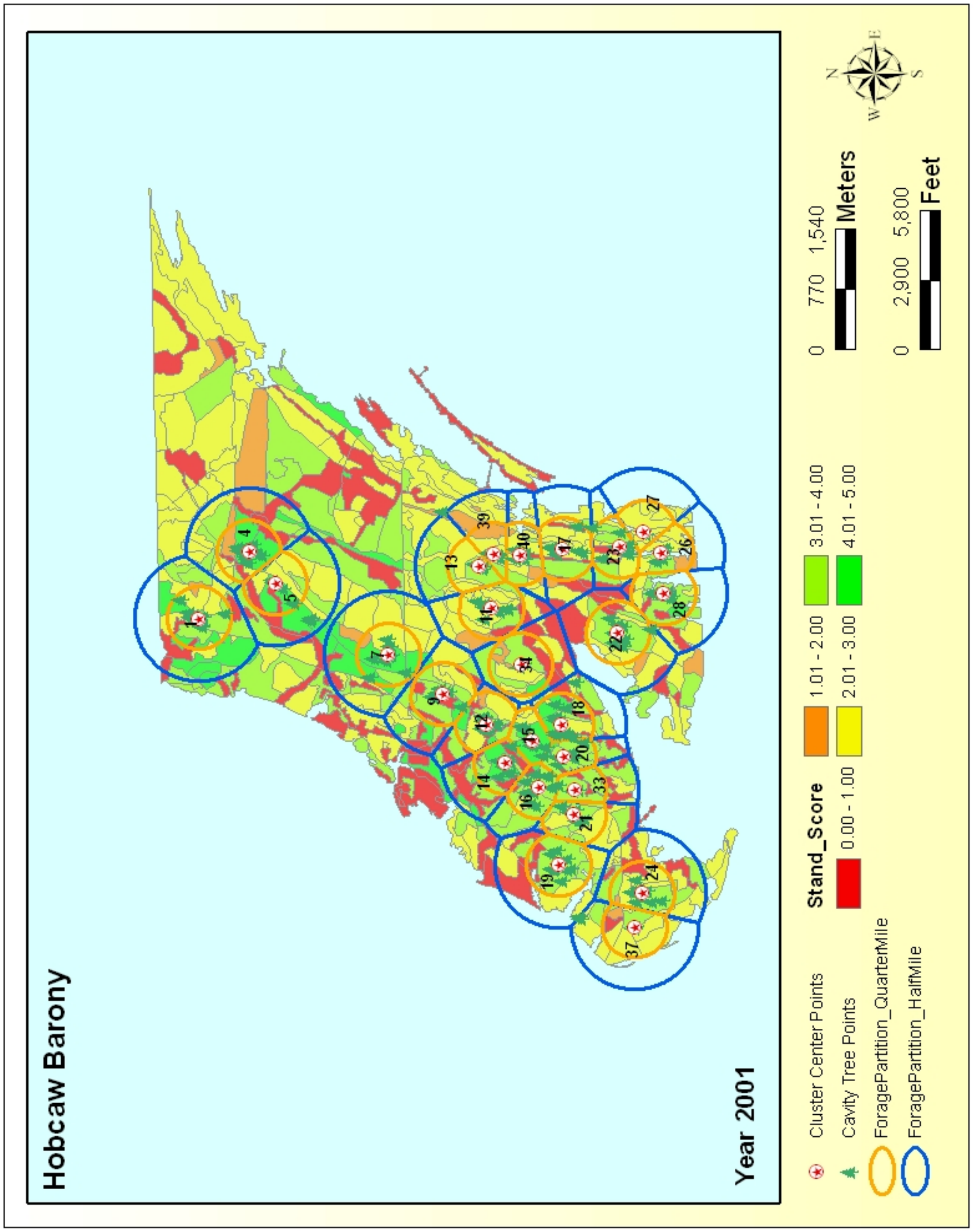


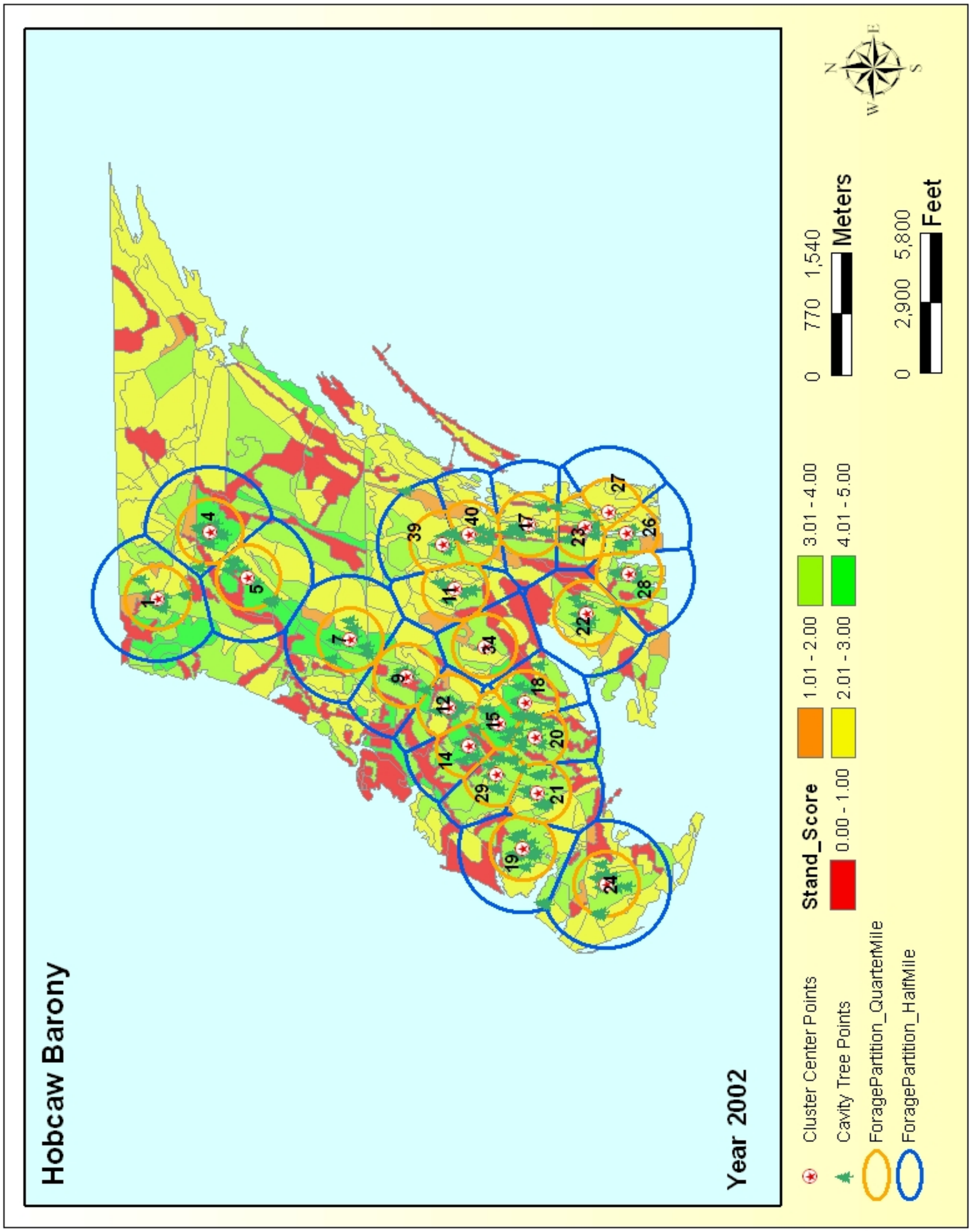
Hobcaw Barony
Year 1997
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W

