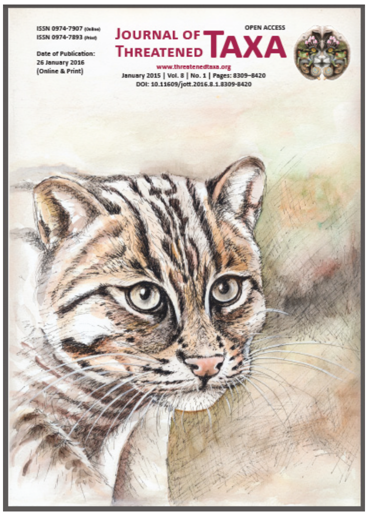

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ARTICLE

HABITAT QUANTITY OF RED-COCKADED WOODPECKER *PICOIDES BOREALIS* (AVES: PICIFORMES: PICIDAE) IN ITS FORMER HISTORIC LANDSCAPE NEAR THE BIG THICKET NATIONAL PRESERVE, TEXAS, USA

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Habitat quantity of Red-cockaded Woodpecker *Picoides borealis* (Aves: Piciformes: Picidae) in its former historic landscape near the Big Thicket National Preserve, Texas, USA

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Abstract: We quantified pine-forested habitat suitable for Red-cockaded Woodpecker *Picoides borealis* in the former historic range of the species to assess the potential for possible re-colonization. We used a remotely-sensed image and geographic information systems (GIS) to create a land-use/land (LU/LC) binary cover map, from which we calculated the habitat suitability index (HSI) based on an estimated home range of 50ha. A sensitivity analysis revealed the necessity for more data to make an accurate estimate, but our analysis of landscape metrics indicates more than 930ha of suitable habitat patches. These patches are heavily fragmented and mostly located on private lands. They can be assessed for understory and herbaceous vegetation and can be restored for possible re-establishment of approximately 18 groups/colonies of Red-cockaded Woodpeckers.

Keywords: Accuracy assessment, Big Thicket National Preserve, global positioning system, habitat fragmentation, habitat suitability, landsat image, metrics, patches.

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Author contribution: VT conducted all field work, performed GIS and remote sensing analysis, and wrote the manuscript. MFA was graduate professor for VT at the University of North Texas. He supervised all work of the study and the paper and performed sensitivity analysis.

Author Details: Vivek Thapa - Currently, he is working as a GIS Manager/CAD Drafter in a land surveying company called All American Surveying, located in North Central Texas, USA. He uses GIS, remote sensing, AutoCAD, to create maps for clients. Miguel F. Acevedo - in addition to his departmental affiliations he is Faculty in the Graduate Program in Environmental Sciences, University of North Texas. His work integrates environmental monitoring and modeling to understand the dynamics of environmental and ecological systems, and to provide socially relevant results concerning pollutants, land use change and climate variability.

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INTRODUCTION

Red-cockaded Woodpecker *Picoides borealis* is Near Threatened (BirdLife International 2013) and nationally an endangered species (USFWS 2014). The bird is endemic to mature pine forests of the southeastern United States, which once extended from Florida to New Jersey and as far west as Texas, reaching inland to Oklahoma, Missouri, Kentucky and Tennessee (Ligon 1970; Jackson 1971; Ferral 1998; USFWS 2005). During the early 19th century the wide spread of agriculture and timber harvesting led to severe habitat degradation and substantially reduced the woodpecker habitat range, which is currently scattered north from Florida to Virginia and west to southeast Oklahoma and southeastern Texas. The species is no longer found in New Jersey, Maryland, Tennessee, Missouri and Kentucky, while in southeastern Texas birds are mostly found in national forests of Angelina, David Crockett, Sabine and Sam Houston, but not in Big Thicket National Preserve (Conner & Rudolph 1995). The drastic reduction of mature pine forests coupled with modern forestry practices such as a reduced timber-rotation period and fire suppression proved detrimental to woodpecker populations, and the species was listed as endangered in 1973 (Hooper et al. 1980; Conner & Rudolph 1989, 1991, 1995; Costa & Walker 1995).

Red-cockaded Woodpeckers are habitat specialists that require large, old and living species of Longleaf *Pinus palustris*, Shortleaf *P. echinata*, Loblolly *P. taeda*, Pond *P. serotina* and Slash *P. elliotii* pine, preferring Longleaf Pine for nesting and foraging (Hooper et al. 1980; Jackson 1994; Hedrick et al. 1998; Conner et al. 2004). The optimal tree age varies with species, i.e., 80–100 years for loblolly and shortleaf pine and 100–120 years for Longleaf Pine with enough heartwood space to support cavity chambers and little or no mid-story hardwood vegetation (Hooper et al. 1980; Conner et al. 1994; Hedrick et al. 1998). Natural or prescribed fires controlled the mid-story overgrowth for decades and the result was open, park-like mature pine woodlands and savannahs with abundant herbaceous ground cover that provided an ideal habitat for these birds. Besides age, the potential cavity tree has high rates of Red-heart Fungal *Phellinus pini* infection that softens the heartwood and facilitates cavity excavation (Conner et al. 1976, 1994, 2004; Conner & Locke 1982; Hooper 1988; Walters 1990).

A colony or cluster is a collection of two to >12 cavity trees in 5–10 acres (approximately 2–4 ha) of land, and the cavity trees are normally located within a one-mile radius from each other (USFWS 2005). A single colony has two to nine birds, with one breeding pair and the rest helpers. A suitable foraging habitat or territory surrounds a colony and covers an area of 30 to 81 contiguous hectares (75–200 acres) of park-like mature pine stands (Hooper et al. 1982; Jackson 1994). Thus only contiguous open stands of mature longleaf and other pine species with herbaceous ground cover offer high quality habitats for Red-cockaded Woodpeckers (Conner & Rudolph 1991).

Few studies exist on the use of geographic information systems (GIS) and remote sensing to study the habitat of Red-cockaded Woodpeckers. Thomlinson (1993) used GIS, remote sensing and landscape ecology to study ecological characters of suitable pine stands in southeastern Texas. Cox et al. (2001) evaluated GIS methods that were used to assess Red-cockaded Woodpecker habitat and cluster characteristics. Ertep & Lee (1994) used GRASS to facilitate Red-cockaded Woodpecker management at Fort Benning Military Reservation. Another recent study by Santos et al. (2010) reports the use of remote sensing based on hyperspectral imagery to study tree senescence in Red-cockaded Woodpecker habitats. They used reflectance properties of the bands to detect senesced pine trees and found Red-cockaded Woodpeckers did not inhabit such trees. We utilized GIS and remote sensing techniques to study the spatial distribution of pine forest in one of the former historical ranges of Red-cockaded Woodpeckers (southeastern Texas) and to assess suitable habitats. We also used habitat suitability index (HSI) models and FRASGSTATS to evaluate or quantify species-habitat relationships. HSI models provide a quantitative measure of the quality of wildlife habitats and can integrate our understanding of wildlife-habitat relationships especially at landscape scales (Larson et al. 2003). In addition, process-oriented and empirical HSI models are commonly used to assess wildlife-habitat relationships (Dettki et al. 2003). Process-oriented models assess plausible causal relationships to provide a general conceptual framework; whereas empirical models analyze data on habitat characteristics collected at specific sites (Thapa et al. 2014).

