A HABITAT SUITABILITY MODEL FOR THE GOPHER TORTOISE:

A GEOGRAPHIC INFORMATION SYSTEMS APPROACH

by

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(Under the Direction of Kathy C. Parker)

ABSTRACT

A geographic information system was used to design a habitat suitability model for the Gopher tortoise in Georgia. The Landcover Map of Georgia and SSURGO soil data are used to locate areas that possess the correct combination of landcover and soil type. The STATSGO data are examined to determine the feasibility of using these data in areas that do not currently have SSURGO data available; the data were found unsuitable as predictors of tortoise habitat. Measurements of percent canopy coverage are examined to assess the accuracy of the model without inclusion of this variable. Thirty percent of habitat deemed suitable by the model in a test area was found to have inappropriate canopy coverage. The model predicted 83 % of suitable habitat correctly when an accuracy assessment was performed using Georgia Natural Heritage Data. The results of this model are compared to those produced by the Georgia GAP Analysis Project.

INDEX WORDS: Habitat suitability model, Gopher tortoise, Geographic information system, Percent canopy cover, Conservation.

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INTRODUCTION

One of only four North American tortoise species, the gopher tortoise (*Gopherus polyphemus)* is federally or state listed as threatened or endangered throughout the entirety of its range, extending from southeastern South Carolina through southern Georgia and most of Florida, westward through southern Alabama and Mississippi, and into the lower southeastern portion of Louisiana (Auffenberg and Franz, 1982; Bury, 1982; Reese, 1987; Wahlquist, 1991). The gopher tortoise is considered a keystone species within its habitat; its burrows provide refuge for more than 330 vertebrate and invertebrate species (Landers and Speake, 1980; Woodruff, 1982; Franz, 1986; Jackson and Milstrey, 1989; Lago, 1991). Burrow commensals include the threatened Eastern indigo snake, pine snake, eastern diamondback rattlesnake, red and gray rat snakes, coachwhip racer, dung beetle, and the gopher frog, which lives nowhere else (Diemer and Speake, 1981; Wahlquist, 1991). In addition, abandoned burrows serve as refugia for many other species, including the raccoon, opossum, fox squirrel, bobcat, bobwhite quail, and armadillo (Landers and Speake, 1980; Campbell and Christman, 1982; Eisenberg, 1983).

The gopher tortoise is a habitat specialist of the longleaf pine (*Pinus palustrus*) ecosystem, (Guyer and Bailey, 1993; Figure 1) once the principal vegetation type in the southeastern Coastal Plain (Frost, 1993), but now considered an endangered ecosystem (Noss et al., 1995). The tortoise assists in the maintenance of the fire sub-climax community by spreading the seeds of wiregrass (*Aristida stricta*), an important, although declining component of the community (Auffenberg, 1978; Noss, 1989). Furthermore, burrows create minidisturbances that maintain canopy openness and enhance plant species richness (Kaczor and Harnett, 1990; Hermann, 1993).

Figure 1. Longleaf pine ecosystem.

Gopher tortoise populations are declining at an alarming rate. The pressures of development, habitat degradation (fire exclusion) and habitat destruction, (kaolin mining, agricultural conversion, managed forest stands) are responsible for the loss of approximately 80% of the population throughout the previous 100 years (Auffenberg and Franz, 1982). In 1982, 80% of the tortoise population was located within northern Florida and southern Georgia; the remaining 20% was scattered throughout the rest of the range and existed as disjunct populations. In Florida alone, the state with the largest population of gopher tortoises, Auffenberg and Franz (1982) predicted that gopher tortoise populations will be eliminated from all unprotected lands by the year 2025 if precautions are not established. Because the fate of Georgia's gopher tortoises resides primarily in the hands of private landowners (Hermann et al., 2002; Kramer et al., 2003), it is vital to implement an aggressive campaign to educate landowners about options available to them, including management practices and conservation easements that afford tax relief. Appropriate habitat protection measures should be initiated now to prevent further degradation of gopher tortoise populations. Additional research is needed to locate optimal habitat for conservation, areas that require changes in land management in order to allow population persistence, and areas that may serve as relocation sites for tortoises residing in zones scheduled for development.