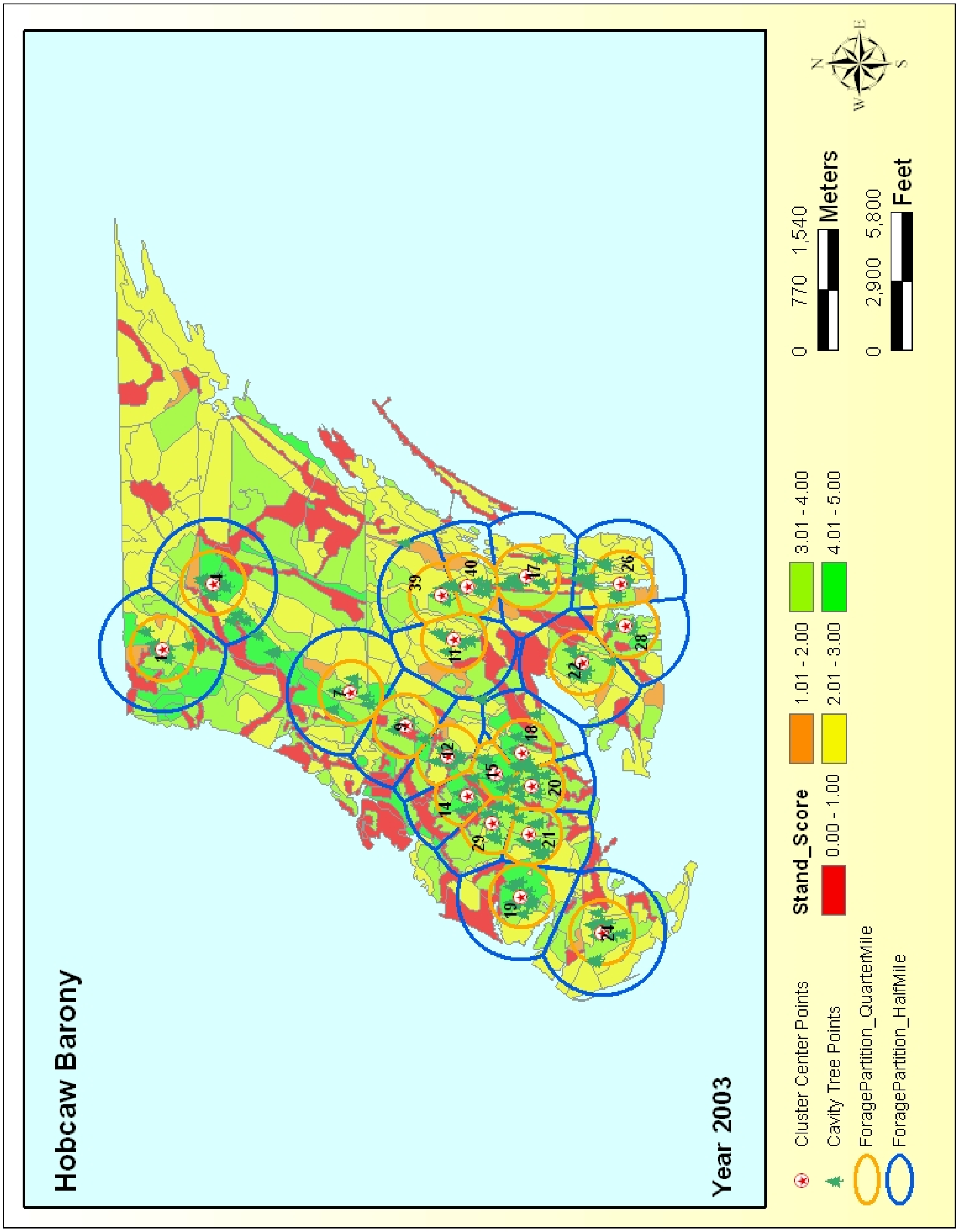

Hobcaw Barony
Year 1998
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W

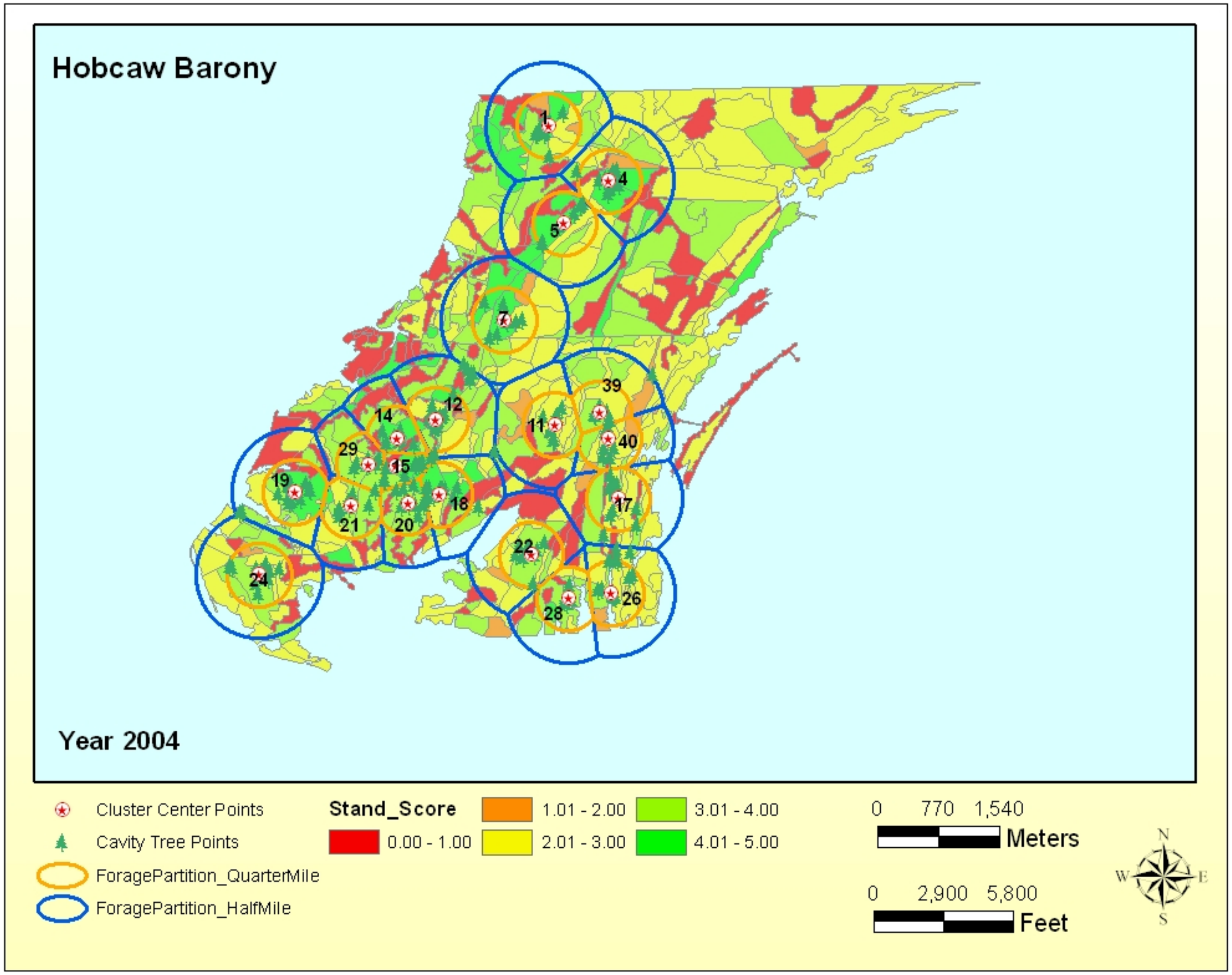

Hobcaw Barony
Year 1999
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet

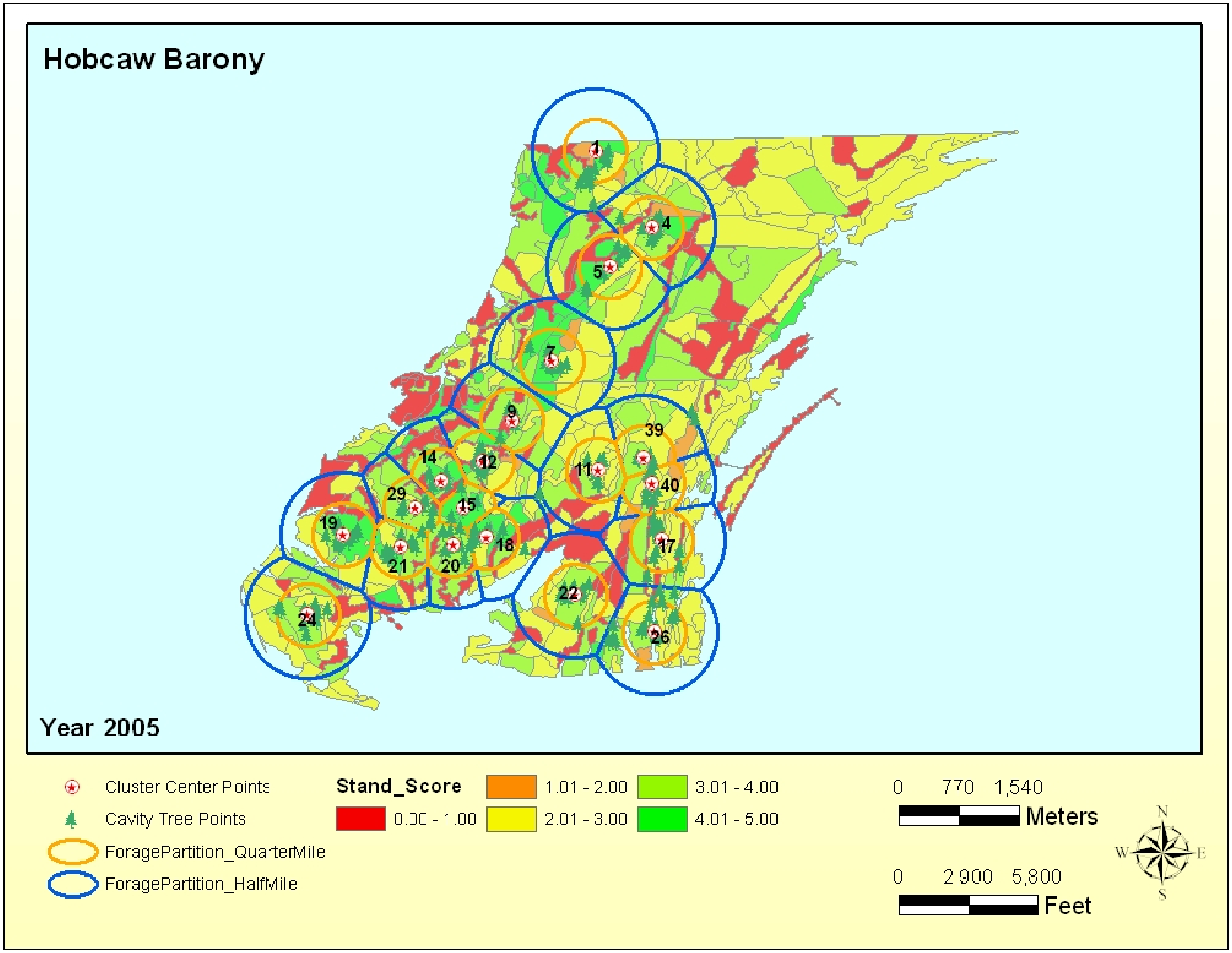

Hobcaw Barony
Year 2000
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet


Hobcaw Barony
Year 2001
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet

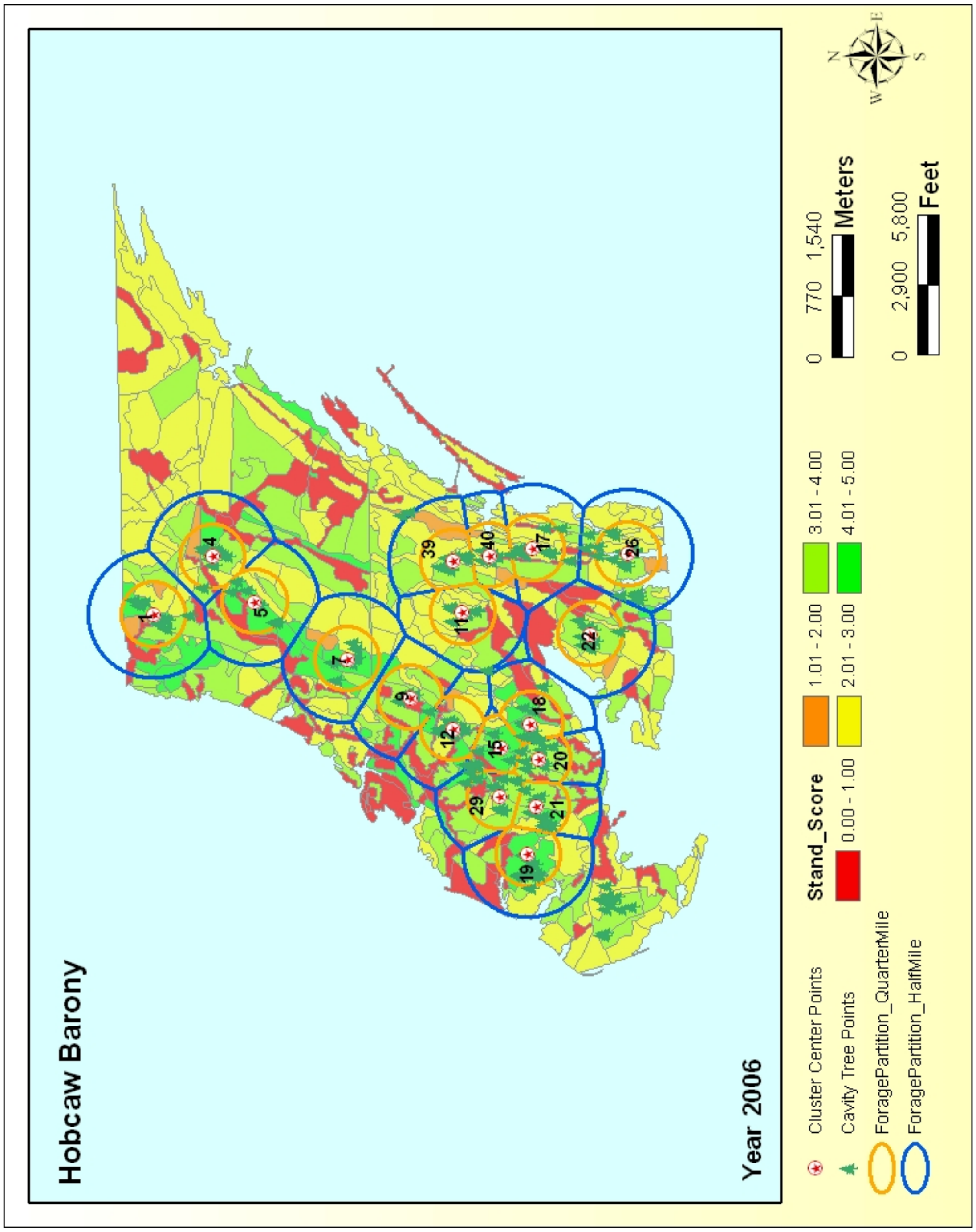

Hobcaw Barony
Year 2002
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet

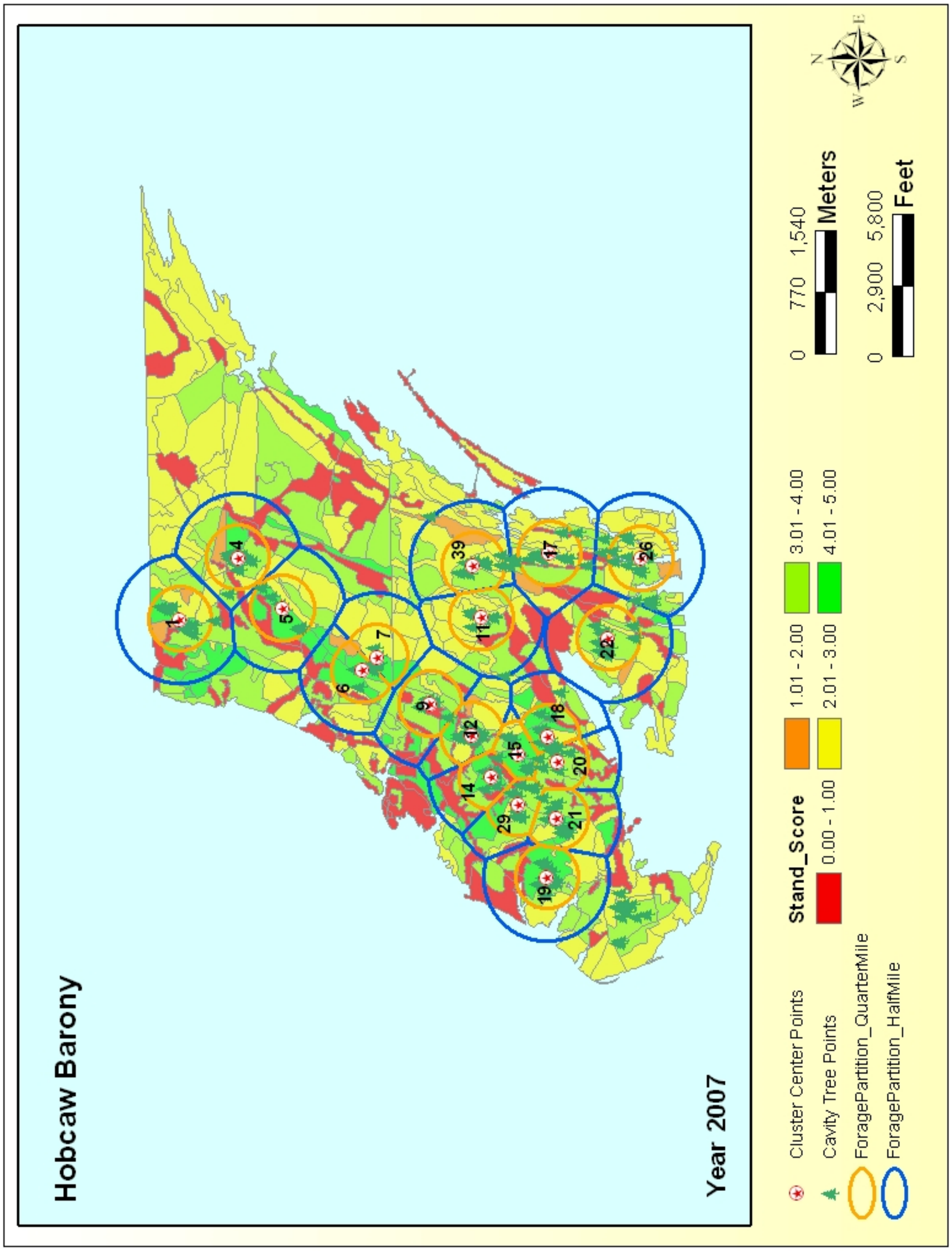

Hobcaw Barony
Year 2003
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W


Hobcaw Barony
Year 2004
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet
N
S
E
W
1
4
5
7
11
12
14
15
17
18
19
20
21
22
24
26
28
29
39
40



Hobcaw Barony
Year 2005
1
4
5
7
9
39
11
40
14
12
29
15
19
18
21
20
17
22
24
26
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet
N
W
E
S


Hobcaw Barony
Year 2006
1
4
5
7
9
11
12
15
17
18
19
20
21
22
26
29
39
40
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540 Meters
0 2,900 5,800 Feet
N
E
S
W


Hobcaw Barony
Year 2007
Cluster Center Points
Cavity Tree Points
ForagePartition_QuarterMile
ForagePartition_HalfMile
Stand_Score
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
0 770 1,540
Meters
0 2,900 5,800
Feet
N
E
S
W
1
4
5
6
7
9
11
12
14
15
17
18
19
20
21
22
26
29
39

<u>Appendix C(USFWS website)</u>

<u>Matrix for Recovery Standards</u> I) Stand characteristics II) Partition characteristics