For this paper we adopted a process-oriented approach to develop a heuristic HSI model for the Red-cockaded Woodpecker. This approach is based on a literature review (U.S. Fish and Wildlife Service's HSI models), field observations (ground-truth) and geographic data obtained from topographic maps (scale 1:24000, USGS). An HSI is based on a set of functional relationships between habitat suitability (expressed as a dimensionless index or score) and habitat requirements (variables). These variables are selected according to their relevance to the organism; for example herbaceous canopy cover, tree canopy cover, tree height, tree age and proximity to water. There is a partial suitability for each variable, which scales from 0 (unsuitable habitat) to 1 (optimum habitat). The overall HSI, which also scales from 0 to 1, is calculated with a formula that represents hypothetical relationships between partial suitability indices. GIS provides a tool to synthesize habitat data derived from remotely sensed sources together with databases of elevation, soil types, land use, and land cover. Thus GIS can be coupled with remote sensing to calculate HSI over relatively large geographic areas, and incorporate landscape variables at multiple spatial scales. We also demonstrate the use of GIS and remote sensing to collect or prepare data for habitat fragmentation study by using software called FRAGSTATS, which is a computational program designed to calculate a wide array of landscape metrics from categorical maps (McGarigal & Marks 1994, 1995; McGarigal 2002). Some of the metrics are commonly used to measure and quantify spatial patchiness in terms of composition (patch types and abundance) and configuration (shape and juxtaposition). These metrics represent the percentage of fragmented habitats, area of largest patch, and—most importantly—the area of remaining potentially suitable habitat (Girvetz et al. 2007).

In this paper, we used aforementioned habitat characteristics and applied remote sensing, GIS and FRAGSTATS techniques to examine abundance, distribution and fragmentation of available pine forest and provide a possible scenario for re-colonization by Red-cockaded Woodpeckers. We have four scientific objectives: (1) to use a Landsat Enhanced Thematic Mapper Plus (ETM+) image to develop a land-use/land-cover map (Laperriere et al. 1980); (2) to develop an heuristic GIS-based HSI model and a map for the woodpecker; (3) to determine the spatial distribution of current potentially suitable habitats; and, (4) to illustrate a general methodology for conservation cartography and spatial analysis that can be adapted to other interior-forest-dwelling avifauna of conservation interest. In addition, we have two policy-oriented objectives: (1) to provide a map of potentially suitable Red-cockaded Woodpecker habitat that may be preserved for (a) existing populations in the region or (b) that may serve as sites for establishing new populations in the region; and (2) to indicate the most important habitat characteristics, such as shape, size, and habitat composition for purposes of proactive Red-cockaded Woodpecker habitat management in the region.

METHODS

Study Area

The study area is located near the Gulf coastal plains of southeastern Texas between the Trinity River to the west and the Neches River to the east, around the small towns of Kountze, Silsbee, Lumberton and suburbs north of Beaumont that adjoins the 39,338ha Big Thicket National Preserve (BTNP) (30–31 ^{0}N to 94–95 ^{0}W) (Fig. 1). Over the last five decades the landscape surrounding the BTNP has been converted from continuous pine forest to a matrix dominated by agriculture, pasture, timber plantations and exurban and suburban development (Wilcove et al. 1986). As a result the pine forests were converted into small patches isolated by a matrix of agricultural or other developed lands (Callicott et al. 2007). The study area was further subjected to intense oil and gas exploration that continues today. While such activities seem to have minimal effects on breeding, proximity to roads and vehicular movement does affect foraging activities of Red-cockaded Woodpeckers (Charles & Howard 1996). Annual precipitation averages 1350mm (Marks & Harcombe 1981; Callicott et al. 2007) and is uniformly distributed throughout the year, but because of its proximity to the Gulf of Mexico the Big Thicket study area experiences a high frequency of devastating tropical storms and hurricanes. Since 1900, 40 tropical storms and hurricanes have struck the Gulf coast, with Rita in 2005 and Ike in 2008 being the most recent big storms to hit Texas (NOAA 2008). However, these hurricanes did not cause damage in the study area as they did in the surrounding counties and areas especially near Galveston Bay, Harris and Angelina (NOAA 2005; Bainbridge et al. 2011). Nevertheless, hurricanes and other extreme natural disturbances such as severe winter can damage large portions of cavity and foraging trees, thereby affecting breeding populations of Red-cockaded Woodpeckers, which in turn leads to loss of genetic diversity (Reed et al. 1988, Bainbridge et al. 2011).

The vegetation types of the study area can be characterized by both community physiognomy and physiographic position. Forests, savannas, and shrub thickets are normally combined with important trees such as pine, oak, and other hardwoods to characterize community physiognomy while upland, slope, floodplain and flatland indicates the physiographic position of the