Habitat suitability models (HSM), by incorporating specific habitat variables vital for species survival, are well-suited to quantitatively illustrate components of habitat evaluation. Traditionally, habitat has been ranked with the use of generated mathematical indices based on intensive analysis of habitat within the field. These early models, however, many times fail to incorporate a spatial element. Habitat quality for many wildlife populations often depends upon the spatial distribution of habitat patches across geographic areas. State-wide digital data sets and remote sensing data are well suited to provide spatial information for habitat assessment.

By incorporating specific habitat requisites and digital data layers, geographic information systems (GIS) allow researchers to identify suitable habitat on a broader spatial and temporal scale and with less intensive field work. Although GIS-based HSM have been created for Florida, only one has been attempted for Georgia.

To locate habitat capable of supporting healthy populations within the state of Georgia, this thesis will utilize existing digital and remotely-sensed data to design a GIS-based habitat suitability model for the gopher tortoise. A range of data at varying scales will be examined to determine the data resolution most appropriate for habitat identification. In addition, the gopher tortoise habitat distribution map recently released by the Georgia GAP Analysis Project is compared to the model created in this study.

Gopher Tortoise Life History

The gopher tortoise, found in xeric environments throughout the sandhills of the southeastern United States, prefers the well drained, sandy soils of the Coastal Plain. The gopher tortoise is unusual in that it digs burrows averaging 4.6 m long that are approximately 1.8 m below the surface, with a width that is just large enough to permit it to reverse direction at any position within the burrow (Hansen, 1963; Figure 2). Active mainly in the late spring and summer, the tortoise emerges primarily to feed and mate. The tortoise resides in the burrow year-round and tends to remain close to it except for foraging and mating excursions, which can lead the tortoise several meters away. The burrows serve as refugia from adverse conditions and predators for the tortoise and its burrow commensals.

Figure 2. Gopher tortoise emerging from burrow.


Geographic Distribution

Auffenberg and Franz (1982) note that the gopher tortoise range occurs to the south and east of Georgia's Fall Line. At the time of their publication, large gopher tortoise populations existed in areas whose soils were derived from the Tuscaloosa Formation, specifically in the sands of the Fall Line Hills district in Marion, Talbot, and Taylor counties. In the middle and lower Coastal Plain, tortoises occur in sandy Miocene deposits and Plio-Pleistocene marine terrace deposits. Established populations can also be found on barrier islands and in alluvium deposited by rivers.

Dietary Requirements

Broad-leaved grasses of the family Poaceae are the most commonly ingested plant material (Garner and Landers, 1981; Macdonald, 1986). Garners and Landers (1981) found wild legumes

(*Fabaceae*) and wiregrass (*Aristida stricta*) to be an important dietary component, while oak leaves (*Quercus* spp.) and pine needles (*Pinus* spp.) are consumed in quantity as well (Macdonald, 1986). Although primarily herbivorous, tortoises are known to consume small quantities of indigestible material and animal matter (Garner and Landers, 1981; Macdonald, 1986). The quantity and composition of food matter ingested varies seasonally and with age (Inkley, 1986).

Water consumed from vegetative consumption most likely provides sufficient water to satisfy water requirements (Minnich and Ziegler, 1977; Garner and Landers, 1981). The gopher tortoise has little to no need for other water sources (Inkley, 1986).

Habitat

The most important determinant regarding habitat selection is the physical condition of the habitat, with soil properties serving as a primary limiting factor (Campbell and Christman, 1982). Well-drained soils with loose texture provide edaphic conditions important for burrow formation (Diemer, 1986). Further limiting factors include the availability of forbs and herbs and a canopy cover that allows sufficient sunlight to provide well-lit nesting sites (Hallinan, 1923; Landers and Speake, 1980; Auffenberg and Franz, 1982).

Seasonal and annual climatic conditions, in addition to edaphic and vegetational parameters, influence habitat selection (Diemer, 1986). Although tortoises are commonly found in well-drained sandhill communities, they often reside in less suitable habitat composed of longleaf pine and turkey oaks. Auffenberg and Franz (1982) record several habitat types for the tortoise in Georgia: longleaf pine-turkey oak, blackjack oak and pine, mesic and xeric hammock, xeric hammock beach and pineland communities, and ruderal communities (fallow fields, road edges, fence rows, etc).