Evolution of Matrix systems

Recovery Standard						
	Score					Weighted
Stand characteristics	1	2	3	4	5	
# 14" + stems (minimum 60 years old)	<5	5-8	9-12	13-17	18+	0.152
BA 14" + pines (minimum 60 years old)	<5	5-9	10-14	15-19	20+	0.139
BA 10-14" pines	>55	51-55	46-50	41-45	0-40	0.038
BA <10" pines	>30	23-29	16-22	10-15	<10	0.025
# < 10" pines	>40	33-39	26-32	20-25	<20	0.013
BA all 10"+ pines	<20	21-26	27-32	33-39	40+	0.051
% herbaceous groundcover	<10	10-19	20-29	30-39	40+	0.101
hardwood midstory	T-D	M-M	M-S		L-S	0.114
L=Low (<7'), M=Medium (7'-15'), T=Tall (>15)	M-D	T-M	T-S		L-M	
S=Sparse, M=Medium, D=Dense					L-D	
% canopy hardwood						0.063
longleaf stands	>30	23-29	16-22	10-15	<10	
loblolly/shortleaf stands	>50	43-49	36-42	30-35	<30	
stand age	<=30	31-39	40-49	50-59	60+	0.139
fire return interval	>=7	6	5	4	<=3	0.089
season of last prescribed burn			NGS		GS	0.076

	Score					Weighted
Foraging Partition Characteristics	1	2	3	4	5	
Total acres of GQFH in partition	<75	75-89	90-104	105-119	120+	0.4
total acres of pine in the partition	<120	120-146	147-173	174-199	200+	0.1
total acres of GQFH within 1/4 mile	<75	75-89	90-104	105-119	120+	0.3
# of contiguous foraging acres	<75	75-89	90-104	105-119	120+	0.2
					GQFH	

(A) Fort Braggs' matrix

Good Quality Forage Habitat Category Description	Category Ranges 1 (Least Desired)- 5 (Most Desired)					
	Criteria	1	2	3	4	5
Pine stands must be at least 60 years old	A Age	<=30	31-40	41-50	51-59	>=60