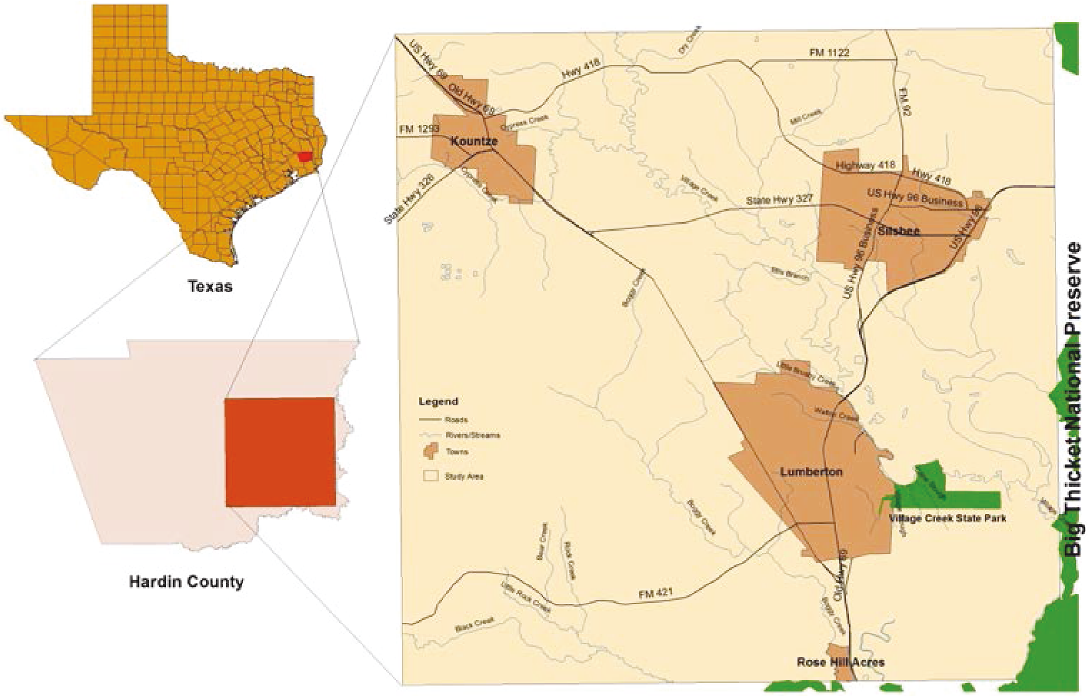

Figure 1. Study site - Portion of former historic habitat range of Red-cockaded woodpecker.

vegetation (Marks & Harcombe 1981). Thus, according to community physiognomy and physiographic position, four broad types of vegetation characterize the Big Thicket region. The upland forest community consists of dominant longleaf pine forest or mixed with a small-tree layer of Bluejack Oak *Quercus incana*. The slope community includes dominant species of shortleaf and loblolly pines with overstory hardwoods of Southern Red Oak *Quercus flacata*, White Oak *Q. alba*, Magnolia *Magnolia grandiflora*, and American Beech *Fagus grandifolia*. The floodplain vegetation consists of hardwood forests of European Hornbeams *Caprinus* sp., Sweetgum *Liquidambar styraciflua* and Water Oak *Q. nigra* mixed with Bald Cypress *Taxodium distichum* and Water Tupelo *Nyssa aquatica* and very few loblolly pines. And the flatlands include dominant species of Basket Oak *Q. michauxii*, Willow Oak *Q. phellos*, Laurel Oak *Q. lauriflora*, *P. taeda* and Red Ash *Fraxinus pensylvanica.*

Data Acquisition and Image Processing

We selected a cloud-free Landsat ETM+ scene of March 2003 for analysis because the spring season was considered optimal for achieving the highest reflectance for floodplain hardwood forests and pine trees (Thomlinson 1993). The image was geographically referenced using ground control points (GCPs) created in ERDAS IMAGINE (a suite of software tools by Leica Geosystems Geospatial Imaging). The GCPs should be uniformly distributed over the image with good coverage near the edges. At least, 16 GCPs are considered reasonable if each GCP can be located with an accuracy of one-third of a pixel size (Bernstein 1983). This number may not be sufficient, however, if the GCPs are poorly distributed or if the nature of the landscape prevents accurate placement (Campbell 1996). Following these guidelines, we extracted 19 GCPs from topographic maps to georectify the image. In addition, the coordinate system was modified into the Universal Transverse Mercator coordinate system (zone 15) and newly revised datum of the 1984 world geodetic system to correlate with the image. Landsat TM data were acquired from six spectral bands: TM1 (0.45–0.52 µm), TM 2 (0.52–0.60 µm), TM3 (0.63–0.69 µm), TM4 (0.76–0.90 µm), TM5 (1.55–1.75 µm) and TM7 (2.08–2.35 µm) (Luiz & Garcia 1997). Other data include topographic maps at a scale of 1:24,000; GIS files of roads and streets; polygons of towns; and aerial reconnaissance of 41 sections of the study area. More detailed data on vegetation were obtained by ground-truth (GPS points) visits to 287 sites. Individual global positioning system (GPS) points were accompanied with notes of soil texture, soil moisture regime, land use, plant composition, and elevation data. Digital cameras were used to take photographs of each site visited. ArcMap, a suite of GIS tools by Environmental Research Systems Inc. (ESRI), was used for GIS processing. A file with GPS points was imported to ArcMap as a shape file.

Field Data Collection and Vegetation Classification

We collected a total of 287 vegetation GPS points in May–June of 2007. We used a cloud-free Landsat image of 2003 to perform supervised classification procedures to derive final land use and land cover (LU/LC) categories. Supervised methods require the user to define the spectral characteristics of known areas of land-use types and develop training sites (Thapa et al. 2014). The training sites or signature is employed to verify and define distinct classes (Jenson 1996). This is achieved either by user's prior knowledge of the geographic features of an area of interest such as identification of distinct, homogenous regions that represent each class (e.g., water or grass) or by ground-truth data such as GPS points, which refers to the acquisition of knowledge about the study area from field work, analysis of aerial photography, and from personal experience (Conner et al. 1975). Ground-truth data are considered to be the most accurate (true) data available about the area of study. They should be collected at the same time as the remotely sensed data, so the data corresponds as much as possible (Stars & Estes 1990). Furthermore, elements of visual interpretations such as color, shape, texture and pattern on aerial photos are commonly used that provides valuable clue during supervised classification. For example, we employed a texture and pattern analysis technique on aerial photos and selected pixels in such areas. With texture and pattern it is easy to differentiate naturally growing trees and human managed plantations, e.g., coconut and pine plantations. We derived seven LU/LC categories (water, urban areas, pine forest, pine plantation, mixed forest, grass, and cypress forest on floodplain) from the Landsat image (Fig. 2). We classified entire pixels into their designated classes according to the vegetation categories found in the study area. For example areas with tall pine trees were classified as 'pine trees', areas with mixed pine and oak trees were labeled as 'mixed forest', areas of floodplain were labeled as 'cypress trees on sloughs' and so on. GPS locations of each category accompanied with aerial and field photos were extensively used during classification process.

Accuracy Assessment

It is necessary to assess the accuracy of any thematic classification to evaluate its intended application, and high accuracy assures consistency and reliability of derived landscape metrics (Xulong et al. 2005; Shao & Wu 2008). Several factors related to the sensors as well as to the classification process contribute to classification errors (Lunetta et al. 1991). It is also critical to measure the quality and accuracy of data used for classification (Congalton & Green 1999). The classification or errors are analyzed by a confusion or error matrix, which is also called accuracy assessment (Congalton & Green 1999). An error matrix or accuracy assessment cell array is a table with entries representing the number of sample units; i.e., pixels, clusters of pixels, or polygons assigned to a specified class relative to the actual class found on the ground (Congalton 1991). Rows contain a list of class values for the pixels in the classified image file and columns represent class values for the corresponding reference pixels, determined by input from the user collected from sources such as aerial photographs, GPS points, previously tested maps or other data. The reference class values are compared with the classified image class values to assess the accuracy of an image classification. According to Anderson et al. (1976), classification accuracy close to 85% is acceptable for a LU/LC study.