The gopher tortoise usually inhabits one habitat type for the duration of its life cycle; therefore, a heterogeneous mix of habitat types is not necessary (Inkley, 1986). There have been reports, however, of an autumn migration from xeric to mesic soil, perhaps due to decreased food supply and winter burrow insulation (McRae et al. 1981). Habitat interspersion is most important in scrub habitats. Maturation of successional stages may influence tortoise movement as tortoises move into ecotonal areas (Auffenberg and Franz, 1982; Campbell and Christman, 1982).

Cover

Inkley reports above-ground cover requirements for refuge as negligible; the primary source of refuge is the burrow (Speake and Mount, 1973; Landers and Speake, 1980). The tortoise tends to remain close to the burrow, to which it scurries for cover when approached. Tuberville (2002) (pers. communication) notes that juveniles often position burrows adjacent to diverse types of cover (tree stumps, juvenile trees, etc.).

Nesting sites tend to be located in or near the burrow apron, the fan-shaped mound of excavated sand that lies at the opening of the burrow. Exceptions include nests found in roads and wildlife plots, sometimes as far as 134 m away (Landers et al., 1980). Nests must receive adequate sunlight to ensure nesting success (Hallinan, 1923; Lander et al. 1980); Landers recommends a maximum of 60% cover (in Inkley, 1986).

Effective Population Size / Minimum Area Requirements

Although Cox et al. (1994) suggest a minimum land area of 200 ha to ensure long-term population survival, the literature suggests that smaller populations of approximately 50 individuals can persist for an undetermined amount of time and are vital to maintaining genetic diversity. In addition, the persistence of small, isolated populations can provide some resistance to the spread of disease and population destruction caused by catastrophic disturbances.

Cox et al. (1987) base their research on Franklin's (1980) recommendation of an effective population (N_e) size of 50 individuals. This number is thought to offer the minimum level of protection to prevent inbreeding depression and protect against extinction. Utilizing data from several studies, they suggest that "approximately 40 breeding adults are needed to establish an N_e of 50" due to the overlap in generations among gopher tortoises (Cox et al., 1987 p 25). They caution that a censused population of 50 – 80 individuals may be necessary to obtain an effective population of 50 tortoises. However, their final recommendation is "A population of 40-50 individuals appears to satisfy several conditions established here for population viability and should be the smallest population size generally considered for habitat protection efforts" (Cox et al., 1987, p 29).

Cox et al. (1987) estimate minimum habitat needed to support 40-50 individuals from sandhill home range data (McRae et al., 1981) to be 10-20 ha. Breininger et al., (1994) estimate that 30-35 ha of lesser quality scrub and pine flatwood habitat may be needed to support the same population size.

Habitat Suitability Indices

Understanding the relationship between wildlife and habitat is crucial for effective conservation and management of wildlife populations. Habitat suitability models, by incorporating ecological requirements of a species with spatial data on specific habitat variables such as land-use, vegetation cover, slope, aspect, and temperature, etc., produce a map of habitat suitability that is a useful component of ecosystem planning and management. Quantitative information regarding land-use change, combined with data on habitat use and availability, allows land-use managers to predict future habitat modifications and make informed decisions for long-term management scenarios. The efficacy of GIS is particularly evident when working with data that cover extensive spatial and temporal scales.

Habitat suitability index (HSI) models were first developed in the early 1980's by the U.S. Fish and Wildlife Service (USFWS) as an integral component of the Habitat Evaluation Procedure (HEP), a procedure designed to "document the quality and quantity of available habitat for wildlife species" (USFWS, 1980). Although these generated mathematical indices are useful for quantitatively assessing habitat, they fail to incorporate spatial elements such as habitat distribution, patch dynamics and habitat connectivity (Carroll and Meffe, 1994). Management of threatened wildlife populations in today's ever-changing and increasingly fragmented landscape requires more spatially explicit models capable of quantifying habitat quality and spatial distribution, in addition to identifying important habitat patches and corridors.