Must be => 18 pines per acre at least 14in DBH	A TPA	<= 10	10.01-11.99	12.01-15.99	16.01-17.99	>=18
BA of Pines =>4in must be between 40-60	B	< 25 or > 75	25-30 or 70-75	30-35 or 65-70	35-40 or 60-65	40-60
Pine BA of Pines 4-10in DBH must be < 10	C BA	>25	20.01-25	15.01-20	10.01-15	<10
Pine 4-10in DBH must be < 20 Trees per acre	C Stems	>=35	30.01-35	25.01-30	20.01-25	<20
Hardwoods => 4in DBH must be <5% of total BA	E	>8.00%	7.01%-8.00%	6.01%-7.00%	5.01%-6.00%	<5.00%
Hardwoods => 4in DBH must be =<10% of the stand	F	>=30 %	25%	20%	15%	<=10%
						Goal

(B) Costa's matrix

Parameter	Poor	Fair	Good	Very Good	Excellent
BA & # stems or pines values are per acre. Inches = DBH.	1	2	3	4	5
# 14"+ stems (min. 60 years)	<5	5-8	9-12	13-17	18+
BA 14"+ pines (min. 60 years)	<5	5-9	10-14	15-19	20+
BA 10"-14" pines	>55	51-55	46-50	41-45	0-40
BA <10" pines	>30	29-23	22-16	15-10	<10
# <10" pines	>40	39-33	32-26	25-20	<20
BA all 10"+ pines	<20	21-26	27-32	33-39	40+
% herbaceous groundcover	<10	10-19	20-29	30-39	40+
hardwood (hdwd) midstory	T-D M-D T-M	M-M T- S	M-S L-D	L-M	L-S
% canopy hdwd					
Longleaf	>30	29-23	22-16	15-10	<10
Shortleaf	>50	49-43	42-36	35-30	<30
stand age	30	31-39	40-49	50-59	60+
total acres of GQFH in partition	<75	75-89	90-104	105-119	120+
total acres of pine in the partition	<120	120-146	147-173	174-199	200+
total acres of GQFH within 1/4 mile	<75	75-89	90-104	105-119	120+
last prescribed burn (years since)	>6	6	5	4	1-3
season of last prescribe burn			NGS		GS
Total Score	16	17-32	33-48	49-64	65-80