Several statistical measures of a classified LU/LC map can be derived from an error matrix, including overall classification accuracy (sum of the diagonal elements divided by the total number of sample points), categorical omission and commission errors, and the KHAT coefficient (an index that measures the agreement between reference and classified data i.e., KHAT=1 when the agreement between reference and classified data reach 100%). A minimum of 204 reference points are required to achieve 85% accuracy with an allowable error of 5% (Jensen 1996). First we generated about 300 random (reference) points, and with help of aerial photos and with prior knowledge of geographic features we assigned values for each random point. Then we compared these reference class values with the classified image class values, which gave us an overall accuracy of 77.33% with KHAT = 0.7277. Then we used GPS locations as reference points and compared them with the class values of image files, which produced an overall accuracy of 81.48% with KHAT = 0.7449 (Table 1). The latter accuracy was deemed acceptable for this study because it was within the 5% allowable margin of error and was closer to 85%.

Habitat Suitability Index Models

We computed the HSI value for each pixel of the resultant classified image according to the following procedure. We selected the pine trees class because this habitat is required for successful breeding and foraging. We assigned a value of 1 to this class and set all others to 0, producing a binary map showing pine trees only. We ran neighborhood analysis in ArcGIS, which is a statistic

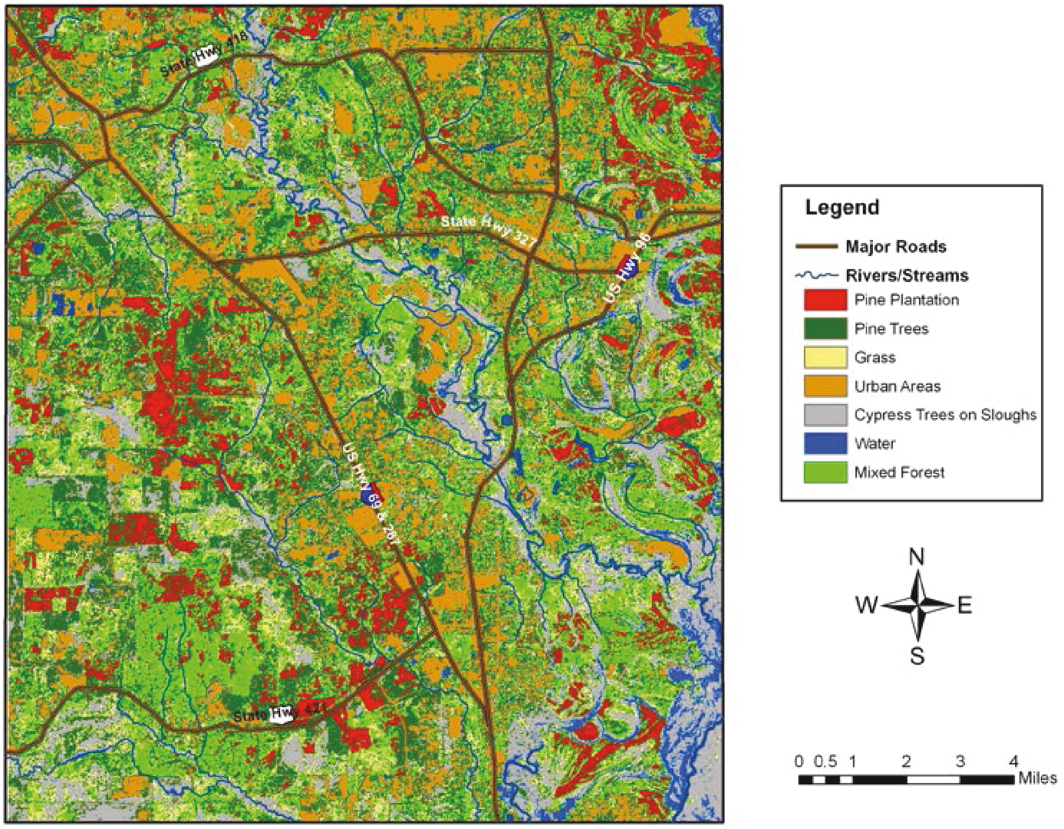

Figure 2. Seven land-use categories derived from supervised classification.

that uses surrounding pixels in a defined neighborhood to assign a value to a target pixel. It is commonly used to find the most dominant land-cover category in a neighborhood or to find the number of certain LU/LC categories within a specified neighborhood. We selected neighborhood size based on the annual home range size of the Red-cockaded Woodpeckers as reported by several studies and determined using a variety of methodologies including 100%, 95%, 50% minimum convex polygons and 95% fixed kernel estimator (DeLotelle et al. 1987; Engstrom & Sanders 1997; Doster & James 1998; Walters et al. 2002; Douglas et al. 2008). According to Franzreb (2006), the minimum convex polygon estimator includes outliers or areas that are not used by the animals (birds in this case), and provides an overestimate of the home-range size making it less suitable as a descriptive statistic in terms of the biology of the species. On the other hand, the fixed kernel estimator is relatively insensitive to the presence of outliers and is less biased and produces more consistent results. Thus we selected the home-range size that was produced by fixed kernel estimator, i.e., ~50ha. To implement this, we selected a neighborhood size of 23´23 pixels, i.e., 529 pixels of 900m^2 each (3030 m), which yields a slightly lower value of 476,100m^2 or 47.61ha or 117.6 acres. A suitability index *S* for a pixel was determined as the proportion of pixels in pine tree cover in the neighborhood around the target pixel. Once all pixels are evaluated, we have an HSI map (Fig. 3).

Habitat Fragmentation and FRAGSTATS

FRAGSTATS accepts Arc/Info (a GIS ESRI tool) polygon files (vector) or “raster” (a matrix or grid of pixels) images in a variety of formats (McGarigal & Marks 1994). For our study we adopted the raster version of FRAGSTATS and used the HSI map as input data. Prior to this, the HSI map was reclassified into three discrete classes using an equal interval method, one of the several classification methods available in ArcMap. We selected this method because it groups the pixels according to their values and allowed us to maximize the difference amongst classes. A pixel was assigned a value of 1, 2, or 3, according to its index value. The index value for 1 was 0.000 to 0.333, 0.333 to 0.666 for 2 and 0.666 to 1 for 3. These three classes represent very unsuitable (1), unsuitable (2), and (3) potentially suitable habitat (Fig. 3). A suite of metrics was selected and computed at patch, class and landscape levels (Table 2). The resultant metrics reflected various

Table 1. Combination of GPS and random points to assess classification accuracy

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy, %	User's Accuracy, %
1. Grass	5	4	3	60.00	75.00
2. Pine plantation	13	11	10	76.92	90.91
3. Pine trees	53	59	44	83.02	74.58
4. Urban area	59	58	52	88.14	89.66
5. Cypress trees on sloughs	12	13	10	83.33	76.92
6. Water	1	1	1	100.00	100
7. Mixed forest	19	17	13	68.42	76.47
Totals	**162**	**163**	**133**		
Overall Kappa Statistics					**0.7449**
Overall Accuracy, %					**81.48**

configurations and compositions of a landscape (Doster et al. 1998; Thapa et al. 2014).