Field-based Survey Estimates

Inkley (1986) generated a HSI model for use within the historic and current range of the gopher tortoise, although he notes that the model has never been tested. The model is applicable during all seasons; however, he cautioned that data should be collected during the season appropriate for each variable. Life requisites of reproduction, food, and cover were accounted for in the model by the following variables: minimum habitat size, percent ground cover, openness of canopy, and depth to water table. Inkley (1986) classified tortoise cover types as pasture and hayland (PH), forest (FO), tree savanna (TS), shrubland (SH), shrub savanna (SS), grassland (GR), and forbland (FB). The model is applicable only where sandy soils equal or exceed one meter in depth. The values of the habitat suitability indices were generated from a review of the literature and input from wildlife biologists.   The HSI value ranges from 0 to 1 and is determined by the following equation:

$$HSI = \text{Min}\ [V_1, (V_2 * V_3 * V_4)^{1/3}]$$

where: V_1 = Minimum area

V_2 = Percent herbaceous ground cover

V_3 = Depth to water table

V_4 = Percent canopy cover

Inkley (1986) considered minimum area of habitat and percent canopy cover as variables fundamental for reproduction. Minimum area (V_1) accounts for habitat size needed to support a viable population; areas less than 4ha are assigned a value of zero while areas greater than 200 ha are assigned a value of one. Based on Landers' (1986) percent canopy cover (V_4) recommendation, areas with less than 60% canopy cover are assigned a suitability index value of one. The HSI decreases as percent canopy cover increases beyond 60%.

Percent herbaceous ground cover accounts for the food requisite. Based on Auffenberg and Iverson's (1979) suggestion of a one-to-one relationship between tortoise density and ground cover, Inkley represented percent herbaceous ground cover within the model by a linear relationship between percent cover of herbaceous plants and habitat suitability.

Inkley assigned soils with water table depths of greater than 270 cm a value of one for V_3. Soils with water table depths less than 61 cm are unsuitable, while soils that fall between these two depths are rated with linearly increasing levels of suitability.

Inkley (1986) mentioned an anonymous HSI that incorporates soils, burn frequency, and depth to water table, but no other information was provided. In addition, Hamilton et al. (1985) developed indices that are habitat specific. They include depth to water table, vegetation conditions, and time since last burn as variables for mixed-oak scrub, saw palmetto scrub, and dune/strand habitats.