(C) Sand Hill’s matrix Stand characteristics

Stand Characteristics	1	2	3	4	5	WS
# 14”+ Pine Stems	<5	5-8	9-12	13-17	18+	0.152
Basal Area 14”+ Pines	<5	5-9	10-14	15-19	20+	0.139
Basal Area 10-14” Pines	>55	51-55	45-50	41-45	0-40	0.038
Basal Area < 10” Pines	>30	23-29	16-22	10-15	0-10	0.025
# Pine < 10”	>40	33-39	26-32	20-25	0-20	0.013
Basal Area of Pine >10”	<20	21-26	27-32	33-39	40+	0.051
% Herbaceous Groundcover	<10	10-19	20-29	30-39	40+	0.101
Hardwood midstory Tall-T(>15’) Dense-D Low-L(<7’) Medium-M Low-L(<7’) Sparse-S (Hardwood pulpwood BA)	T-D M-D T-M >30	M-M T-S 22-30	M-S L-D 16-22	L-M 10-16	L-S <10	0.114
% Canopy Hardwoods Longleaf Stands Loblolly/Shortleaf Stands	 >30 >50	 23-29 43-49	 16-22 36-42	 10-15 30-35	 <10 <30	0.063
Stand Age	30	31-39	40-49	50-59	60+	0.139
Fire Return Interval	7+	6	5	3-4	<3	0.089
Fire Type			NGS		GS	0.076

Partition characteristics   Site Index Age 50,L=<50,M=50-75,H=75+

Forage Partition Characteristics	Score						WS
	SI	1	2	3	4	5	
Total acres GQFH in Partition		<75	75-89	90-104	105-120	120+	0.4
Total acres Pine (>30 yrs.) in Partition	L M H	<100 <100 <90	100-150 100-125 90-105	150-200 125-150 105-120	200-250 150-175 120-135	250+ 175+ 135+	0.1
Total acres GQFH within ¼ mile		<40	40-60	61-90	91-119	120+	0.3
# of contiguous Foraging acres in Partition	L M H	<100 <100 <90	100-150 100-125 90-105	150-200 125-150 105-120	200-250 150-175 120-135	250+ 175+ 135+	0.2

Ranking of stand and partition characteristics

Scale = 1 (most important) to 10 (least important)

Stand characteristic	Research		Management		Regulatory		Mean	Low	High	Rank
# 14" + stems	2	3	3	1	4	1	2.3	1	4	1
BA 14" + pines	5	2	7	2	5	2	3.8	2	7	2
BA 10-14" pines	7	4	10	8	8	5	7.0	4	10	8
BA <10" pines	9	8	4	9	6	8	7.3	4	9	9
# < 10" pines	8	9	8	10	9	3	7.8	3	10	10
BA all 10"+ pines	10	5	9	3	10	4	6.8	3	10	7
% herbaceous groundcover	1	10	5	7	2	9	5.7	1	10	5
Hardwood midstory	4	6	1	4	3	6	4.0	1	6	4
% canopy hardwood	6	7	6	5	7	7	6.3	5	7	6
stand age	3	1	2	6	1	10	3.8	1	10	2

Foraging Partition Characteristic	Research		Management		Regulatory		Mean	Low	High	Rank
total acres of GQFH in partition	1	2	1	2	1	3	1.7	1	3	1
total acres of pine in the partition	6	6	5	6	6	4	5.5	4	6	6
total acres of GQFH within 1/4 mile	4	3	2	1	3	1	2.3	1	4	2
last prescribed burn (years)	2	4	3	3	2	5	3.2	2	5	3
season of last prescribed burn	3	5	4	4	4	6	4.3	3	6	5
# of contiguous foraging acres	5	1	6	5	5	2	4.0	1	6	4

Appendix D (USFWS website)

1. Tree data:

Convert the database table (*.dbf) of cavity trees containing x, y tree coordinates to a shapefile. The *.dbf file must have the fields for the following data Field names are limited to 10 characters in shape files.

a) Tree_Number (text field)

b) Cluster_Number (double field)

c) Easting (double field)

d) Northing (double field)

2. Stand Data

The attributes or field types in the stand feature class are as follows:

STAND_ID (Text, length = 8)

TYPE (Text, length = 9)

Note: The application will look for the following abbreviations in the TYPE field to identify stands that are longleaf and those that are not predominantly pine. Any abbreviation other than those listed is assigned by the application to "other pine" species. But in the application the following abbreviations are used for all other stand types:

OP or OPEN for open areas such as drop zones, fields, or roads

WATER for streams, ponds, or lakes

UHAR for upland hardwood stands

LHAR for lowland hardwood stands

OT for any other, non-pine stands

LL for longleaf pine stands

DESCRIP (Text, length = 25, description of stand type)

PINE_AGE (Double, age of pine stand)

PTPA_4_10 (Double, pine trees per acre that are <10" DBH)

PTPA_10_14 (Double, pine trees per acre that are 10-14" DBH)

PTPA_14 (Double, pine trees per acre that are ≥ 14" DBH)

PBA_4_10 (Double, basal area of pine trees <10" DBH)

PBA_10_14 (Double, basal area of pine trees 10-14" DBH)

PBA_14 (Double, basal area of pine trees ≥ 14" DBH)

HTPA_4_10 (Double, hardwood trees per acre that are <10" DBH)**

HTPA_10_14 (Double, hardwood trees per acre that are 10-14" DBH)

HTPA_14 (Double, hardwood trees per acre that are ≥ 14" DBH)

HBA_4_10 (Double, basal area of hardwood trees that are < 10" DBH)**

HBA_10_14 (Double, basal are of hardwood trees that are 10-14" DBH)

HBA_14 (Double, basal area of hardwood trees that are ≥14" DBH)

HWDMID (Double, coded values for midstory height and density, see Procedures document))

SITE_INDEX (Double, site index)**

NO_BURNS (Short Integer, number of years since last burn)

TYPE_BURN (Short Integer, coded values for season of last burn, see Procedures document)

HERBACEOUS_GRDCVER (Double, percent herbaceous groundcover)

**NOTE: The fields marked with ** are required for proper structure of the stands attribute table but the data in them is not used in the analysis.

Recovery Standard

Stand values for each characteristic in the Recovery Standard are compared to the values that define the scoring ranges for each characteristic in the matrix. A stand is assigned a score, 1 through 5, for each characteristic based on the stand's value, and that score is then stored in the geodatabase. Each of these scores is multiplied by the respective characteristic's weighting factor, a number between 0 and 1. These weighted scores are then summed for each stand to produce a final stand score that ranges between 1 and 5. The process is then repeated for each stand in the geodatabase.

Standard for Managed Stability

Stand values for each characteristic in the Standard for Managed Stability are compared to the values that define pass/fail in the matrix. A stand is assigned a 1 for those characteristics where it meets the standard and a 0 for those characteristics where it does not. The exception to this rule applies to two characteristics, BA all 10"+ Pines and Total BA. The values for these characteristics are allowed to exceed the upper end of their range (70 and 80, respectively) for these characteristic if the excess in BA is due to large (>14") trees. That is, the application will look to see if the BA for 4-10" tress is less than 20 (Total BA only) and if the BA for 10-14" trees is less than 40. For Total BA, the application will also look to see if hardwoods greater than 10" contribute no more than 10 BA. If so, the stand will pass Managed Stability for these two characteristics even though the BA exceeds the stated limit.

Followings are the other 17 feature classes populated by the application in the process of score calculation (Source:USFWS Website):

1. “ClusterCenterPoints – This feature class contains cluster center and calculated as the mean location of all cavity trees in a partitions.
2. ForagePartition_HalfMile – This feature class contains ½ mile foraging partitions and calculated by buffering each cluster center by ½ mile and constraining that buffer, with adjacent neighboring partitions.
3. ForagePartition_QuarterMile – It contains ¼ mile foraging partitions calculated by buffering each cluster center by ¼ mile.
4. Habitat_Removal – It contains the footprint of proposed projects that will require complete clearing of the outlined area.
5. Mgmt_Stands – It contains Stands feature class data that has been altered by the program based on user input regarding proposed management changes such as thinning or midstory control.
6. MgmtFP_HalfMile –It contains the ForagePartition_HalfMile feature class, calculated as above, for partitions that will be affected by proposed management changes.
7. MgmtFP_QuarterMile – It contains the ForagePartition_QuarterMile feature class, calculated as above, for partitions that will be affected by proposed management changes.
8. MgmtStands_Clipped – It contains the data in the Mgmt_Stands feature class, clipped to the MgmtFP_HalfMile partitions.