RESULTS

Image Processing

From a total of 287 GPS points, we used 162 points for classification accuracy. The rest (125) were used to classify the image. Use of GPS points and visual interpretation of aerial photos proved effective in Landsat ETM+ classification and facilitated the process. Our results show pine trees and grass have the lowest classification accuracy with 74.58% and 75% respectively. For pine trees this might be due to insufficient GPS points, because we could not gather data from private land containing pure stands of old pine trees. For grass it is possible to include agricultural lands, a common problem with landsat images having 30m resolution. In addition, short-grass areas (grazed pastures or manicured lawns) and dirt roads had overlapping values with other urban areas such as patches of bare soil and asphalt roads. We classified pine plantations with 90.91% accuracy because they were easily identified based on texture and pattern on aerial photos and GPS data collected from within plantation areas. Similarly, we classified urban areas with 89.66% accuracy as they are also easily identifiable on aerial photos and GPS data. Water pixels were classified with 100% accuracy. And it is one of the geographic features that a user can accurately classify in remote sensing applications as water pixels exhibits the lowest reflectance property when examined in a spectral profile. Profile Tools of ERDAS allow the users to examine spectral behavior of pixels of different features. Cypress trees on sloughs class was classified with 76.92% accuracy. Cypress trees occur mostly in sloughs of floodplains mixed with oak species and several factors such as topographic shadows and deep water contributed to the low accuracy of this class. Similar to water, wet sandy banks of creeks, streams, rivers, and sloughs have a lower reflectance in most bands and they became a source of confusion. Statistical analysis of spectral responses or profile from training samples, as well as ellipse and dendrogram plots, showed a similar reflectance with dark pixels (wet soils, black soil, and topographic shadows). Furthermore, vegetated (forest, urban, grass) and non-vegetated (water) were spectrally distinct. In order to redefine, refine and improve accuracy, we constantly reduced, merged and masked the confused classes.

Table 2. Two selected FRAGSTATS metrics

Area/Density/Edge Metrics	Connectivity Metrics
CA/TA = Total Class Area (ha) PLAND = Percentage of Landscape (%) NP = Number of patches LPI = Largest Patch Index (%)	COHESION = Patch Cohesion Index

Metrics at Patch, Class, and Landscape Levels

We calculated two metrics i.e. area/density/edge and connectivity of three different patch types (class) or habitat types: very unsuitable, unsuitable and potentially suitable (Table 2). These metrics were used to examine composition and configuration of patches in the study area (McGarigal et al. 2002). FRAGSTATS provides individual patch properties at three levels: patch, class and landscape, but we quantified patch properties at class level only because most metrics are redundant and provide similar values at patch and landscape levels. For example, total core area (TCA) at

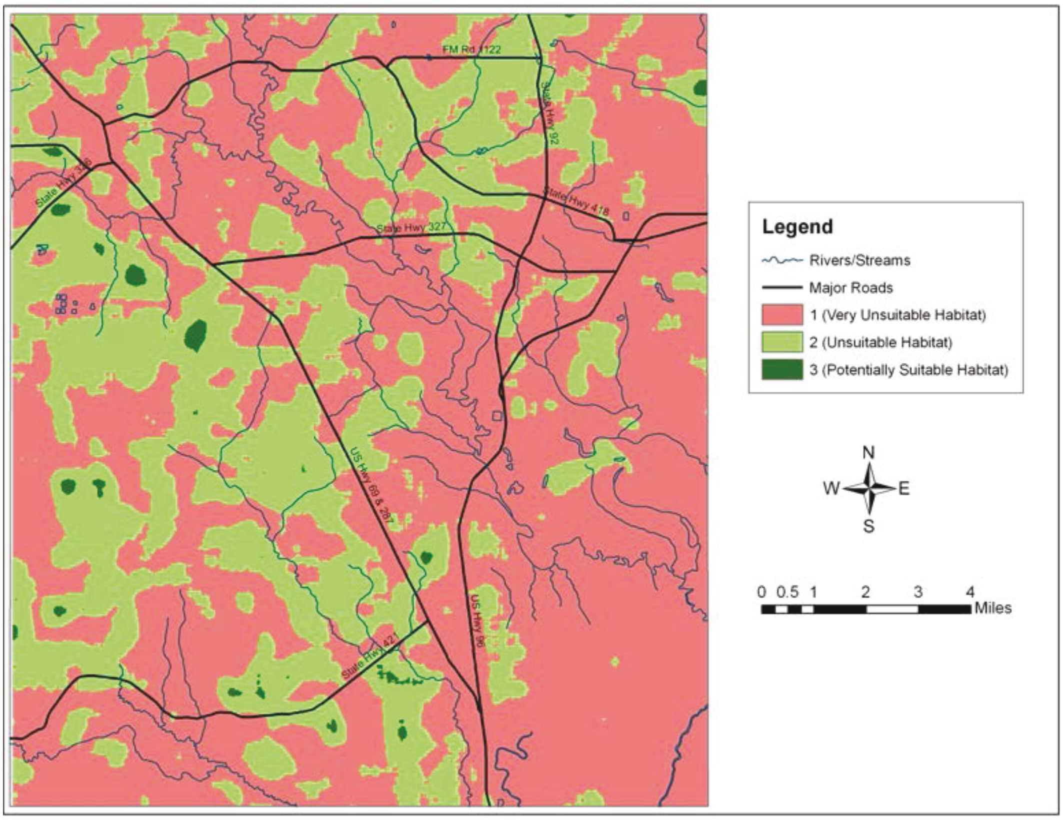

Figure 3. Habitat suitability index(HSI) map with three habitat types - very unsuitable, unsuitable, and potentially suitable.

class and landscape levels is defined the same as core area at patch level except the core area is aggregated over all patches of the corresponding patch type at the class and landscape levels. Since the selection of class breaks 0.333 and 0.666 was arbitrary, we performed sensitivity analysis by perturbing these nominal break values by 10% to examine the effect on the resultant habitat suitability indices (Table 3). We then used the manual classification method in ArcMap to create maps for visual inspection (Figs. 4–6). We used a total of nine break selections including the nominal values (Table 4). The perturbations above and below the nominal values effected the value of HSI as shown in Table 5.