GIS-based Models

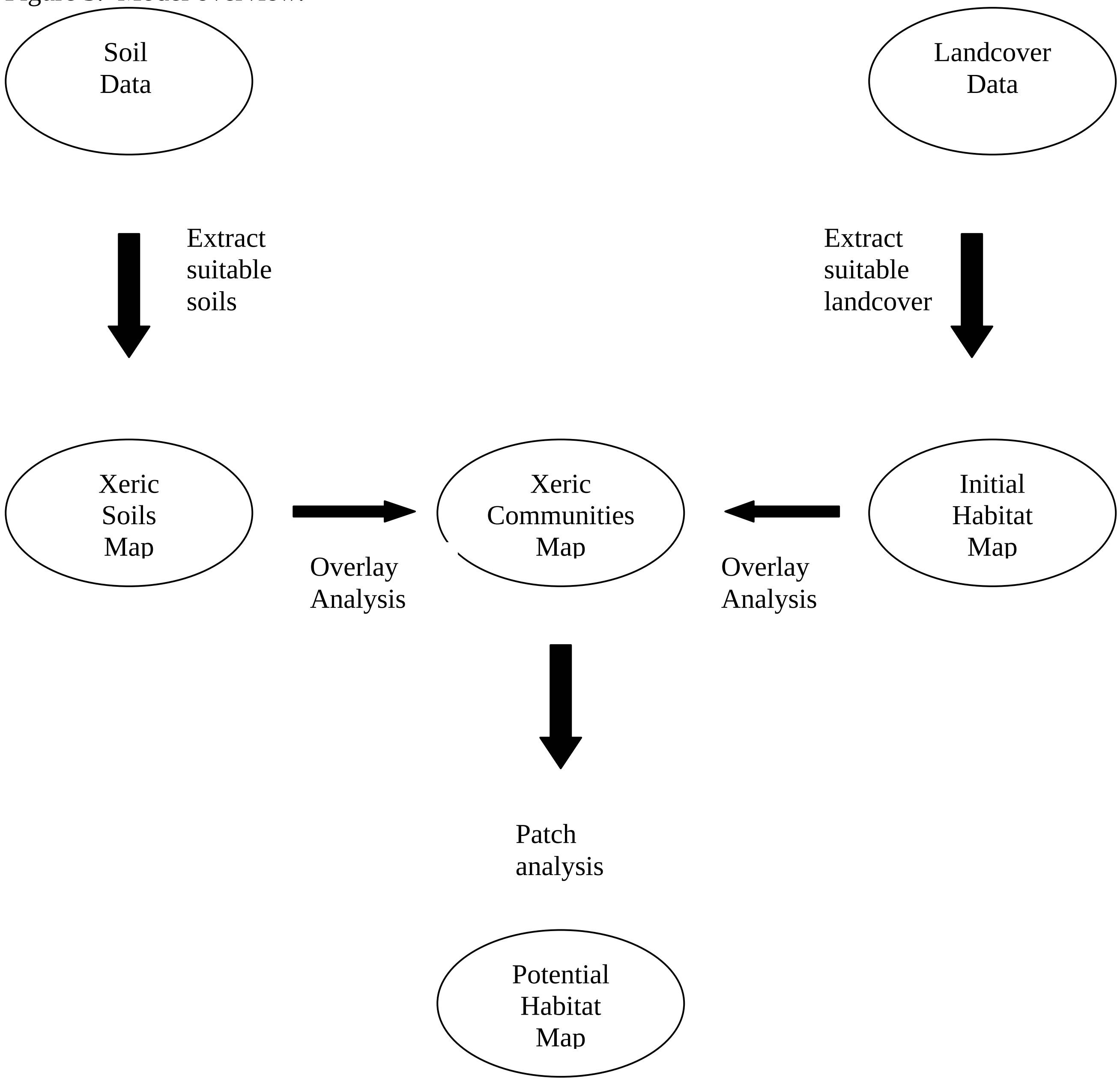
Cox et al. (1994) developed a GIS-based model to estimate the number of patches of suitable habitat capable of supporting viable populations of tortoises on conservation lands within Florida. To generate an initial map of potential gopher tortoise habitat, they isolated xeric land-cover types (sandhill, oak scrub, sand pine scrub) and land-cover types located over xeric soils (pineland, dry prairie, mixed-hardwood pine). Areas capable of supporting populations of at least 40-50 individuals were extracted from the initial potential habitat map by locating neighboring patches of habitat greater than 20 ha and smaller patches within 60 m of the larger patches. Conservation lands were examined to identify areas capable of supporting a population of 200 individuals. Assuming a density of 3 individuals per hectare, they isolated patches of 67 ha or larger and identified 93 areas within conservation lands that provided the minimum level of habitat protection necessary to maintain gopher tortoise populations.

McCoy et al. (2002) compared GIS and survey estimates of gopher tortoise habitat and numbers of individuals in Florida. They analyzed land cover, soils, and natural vegetation to create xeric soil, community, and habitat maps. Overlay analysis was performed to select those areas with correspondence as potential gopher tortoise habitat; the final product depicted areas of 20 ha or larger. They found that the GIS method underestimated total area of habitat and numbers of individuals, a difference they attribute to the more qualitative nature of the GIS-based method. Although the GIS method was deemed somewhat inferior to the survey method, they concluded that it produced important information nonetheless, particularly concerning the location of habitat that can play an important role in the management and conservation of the species.

Objectives

Although a habitat distribution map has been created to examine gopher tortoise habitat in Georgia, there have been no GIS-based HSMs that incorporate variables other than landcover. For this study, therefore, GIS techniques are used to analyze habitat requisites in order to locate potential gopher tortoise habitat and areas of conservation interest within Georgia. The initial analysis employs methods similar to those utilized by Cox et al. (1994) and McCoy et al. (2002) to create a potential habitat map (Figure 3). Potential habitat areas are those that possess the correct combination of soil and landcover type. Further analysis identifies large areas contained by public conservation lands, in addition to private lands, that may be instrumental in the sustenance of viable gopher tortoise populations. Potential habitat maps are then constructed for both 1988 and 1998, and examined for temporal changes.