9. Proj_Mgmt_Stands – It contains the Stands feature class data for those partitions that will be impacted by the project(s) outlined in the Habitat_Removal feature class and the management changes outlined in the Mgmt_Stands feature class.
10. Proj_MgmtFP_HalfMile – It contains the ForagePartition_HalfMile for those partitions that will be impacted by the project(s) outlined in the Habitat_Removal feature class and the management changes outlined in the Mgmt_Stands feature class.
11. Proj_MgmtFP_QuarterMile – contains the ForagePartition_QuarterMile for those partitions that will be impacted by the project(s) outlined in the Habitat_Removal feature class and the management changes outlined in the Mgmt_Stands feature class.
12. Proj_MgmtStands_Clipped – contains the data in the Proj_Mgmt_Stands feature class, clipped to the ½ mile foraging partitions for those partitions affected by the project(s) in the Habitat_Removal feature class and the management changes outlined in the Mgmt_Stands feature class.
13. ProjFP_HalfMile – contains the ForagePartition_HalfMile feature class, calculated as above, for partitions that will be affected by the project(s) outlined in the Habitat_Removal feature class.
14. ProjFP_QuarterMile – contains the Forage Partition_QuarterMile feature class, calculated as above, for partitions that will be affected by the project(s) outlined in the Habitat_Removal feature class.

15. ProjStands – contains timber stand data collected during foraging habitat analysis or timber inventory for those stands that will be affected by the project(s) outlined in the Habitat_Removal feature class.
16. ProjStands_Clipped – contains the data in the ProjStands feature class, clipped to the ½ mile foraging partitions for those partitions affected by the project(s) outlined in the Habitat_Removal feature class.
17. Stands_Clipped – contains timber stand data collected during foraging habitat analysis or timber inventory that have been clipped to the ½ mile partitions"

The four tables that are present in the geodatabase contain the matrix standards. The application used these tables to assign the score for each characteristic of a stand.

1. LKUP_ForageAssess_Default – It contains the upper and lower limits for each scoring category for the characteristics used in evaluations of foraging habitat against the Recovery Standard, the weighted assigned to each characteristic, and management recommendations to improve scores for each characteristic
2. LKUP_ManStability – It contains the values determining pass/fail for each characteristic used in evaluations of foraging habitat against the Standard for Managed Stability, management recommendations to improve scores in each category, and indicator variables for which characteristics are used in the evaluation as well as which characteristics are required in the evaluation

The geodatabase also contains two tables for internal use of the application. These tables can not be modified:

3. GBD_DefaultLKP_MS

4. GBD_DefaultLKP_RE”

Appendix E

List of hardwood species.

Code	Species
ASH	Ash
ASP	Aspen
BAS	Basswood
BEE	Beech
BIR	Birch
BLC	Black Cherry
BLG	Black Gum
BLL	Black Locust
BLO	Black Oak
BLW	Black Walnut
BOX	Boxelder
BUC	Buckeye
BUO	Bur Oak
BUT	Butternut
CHO	Chestnut Oak
COT	Cottonwood
CUC	Cucumber Tree
CYP	Cypress
DOG	Dogwood
ELM	Elm
ERC	Eastern Red cedar
HAC	Hackberry
HAM	Hard Maple Group
HEM	Eastern hemlock
HIC	Hickory
HOL	Holly
MAG	Magnolia
MIC	Misc. Conifer
MRO	Misc. Red oak
MUL	Mulberry
MWO	Misc. White Oak
NRO	Northern Red Oak
OSO	Osage Orange
OVO	Overcup Oak
PEC	Pecan
PER	Persimon
PIO	Pin Oak
POO	Post Oak
REM	Red maple

Contd.

Code	Species
RIB	River Birch
SAS	Sassafras
SCO	Scarlet Oak
SHO	Shingle Oak
SIM	Silver Maple
SRO	Southern Red Oak
SWB	Sweet bay
SWG	Sweet gum
SWO	White Oak
SYC	Sycamore
TUP	Tupelo
WAO	Water Oak
WIE	Winged Elm
WIO	Willow Oak
YEB	Yellow Birch
YEP	Yellow Poplar
ZBO	Blackjack Oak
ZCH	Chinquapin oak
ZCO	Cherry bark Oak
ZHL	Honey Locust
ZSB	Sweet Birch
ZSC	Swamp Chestnut Oak
ZSO	Shumard Oak
MISC	Miscellaneous

Pine species list:

Code	Species
LOP	Loblolly pine
MYP	Miscellaneous pine
SHP	Shortleaf pine
SLP	Slash pine
VIP	Virginia pine
WHP	White pine
ZLP	Longleaf pine

REFERENCES

Baker, W.W. 1971. Observations on the food habits of the red-cockaded woodpecker. In: R.L. Thompson (Ed.). The ecology and management of the red-cockaded woodpecker: Proceedings of a symposium; May 26-27; Folkston, GA. Tall Timbers Research Station, Tallahassee, FL. Pp. 100-107.

Bean, S.D. and B.K. Ellis. 1984. User manual for Tennessee valley inventory processor system. Tennessee Valley Authority, Norris. TN. 56 p.

Beyer, E.D. Jr., R. Costa, R.G. Hooper, and C.A. Hess. 1996. Access habitat quality and reproduction of red-cockaded woodpecker groups in Florida. Journal of Wildlife Management. 60(4): 826-835.

Bowman, R. and C. Huh. 1995. Tree characteristics, resin flow, and heartwood rot in Pines (*Pinus palustris, Pinus elliottii*), with respect to red-cockaded woodpecker cavity excavation, in two hydrologically-distinct Florida flatwood communities. In: D.L. Kulhavy, R.G. Hooper, and R. Costa (Eds.). Red-cockaded woodpecker: recovery, ecology and management. Center for Applied Studies in Forestry, College of Forestry, Stephen F. Austin State University, Nacogdoches, Texas, USA. Pp. 415-426.

Bradshaw, D.S. 1995. Habitat use by a relict population of red-cockaded woodpeckers in southeastern Virginia. In: D.L. Kulhavy, R.G. Hooper, and R. Costa (Eds.). Red-cockaded woodpecker: recovery, ecology and management. Center for Applied Studies in Forestry, College of Forestry, Stephen F. Austin State University, Nacogdoches, Texas, USA. Pp. 482-488.

Clark III, A. 1992. Influence of tree factors and site on formation of heartwood in loblolly and longleaf pine for RCW colonization in the Southeast. Final Report. Southeastern Forest Experiment Station. Athens, GA. 30p.

Copeyon, K.C., J.R. Walters, and J.H. Carter III. 1991. Introduction of red-cockaded woodpecker group formation by artificial cavity construction. Journal of Wildlife Management. 55(4):549-556.

Coles W.J., D. Hughell, and W.D. Smith. 2000. An optimal foraging model for the red-cockaded woodpecker. U.S. Forest Service General Technical Report NC 205. Pp. 118-121.

Conner, R.N. and D.C. Rudolph. 1989. Red-cockaded woodpecker colony status and trends on the Angelina, Davy Crockett, and Sabine National Forests. U.S. Forest Service Research Paper SO-250.

Conner, R.N. and D.C. Rudolph. 1991. Effect of midstory reduction and thinning in red-cockaded woodpecker cavity tree clusters. Wildlife Society Bulletin.19: 63-66.

Conner, R.N., D. Saenz, D.C. Rudolph, W.G. Ross, and D.L. Kulhavy. 1998a. Red-cockaded woodpecker nest-cavity selection: relationships with cavity age and resin production. The Auk. 115(2): 447-454.

Costa, R. and R. Escano.1989. Red-cockaded woodpecker status and management in the southern region in 1986. US Forest Service Technical Publication R 8-TP12.

Costa, R. 1992. Red-cockaded woodpecker procedures manual for private lands. U.S. Fish and Wildlife Service. Atlanta, GA. 35 pp.

Crosby, G.T. 1971. Home range characteristics of the red-cockaded woodpecker in northcentral Florida. In R. L. Thompson (Ed.). The ecology and management of the red-cockaded woodpecker. Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior, and Tall Timbers Research Station, Tallahassee, Florida, USA. Pp. 60-73.