Total (Class) Area (CA/TA) and Percentage of landscape (PLAND) metrics measure landscape composition (Table 5). CA measures how much of the landscape is occupied by a particular patch type. CA approaches 0 when a landscape consists of a single patch type, i.e. the landscape is not fragmented and CA > 1 indicates fragmentation of the landscape. For potentially suitable habitat patch, the value of CA/TA falls in three distinct classes, i.e., 0.599–1, 0.666–1 and 0.733–1 for nine break selections and the amount of land occupied decreases with decreasing range of pixel values. For example, in the total study area of 52,371.90ha, potentially suitable habitat reach 2,177.10ha when the break is 0.599 (Fig. 4), decreases to 933.48ha when the break is 0.666 (Fig. 5), and further decreases to 344.61ha when the break is 0.733 (Fig. 6) (Table 5). PLAND quantifies the proportional abundance of patch type in a landscape, i.e., similar to CA, PLAND approaches 0 when a landscape consists of single patch type. In other words, PLAND metrics largely mirror the patterns of CA. The PLAND metric revealed that potentially suitable habitat occupies 4.16% when the break is 0.599, decreases to 1.78% when the break is 0.666, and further decreases to 0.66% when the break is 0.733. Thus the amount of potentially suitable habitat area decreases with increasing break values and vice versa. Number of patches (NP) is a simple measure of the extent of subdivision or fragmentation of a patch type. NP = 1 when the landscape contains only a single patch type and NP > 1 indicates degree of fragmentation. NP for potentially suitable habitat varies from 28 to 67 and 72 as the break value changes from 0.599, 0.666 and 0.733, indicating that this habitat type is more fragmented than the unsuitable and very unsuitable types (Table 5). Largest Patch Index (LPI) is a simple measure of dominance as it quantifies the percentage

Table 3. Perturbation above and below the nominal break values

Breaks	-10%	Nominal	+10%
Unsuitable Breaks (UB)	0.3	0.333	0.366
Suitable Breaks (SB)	0.599	0.666	0.733

Table 4. Nine break selections

Breaks Selection	Habitat Type		
	1	2	3
1	0-0.3	0.3-0.599	0.599-1
2	0-0.333	0.333-0.599	0.599-1
3	0-0.366	0.366-0.599	0.599-1
4	0-0.3	0.3-0.666	0.666-1
5	0-0.333	0.333-0.666	0.666-1
6	0-0.366	0.366-0.666	0.666-1
7	0-0.3	0.3-0.733	0.733-1
8	0-0.333	0.333-0.733	0.733-1
9	0-0.366	0.366-0.733	0.733-1

of total landscape occupied by the largest patch. LPI = 0 when the largest patch of the corresponding patch type is small and 100 when the largest patch occupies the entire landscape. The largest patch of potentially suitable habitat occupies only 0.1–0.42 % of the landscape as compared to 30–60 % and 18–40 % for very unsuitable and unsuitable habitat types respectively. This corroborates the results of CA/TA and PLAND that showed presence of small amount of potentially habitat types as compared to the other two.

Connectivity is considered a vital element of landscape structure, and we used a single connectivity metric, COHESION, to observe physical connection between patches. COHESION = 0 when patches are less connected and approaches 100 when they are more connected. Our analysis showed the potential suitable habitat patch type is physically disconnected as indicated by 93–96 as compared to the other two habitat types with sometimes approaching almost 100 showing they are more connected and contiguous.

DISCUSSION

Image Processing

Overall, the LU/LC map derived from satellite imagery was satisfactory because categories were adequately mapped and resulted only in minor misclassifications. The resultant map was refined with spatial masking and recoding to achieve acceptable accuracy. Use of aerial photographs and GPS points proved effective in improving classification accuracy. The contrasting reflectance of bare areas and vegetation in the visible and infrared bands facilitated accurate identification. However, accurate delineation of grass from crops and shrubs represented a challenge (as in many remote sensing studies). Visual examination of the satellite imagery of the study area and field work revealed numerous dirt roads crisscrossing the entire landscape. Our study area once contained booming oil towns and clearly shows signs of human-induced fragmentation. Several pipelines, power lines and railroads cut through the study area, dissecting the landscape into smaller fragments.

GPS locations of different categories or classes proved to be the most critical data during LU/LC classification of the landsat image in facilitating and enhancing

Table 5. Class metric results

Breaks Selection	CA/TA (ha)			PLAND (%)			NP			LPI			COHESION		
	Habitat Type			Habitat Type			Habitat Type			Habitat Type			Habitat Type		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	23275.08	26919.72	2177.1	44.44	51.40	4.16	261	201	72	29.39	32.26	0.42	99.69	99.82	96.43
2	28629.81	21562.99	2177.1	54.67	41.18	4.16	192	232	72	38.27	22.65	0.42	99.79	99.7	96.43
3	33379.29	16815.51	2177.1	63.73	32.11	4.16	158	247	72	57.24	16.05	0.42	99.91	99.56	96.43
4	23275.08	28163.34	933.48	44.44	53.77	1.78	261	197	67	29.39	34.49	0.17	99.69	99.82	94.18
5	28629.81	22808.61	933.48	54.67	43.55	1.78	192	229	67	38.27	24.78	0.17	99.79	99.70	94.18
6	33379.29	18059.13	933.48	63.73	34.48	1.78	158	243	67	57.24	17.94	0.17	99.91	99.57	94.18
7	23275.08	28752.21	344.61	44.44	54.90	0.66	261	196	28	29.39	35.55	0.1	99.69	99.82	93.07
8	28629.81	23397.48	344.61	54.67	44.67	0.66	192	228	28	38.27	25.76	0.1	99.79	99.70	93.07
9	33379.29	18648	344.61	63.73	35.61	0.66	158	242	28	57.24	18.74	0.1	99.91	99.56	93.07

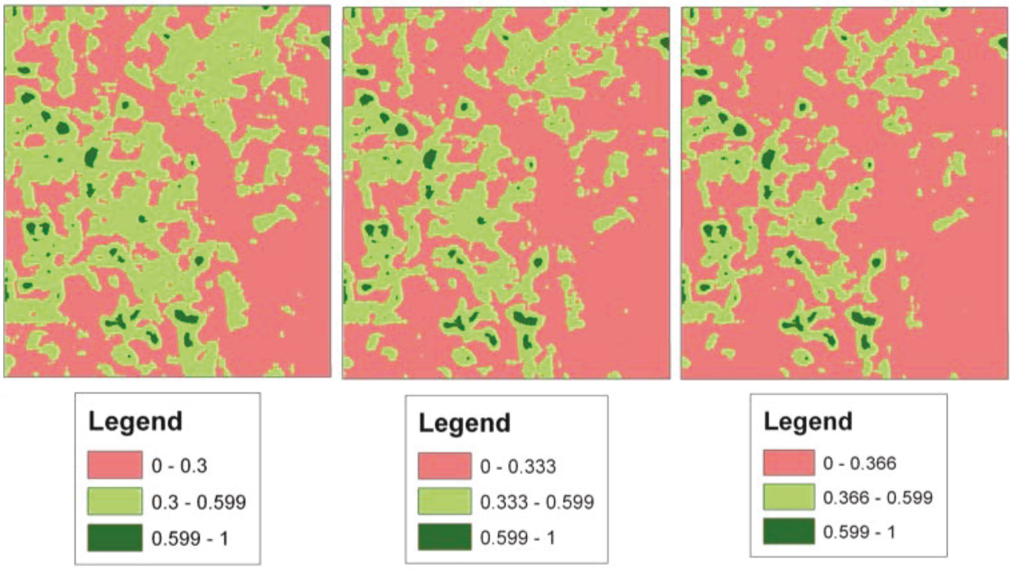

Figure 4. 10% perturbation below nominal value.