Figure 3. Model overview.



Specific objectives of this study include the following:

1. Create a HSM for the area in Georgia south of the Fall line that coincides with the known range of gopher tortoises and considers habitat factors such as landuse/cover, soil characteristics, patch size, and percent canopy cover.

2. Examine changes in habitat availability over a decade.
3. Assess the utility of small scale soil data compared to large scale soil data.
4. Determine the importance of the percent canopy cover variable.
5. Evaluate the effects of differences of scale within classification schemes.

New land-use/cover data of higher resolution were released by the Georgia GAP Analysis Project at the end of this study that could enhance the model results. These data are analyzed for one survey area and a comparative analysis conducted. The Gopher tortoise distribution map recently released as part of the Georgia GAP Analysis Project (Kramer et al., 2003) is discussed as well.

METHODS

Overview and Study Area Delineation

Table 1 summarizes the data sources used in the analyses for the model components. All data are projected to the Lambert Conformal Conic projection. The study area comprises the range of the gopher tortoise contained by the Georgia state boundary. Due to variation within the literature in reference to the upper limits of the range, an approximation was created by bisecting the state at the uppermost limit depicted by the collection of available range maps (Figure 4). Range maps consulted include those from the Peterson's Field Guide to Reptiles and Amphibians of Eastern and Central North America (Conant and Collins, 1998) and the National Audubon Society Field Guide to North American Reptiles and Amphibians (Behler and King, 1995).

Table 1. Summary of Analyses and Data Sources.

Model Component	Data Source	Geographical Extent of Analysis
Soil Resolution	STATSGO soil data SSURGO soil data	Survey Area 245 Entire Study Area
Landcover Resolution	1998 Landcover Map, 18 classes 1998 Landcover Map, 44 classes	Survey Area 245
Temporal Change	1988 Landcover Map 1998 Landcover Map, 18 classes	Entire Study Area
Patch Size	1988 Landcover Map 1998 Landcover Map, 18 classes	Entire Study Area
Accuracy Assessment	1998 Landcover Map, 18 classes	Survey Area 245
Canopy Cover	1993 NAPP Orthophotos	Survey Area 245
GAP Comparison	GAP Tortoise Distribution Map Potential Habitat Map	Survey Area 245

Soil Data Analysis and Comparison

An initial assessment of digital soil data available for Georgia, obtained from the United States Soil Conservation Service, was conducted to determine the ramification of scale variation and the comparative usefulness of these data. STATSGO data (USDA, 1991) were originally developed by the National Cooperative Soil Survey by generalizing county soil surveys and are distributed at a scale of 1:250,000. SSURGO data (USDA, 1994) are digitized reproductions of county soil surveys; scales range from 1:12,000 to 1:63,360. STATSGO data are available for the entirety of the gopher tortoise range within Georgia, SSURGO data, however, are available for only 13 survey areas, which are county-based or composed of multiple counties. (Figure 4).

A xeric soils map (XSM) of appropriate soil types, those that are well-drained or extremely well-drained, have an annual flood rate of none or rare, have a minimum depth to water-table of greater than 60 cm, and are in either class A or B hydrologic group (drainage classes) were extracted from STATSGO and the 13 SSURGO soil surveys. A preliminary visual comparison of appropriate soil types in a county that possesses both data was performed to examine the effect of differences in scale and the suitability of utilizing the STATSGO data in counties lacking SSURGO coverage.

The STATSGO data were obtained from the Georgia GIS Data Clearinghouse in ArcInfo interchange file format. The interchange file was imported into ArcInfo as a coverage, clipped to the study area boundary, and subsequently queried with ArcGIS using the criteria listed above to delineate those soils that are preferred by the gopher tortoise (Figure 5a).