DeLotelle, R.S., R.J. Epting, and J.R. Newman. 1987. Habitat use and territory characteristics of red-cockaded woodpeckers in Central Florida. Wilson Bulletin. 99(2): 202-21.

Davenport, D.E., R.A. Lancia, J.R. Walters, and P.D. Doerr. 2000. Red-cockaded woodpeckers: A relationship between reproductive fitness and habitat in the North Carolina Sandhills. Wildlife Society Bulletin. 28: 426-434.

Dennis, J.V. 1968. Rare red-cockaded woodpecker under study at Hobcaw. Conservation Catalyst 2: 12-14.

Dickson, J.G. 2001. Wildlife of Southern Forest Habitat and Management. Handcock publishers. Blaine, Washington. 480 p.

Duncan, L., L. Andrews, R. Costa, and S. Lohr. 2001. A safe harbor for the red-cockaded woodpecker. Endangered Species Bulletin. 26: 16-18.

Engstrom, R.T. and F.J. Sanders. 1997. Red-cockaded woodpecker foraging ecology in an old growth longleaf pine forest. Wilson Bulletin. 109(2): 203-217.

Epting, R. T., R.S. DeLotelle, and T. Beaty. 1995. Red-cockaded woodpecker territory and habitat use in Georgia and Florida. In D.L. Kulhavy, R.G. Hooper, and R. Costa (Eds.). Red-cockaded woodpecker: recovery, ecology, and management, Center for Applied Studies in Forestry, Stephen F. Austin State University., and Nacogdogches, Texas. Pp. 270-276.

Faranzerb, K. E. and F.T. Llyod. 2000. Integration of Long-term research into a GIS – based landscape habitat model for the red-cockaded woodpecker studies. In Avian Biology No. 21: 65-74.

Franzreb, K.E. 1992. Habitat preferences of foraging red-cockaded woodpeckers at the Savannah River site, South Carolina. Source: In: R. Costa and S.J. Daniels (Eds.). Red-cockaded woodpecker: Road to recovery. Blaine, WA: Hancock House Publishers. Pp. 553-561.

Frances, J.J., C.A. Hess, and D. Kuferin. 1997. Species –centered environmental analysis: indirect effects of fire history on red-cockaded woodpeckers Ecological applications. 7(1): Pp. 118-129.

Frances, J.J, C.A. Hess, B.C. Kicklighter, and R.A. Thum. 2001. Ecosystem management and the niche gesalt of the red-cockaded woodpecker in longleaf pine forest. Ecological Applications. 11(3): 854-870.

Gardner, L.R., W. Mitchner, E. Blood, T.M. Williams, D.J. Lipscomb, and W.H. Jefferson. 1991. Impact of Hurricane Hugo-salinization of a costal forest. J. Coast. Res. SI8: 301-317.

Gresham, C.A., T.M. Williams, and D.J. Lipscomb. 1991. Hurricane Hugo damage to southeastern U.S. coastal forest tree species. Biotropica. 23(4a): 420-426.

Grimes, T. L. 1977. Relationship of red-cockaded woodpecker (*Picoides borealis*) productivity to colony area characteristics. M.Sc. Thesis. Clemson University, Clemson, SC.

Harlow, R. F., and M.R. Lennartz. 1977. Foods of nestling red-cockaded woodpeckers in coastal South Carolina. Auk 94:376-377.

Harlow, R. F., R. G. Hooper, and M. R. Lennartz. 1983. Estimating numbers of red-cockaded woodpecker colonies. Wildlife Society Bulletin 11:360-363.

Hardesty, J., R.J. Smith, C.J. Petrick, B. W. Hagedorn, and H.F. Percival. 1995. Status and distribution of the fourth largest population of red-cockaded woodpeckers: preliminary results from Eglin AFB, Florida. In D.L. Kulhavy, R.G. Hooper, and R.Costa, (Eds.). Red-cockaded woodpecker: recovery, ecology and management. Center for Applied Studies in Forestry, College of Forestry, Stephen F. Austin State University,Nacogdoches, Texas, USA. Pp. 494-502.

Henry, G.H. 1989. Guidelines for preparation of biological assessment and evaluations for the red-cockaded woodpecker. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region.

Hodges, J.D., W.W. Elam, W.E. Watson, and T.E. Nebeker. 1979. Oleoresin characteristics and susceptibility of four southern pines to southern pine beetle (*Coleopteran Scolytidae*) attacks. Canadian Entomologist. 111: 889-896.

Hooper, R.G. and M.R. Lennartz. 1981. Foraging behavior of red-cockaded woodpecker in South Carolina. The Auk. 98: 321-334.

Hooper, R.G., L. J. Niles, R.F. Harlow, and G.W. Wood. 1982. Home ranges of red-cockaded woodpeckers in coastal South Carolina. The Auk. 99: 675-682.

Hooper, R. G., and R. F. Harlow. 1986. Forest stands selected by foraging red-cockaded woodpeckers. U.S. Forest Service Research Paper SE-259.

Hooper, R. G., W. E. Taylor, and S. C. Loeb. 2004. Long-term efficacy of artificial cavities for red-cockaded woodpeckers: lessons learned from Hurricane Hugo. In R.Costa, and S. J. Daniels (Eds.). Red-cockaded woodpecker: road to recovery. HancockHouse, Blaine, Washington, USA. Pages 430-438.

Jackson, J.A. 1971. The evolution, taxonomy, distribution, past populations, and current status of Red-cockaded woodpecker. In R.L. Thompson (Ed.). Ecology and management of the red-cockaded woodpecker. U.S. Bureau of Sport Fishing and Wildlife timbers Research Station, Tallahassee, FL. Pp. 4-29.

Jackson, J. A. 1974. Gray rat snakes versus red-cockaded woodpeckers: predator-prey adaptations. Auk 91:342-347.

Jackson, J.A., M.R. Lennartz, and R.G. Hooper. 1979. Tree age and cavity initiation by red-cockaded woodpeckers. Journal of Forestry. 77(2): 102-103.

Jackson, J. A., and B. J. S. Jackson. 1986. Why do red-cockaded woodpeckers need old trees? Wildlife Society Bulletin 14:318-322.

Jackson, J.A. 1994. Red-cockaded woodpecker. Birds of North America. 85: 1-20.

James, F. C., C. A. Hess, B. C. Kicklighter, and R. A. Thum. 2001. Ecosystem management and the niche gestalt of the red-cockaded woodpecker in longleaf pine forests. Ecological Applications 11:854-870.

Jones, C. M. and H.E. Hunt. 1996. Foraging habitat of the red-cockaded woodpecker on the D'Arbonne National Wildlife Refuge, Louisiana. Journal of Field Ornithology. 67: 511-518.

Kennedy, E.T., R. Costa, and W.M. Smathers Jr.. 1996. New directions for red-cockaded woodpecker habitat conservation: Economic Incentives. Journal of Forestry. 94: 22-26.

Lennartz, M. R., P.H. Geissler, R.F. Harlow, R.C. Long, K.M. Chitwood, and J. A. Jackson.1983. Status of the red-cockaded woodpecker on federal lands in the south. In D. A. Wood (ed.). Red-cockaded woodpecker symposium II proceedings. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida. Pp. 7-12

Lennartz, M.R. and V.G. Henry. 1985. Red-cockaded woodpecker recovery plan. U.S. Fish and Wildlife Service, Atlanta, GA. Pp. 88.

Lennartz, M.R., R.G. Hooper, and R.F. Harlow. 1987. Sociality and cooperative breeding of red-cockaded woodpeckers, *Picoides borealis* Behavior. Ecology Sociobiology. 20: 77–88.

Letcher, B.H., J.A. Priddy, J.R. Walters, and L.B. Crowder. 1998. An individual-based, spatially explicit simulation model of the population dynamics of the endangered red-cockaded woodpecker, *Picodes borealis*. Biological Conservation. 86: 1-14.

Ligon, J. D. 1970. Behavior and breeding biology of the red-cockaded woodpecker. The Auk. 87: 255-278.

Ligon, J.D., P.B. Stacey, R.N. Conner, C.E. Bock, and C.S. Adkisson. 1986. Report of the American Ornithologists' Union Committee for the conservation of the red-cockaded woodpecker. Auk 103:848-855.