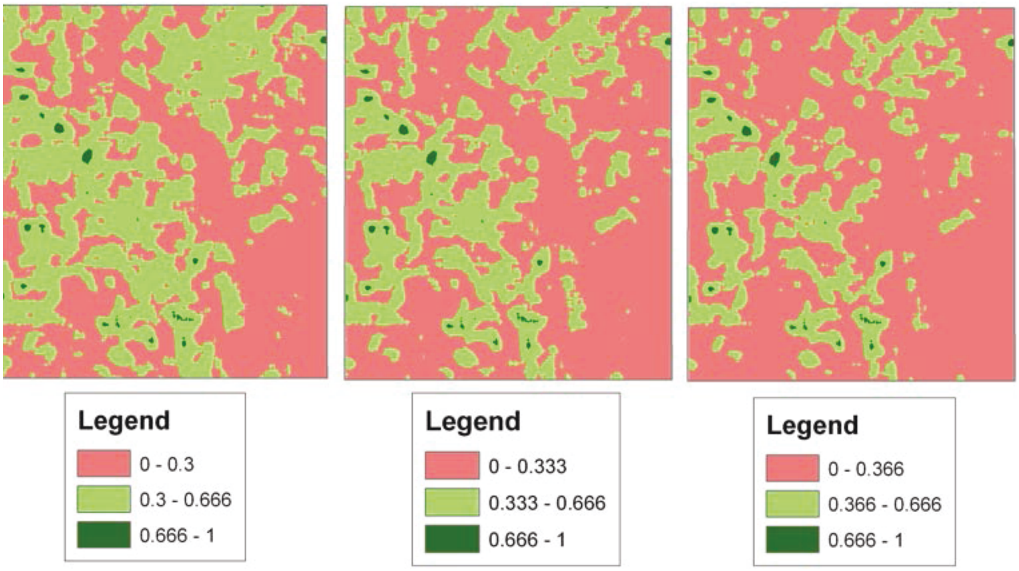

Figure 5. No perturbation.

classification accuracy. Composition metrics such as CA/TA, NP and PLAND revealed heterogeneous structure of the landscape especially the number of patches. NP ranged from 400–550 patches depending on the break selections. For example, NP for first break value is 534 with 261 patches belonging to very unsuitable, 201 for unsuitable and 72 for potentially suitable habitats. The NP for potentially suitable habitat patches decreases with decreasing pixel values from 0.733 to 1 for which NP is only 28 (Table 5). Similarly, CA/TA and PLAND indicated low amount of land occupied by potentially suitable habitat patches (PLAND = 0.66–4.16 %) as compared to 40–60 % of land occupied by the other two habitat types respectively. On the other hand, configuration metrics such as LPI and COHESION produced expected results. LPI for potentially suitable habitat ranged from 0.1–0.42 % for the nine break values indicating even the largest patch occupies only 2,177.10ha of the total 52,371.90ha landscape (for first break value) (Fig. 4).

The composition metrics showed that about 18–60 % of the study area is composed of unsuitable habitats for the birds that included floodplain areas near major rivers and streams, pine plantations, areas around small towns and mixed forests. The metrics further indicated

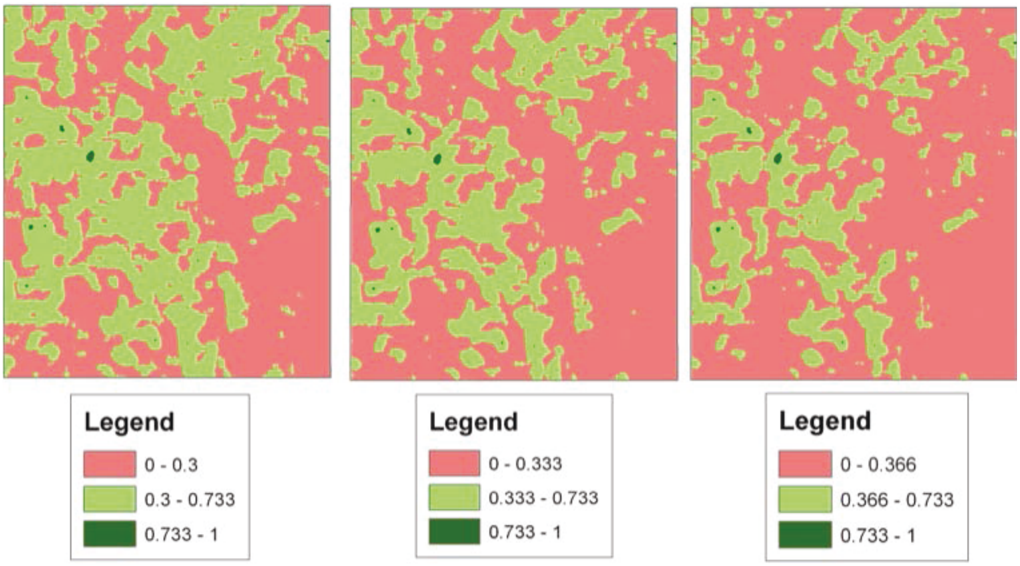

Figure 6. 10% perturbation above nominal value.

only about 0.66–4.16 % of the study area is composed of potentially suitable habitat and included areas located away from urban areas and major roads. NP and COHESION exhibited severe fragmentation of potentially suitable patches in the west, central and northeast portion of study area (Fig. 7). This suggests that the isolation and size of smaller fragments might be the cause of decline of clans from those patches, because a territorial species with restrictive habitat requirements and limited gap-crossing ability will likely be sensitive to isolation effects (Conner & Rudolph 1991; Dale et al. 1994; With & Christ 1995; Pearson et al. 1996).

The connectivity metrics (COHESION) provided vital information about the structure of landscape, i.e., the patches of potentially suitable habitat patches are more physically disconnected than the other two unsuitable habitat patches. Thus we were able to show composition, configuration and connectedness of the three habitat patches that formed a heterogeneous habitat across the study area.