The SSURGO data were obtained for each of the 13 survey areas in coverage format from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Division. Attribute tables from SSURGO data and the National

Map Unit Interpretation Records (MUIR) database were imported into Microsoft Access using the SSURGO 2.0 Microsoft Access Template Database for Microsoft Access 2002 provided by the National Soil Information System (NASIS). The map unit aggregate (muaggatt) table was then exported in Microsoft Excel format (.xls). The table widths were modified with Microsoft Excel to display full attribute information and saved in dBase V file format (.dbf). The resultant muaggatt table was joined to the soil survey coverage using the map unit symbol (musym) field. Because ArcMap is more user-friendly than ArcInfo and allows the user to save the query expression, it was used to isolate soils preferred by the gopher tortoise. The selected records were saved as a layer file, exported as a shapefile (.shp), and then converted to a coverage using a combination of ArcMap, the ArcToolbox, and ArcInfo. Null polygons resulting from island polygons were flagged to create a mask which was then erased to create the final SSURGO soil coverage (Figure 5b).

Landcover Analysis

Potential gopher tortoise habitat was extracted from the 1998 Landcover Map of Georgia (1:24,000-scale, 18-class) to create the initial habitat map (IHM) (NARSAL, 2001). The landcover map, created from 30 metre Landsat Thematic Mapper (TM) imagery, was created with two iterations. The first was classified into 18 landuse/cover classes using an unsupervised classification method with an accuracy of 84%. The detailed 44 class map, released March, 2004, was created by expanding the 18 classes from the first iteration using decision rules, topographic modeling, a topographic relative moisture index, supervised and unsupervised classification, and hand digitizing. The second iteration produced accuracy rates from 33.7 % to

100 %.   A more detailed description of the methods employed to create the map is given in Payne et al., (2003). The 18 original landcover classes were reduced to the six habitat types that the gopher tortoise has been known to occupy within Georgia: evergreen forest, mixed woodlands, pastures, dunes/beaches, utility swaths, and clear-cut/sparse areas. The IHM was created by extracting these habitat types in ArcInfo Grid; the resultant raster layer was clipped to the boundaries of the SSURGO soil survey areas and then converted to an ArcInfo coverage (Figure 6).

Equivalent methods were utilized with the 1998 Landcover Map of Georgia (1:24,000-scale 44-class) (Figure 7) and the Georgia Department of Natural Resources (GDNR) 1988 Landcover Map (1:100,000-scale) (Figure 8). Table 2 lists habitat types extracted for each landcover map. Note: Due to the late release date of the 44 class landcover map, results are tabulated only for Survey Area 245.

Table 2. Landcover classes used for habitat extraction

1988 GDNR Landcover	**1998 NARSAL Landcover (18 classes)**	**1998 NARSAL Landcover (44 classes)**
Clearcut/Young Pine	Beaches	Beaches
Pasture	Utility Swaths	Coastal Dunes
Coniferous Forest	Clearcut, Sparse	Clearcut, Sparse
Mixed Forest	Evergreen	Pasture, Hay
	Mixed Woodlands	Xeric Hardwood
	Pasture	Open Loblolly Shortleaf
		Xeric Pine
		Xeric Mixed Pine
		Loblolly Shortleaf
		Loblolly Slash
		Sandhill
		Longleaf

Habitat Analysis

The xeric soils map was intersected with the IHM, resulting in the xeric communities map (XCM), which illustrates only those areas that possess both suitable landcover and soil types. A mask was used to filter out the island polygons that contained no data. The polygons of the XCM were then dissolved based upon the grid-code to eliminate coterminous polygon boundaries. Georgia state highways were buffered 30 m and the resultant coverage subtracted from the preliminary coverage to create the final XCM (Figure 9).

Patch Analysis

The final potential habitat map (PHM) was created by extracting from the XCM patches of land that are 20 ha or larger, a value based on Cox et al (1987) as the recommended minimal area needed to support a viable population of 40-50 gopher tortoises. Any patch larger than 4 ha, the smallest area thought to support one tortoise, that partially lies within a 60 m buffer of the larger patches was included in the PHM (Figure 10). Patches 200 ha or larger within public or conservation lands are also noted as significant habitat, as these areas meet the Cox definition of areas that provide the “minimum level of habitat protection” necessary to ensure long term tortoise protection (Cox et al. 1994). Potential habitat maps were created for each survey area for both the 18 class 1998 data (Appendix A) and 1988 Landcover Maps (Appendix B).