Lipscomb, D.J. and T.M. Williams. 1983. Logging history of Hobcaw forest. Department of Forestry, Clemson University, Clemson, S.C. Forestry. Bulletin. No. 38: 12Pp.

Lipscomb, D.J. and T.M. Williams. 1998. An AML to calculate colony areas and foraging zone of the red-cockaded woodpecker. 18th Annual ESRI User Conference Proceeding. CD-ROM Chapter. Environmental Systems Research Institute, Redman CA.

Lipscomb, D.J. and T.M. Williams. 2004. Development of A geographic information system based model of red cockaded woodpecker habitat. In Costa, R., and S. J. Daniels (eds.). Red-cockaded woodpecker: road to recovery. Hancock House Publishers, Blain, Washington. Pp 520-525.

Lipscomb, D.J. and T.M. Williams. 2005. Examining RCW management changes in the 2003 recovery plan using habitat mapping In Proceedings of the 4th Southern Forestry and Natural Resource GIS Conference. Published by Warnell School of Forest Resources, University of Georgia, and Athens, Georgia. Pp 27-36.

Lipscomb, D.J. and T.M. Williams. 2006. GIS tool for evaluating the impact of proposed cuts on red-cockaded woodpecker habitat. In Proceedings of the 5th Southern Forestry and Natural Resource GIS Conference Ashville, North Carolina. Pp. 139-147.

Locke, B.A., R.N. Conner, and J.C. Kroll. 1983. Factors influencing colony site selection by red- cockaded woodpeckers. In D.A. Wood (Ed.). Red-cockaded woodpecker symposium II. Florida Game and Fresh Water Fish Commission, Tallahassee, FL. Pp. 46-50.

Loeb, Susan C., W.D. Pepper, and A.T. Doyle. 1992. Habitat characteristics of active and abandoned red-cockaded woodpecker colonies. Southern Journal of Applied Forestry. 16: 120-125.

Lohr, S.M., W.E. Taylor, and J.C. Watson. 2004. Restoration, status, and future of the red-cockaded woodpecker on the Francis Marion national forest thirteen years after hurricane Hugo. In R. Costa and S.J. Daniels (Eds.). Red-cockaded woodpecker: road to recovery. Hancock House, Blaine, Washington, USA. Pp. 230-237

Mason, R.R. 1971. Soil moisture and stand density affect oleoresin exudation pressure in a loblolly pine plantation. Forest Science. 17: 170-177.

Nalley, J.C. 1998. Determination of baseline responsibilities for a red-cockaded woodpecker safe harbor agreement on Hobcaw Barony, Georgetown County. M.Sc. Thesis. Clemson University, Clemson, SC.

Porter, M.L. and R.L. Labiskey. 1986. Home range and foraging habitat of red-cockaded woodpeckers in northern Florida. Journal of Wildlife Management. 50: 239-247.

Ramey, P. 1980. Seasonal, sexual, and geographical variation in the foraging ecology of red-cockaded woodpeckers (*Picoides borealis*). M.S. thesis, Mississippi State University, Mississippi.

Reed, M.J., J.R. Walters, T.E. Emigh, and D.E. Seaman. 1993. Effective population size in red-cockaded woodpeckers: population and model differences. Conservation Biology. 7(2): 302–308.

Regional Society of American Foresters Position Statement. 1992. Red-cockaded woodpecker protection and habitat management on private land. Journal of Forestry. 90: 38-39.

Ross, W.G., D.L. Kulhavy, and R.N. Conner. 1997. Stand conditions and tree characteristics affect quality of longleaf pine for red-cockaded woodpecker cavity trees. Forest and Ecology Management. 91: 145-154.

Rudolph, D. Craig, R.N. Conner, and J. Turner. 1990a. Competition for red-cockaded woodpecker roost and nest cavities: effects of resin age and entrance diameter. Wilson Bulletin. 102: 23-36.

Rudolph, D. C., H. Kyle, and R. N. Conner. 1990b. Red-cockaded woodpeckers versus rat snakes: the effectiveness of the resin barrier. Wilson Bulletin 102:14-22.

Rudolph, D. C., R.N. Conner, and R.R. Schaefer. 2002. Red-cockaded woodpecker foraging behavior in relation to Midstory vegetation. Wilson Bulletin. 114(2): 235-242.

Schiegg, K., J.R. Walters, and J.A. Priddy. 2002. The consequences of the disrupted dispersal in fragmented red-cockaded woodpecker *Picoides borealis* populations. Journal of Animal Ecology. 71: 710-721.

Schillaci, J.M. and R.J. Smith. 1994. Red-cockaded woodpeckers in northwestern Florida produce a second clutch. Florida Field Naturalist. 22: 112-113.

Skorupa, J.P. 1979. Foraging ecology of red-cockaded woodpecker in South Carolina. M.S. Thesis, University of California, Davis, California. 96 p.

USFWS. 2003. Recovery plan. Fish and Wildlife Services, United States Department of Interior. P.316

USFWS. 2003. Executive summary of red cockaded woodpecker recovery plan 2003

USFWS. 2005. Foraging habitat guidelines. Fish and Wildlife Services, United States Department of Interior.

USFWS. 2007. RCW foraging habitat matrix application. Webpage: http://www.fws.gov/filedownloads/ftp_rcwrecovery/: RCW FAP documents (Introduction and Procedure).

Vabalean, J.B. and P.D. Doerr. 1978. The relationship of understory vegetation to red-cockaded woodpecker activity. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 32: 82-92.

Walters, J. R., P.D. Doerr, and J.N. Carter III. 1988. The cooperative breeding systems of the red-cockaded woodpecker. Ethology. 78: 275-305.

Walters, J.R. 1990. Red-cockaded woodpeckers: A “primitive” cooperative breeder in P.B. Stacey and W.D. Koenig (Eds.). Cooperative breeding Birds: long term studies of ecology and behavior. Cambridge university press, Cambridge. Pp. 69-101.

Walters, J.R. 1991. Application of ecological principles to the management of endangered species: the case of the red-cockaded woodpecker. Annul. Rev. Ecol. Syst. 22: 505-523.

Walters, R. J., C.K.Copeyon, and J.H. Carter, III. 1992. Test of the ecological basis of cooperative breeding in red-cockaded woodpeckers. The Auk. 109 (1): 90-97.

Walters, J.R., L.B. Crowder, and J.A. Priddy. 2002. Population viability analysis for red-cockaded woodpecker using an individual based model. Ecological Applications. 12: 249-260.

Walters, J.R., S.J. Daniels, J.H. Carter III, and P.D. Doerr. 2002. Defining quality of red-cockaded woodpecker foraging habitat based on habitat use and fitness. The Journal of Wildlife Management. 66(4): 1064-1082

Williams, T.M. and D.J. Lipscomb. 2002. Natural recovery of red-cockaded woodpecker cavity trees after Hurricane Hugo. Southern Journal of Applied Forestry. 26(4): 197-206.

Williams, T.M., D.J. Lipscomb, and G. Chastain. 2004. Changes in status of cavity trees on the Hobcaw forest between 1989 and 2001. In red-cockaded woodpecker: road to recovery. R. Costa and S. J. Daniels (Eds.). Hancock House Publishers, Blain, Washington. Pp. 439-446.

Wood, D.A. 1977. Status, habitat, home range, and notes on the behavior of the red-cockaded woodpecker in Oklahoma. M.S. Thesis, Oklahoma State University, Stillwater, Oklahoma, USA.

Wood, G.W. 1981. Influence of timber harvesting on the red-cockaded woodpecker. Belle W. Baruch Institute, Clemson University Contract No. 18-409. Supplement No. 21.

Wood, G.W., L.J. Niles, R.M. Hendrick, and T.L. Grimes. 1985. Influence of clearcutting on red-cockaded woodpecker reproduction and nesting tending. Department of Forestry, Clemson University, Clemson, S.C. Forestry. Bulletin. No. 45: P. 11.

Zhang D. and S.R. Mehmood. 2002. Safe Harbor for the red-cockaded woodpecker private forest landowners share theirs views. Journal of Forestry. 100(5): 24-29.