CONCLUSION

We presented a method of quantifying composition and configuration of possible habitats for the Red-cockaded Woodpecker using GIS, remote sensing and FRAGSTATS. We did not include other variables which may impact habitat quality and HSI such as tree age, tree diameter and tree species because these are difficult to assess from a Landsat image and measure within private lands. Hyperspectral images can provide these variables as reported in a recent study by Santos et al. (2010). Data collected from inside the private properties would aid in validation and increase of HSI. Thus our methods could be coupled with variables obtained from hyperspectral images for better understanding of the current potential suitable habitat available in the study region. Using sensitivity analysis we were able to show that only few areas contain adequate amount of pine trees that could sustain a group of woodpeckers. However, to assess the full quality of the habitat we would require inclusion of other variables as noted above and as indicated by results from sensitivity analysis.

The results revealed a highly fragmented nature of available habitats in public and private rural lands especially near the towns of Kountze, Silsbee, and Lumberton. Most of the potentially suitable habitats were found well away from the towns, especially on the west side of the study area near Highways 326 and 421, and private lands in between them (Fig. 7). FRAGSTAT analysis revealed 344ha to 2,177ha of available potentially suitable habitat; visual inspection of the habitat suitability map shows that these habitats are highly fragmented near the towns and on private rural lands.

We assume that Red-cockaded Woodpeckers are absent near towns due to small fragments of possible habitats and lack of foraging habitat, traffic activity and patch isolation. Of 28–72 suitable habitat patches, some could be more than 50 ha and are located on public and private rural lands (Fig. 7). These areas could hold some

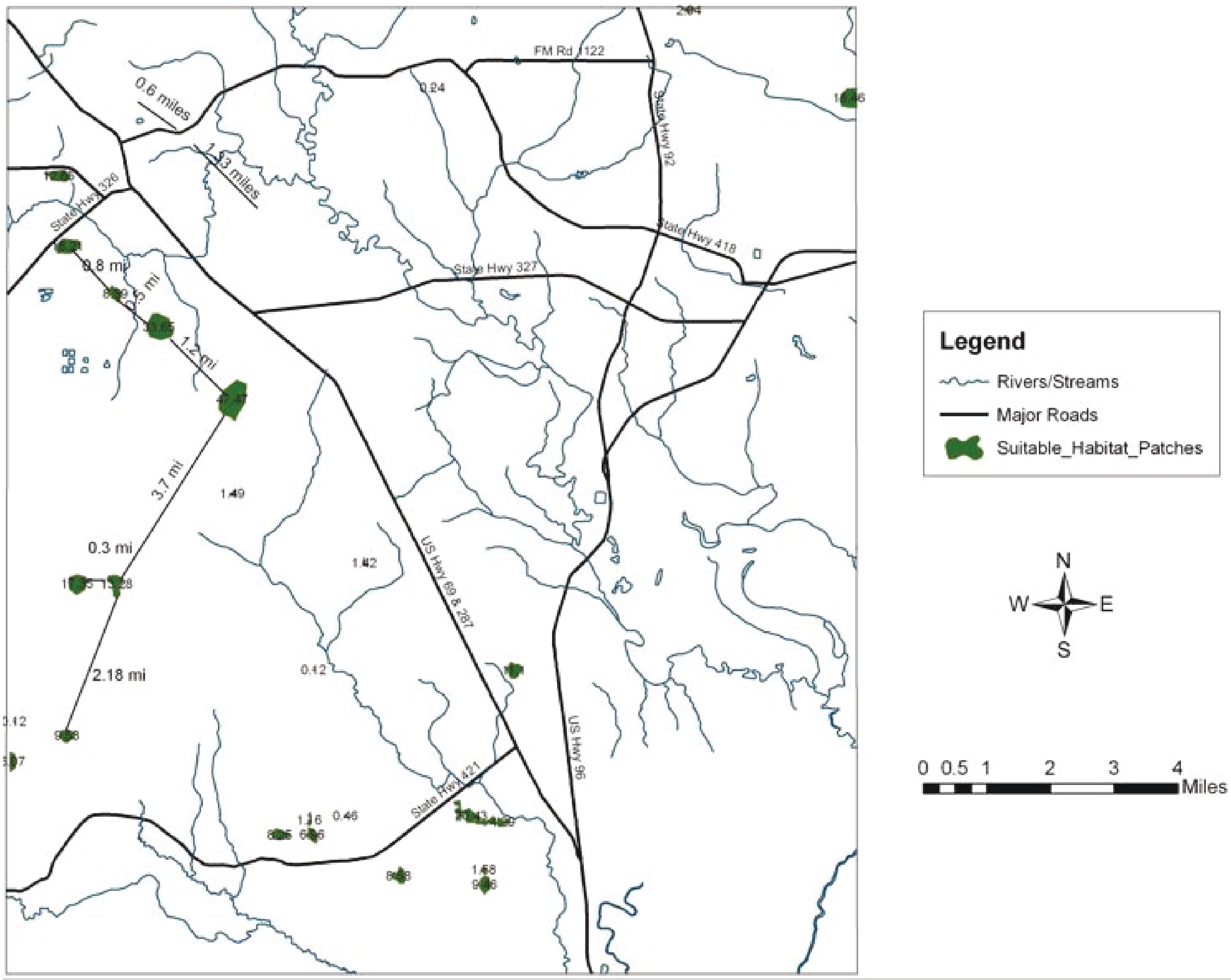

Figure 7. Distances amongst and acreages of potentially suitable habitat patches in hectares.

clans of Red-cockaded Woodpeckers because of the presence of massive pockets of pure pine stands. Previous studies determined that areas larger than 50ha are able to sustain a group of Red-cockaded Woodpeckers given that they contain old, red heart fungus infected cavity trees with little or no mid-story. Landowners who have a Red-cockaded Woodpecker group or groups can do much to enhance survival regardless of the size of their property by controlling mid-stories and building artificial cavities. USFWS assists landowners to manage habitat and even provides incentives and grants to promote Red-cockaded Woodpecker conservation.

This study is confined to determining the quantity of potentially suitable Red-cockaded Woodpecker habitat in the current landscape near and around the Big Thicket National Preserve. We conclude that there are very few large patches (the largest one is 47.47ha) that can sustain a clan or populations of Red-cockaded Woodpeckers under ideal habitat conditions. Most of the patches are located within a distance of one mile and they may be targeted for restoration and expansion efforts. Other factors such as encroaching mid-story and suppressed fire should also be assessed. To further assess the quality of these patches a thorough study of mid-story vegetation, pine tree age, diameter and species is strongly recommended in the potential suitable habitat patches. In addition, our study reveals that a woodpecker census in the region might be fruitful and that with proper management practices to preserve red-cockaded-woodpecker habitat both in private and federal lands, existing populations (if any) might be conserved and new populations might be established there.

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