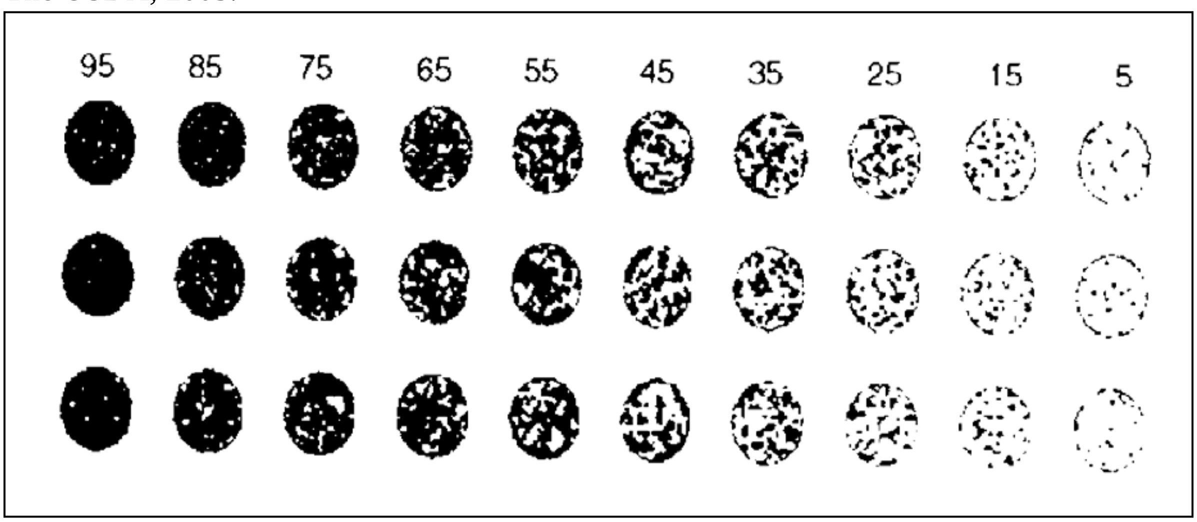
Accuracy Assessment

Georgia Natural Heritage Data (GNHD) were used to conduct a cursory accuracy assessment for the SSURGO survey areas used in this study. The GNHD is a collection of animal and plant occurrences and museum records compiled by the GDNR. The dataset contains presence/absence data (not all quads have recorded data) and is organized on a 1:24,000-scale USGS topographic quadrangle basis. The GNHD are not complete, they are simply a collection of known occurrences. The data were downloaded in ESRI shapefile format from the GNHD website and analyzed to determine the ability of the model to detect areas that are known to contain tortoises (GNHD, 2004). Quads that contain gopher tortoise records were selected from the GNHD and then intersected with the SSURGO county soil survey areas. Each quad that was completely contained by a survey area was analyzed to determine if the model predicted habitat within the quad boundary; partial quads were not used in the analysis. To obtain a numerical assessment of accuracy, the detection rate was calculated by dividing the number of complete quads that contained predicted habitat by the number of complete quads containing tortoise records.

Aerial Photo Interpretation

Aerial photo interpretation of percent overstory canopy cover is costly and time consuming. The variable, however, is important to gopher tortoise habitat selection. To analyze the model's ability to identify habitat without the inclusion of the variable, a visual method for estimating canopy cover was performed on four randomly selected 1993 USGS Digital Orthophoto Quarter Quads at 1:40,000-scale (USGS, 1996). The SSURGO Survey Area 245 (Richmond County) was divided into four quads; stratified random sampling and a random number table were used to select one photo from each quad (Figure 11). A visual assessment based on the comparison template below (USDA, 2003) was utilized to choose areas with greater than 60% canopy cover, a value derived from the literature (Figure 12). These areas were considered unsuitable tortoise habitat because they significantly reduce the amount of light reaching the forest floor. They were digitized and subsequently erased from the original coverage to display only those areas with appropriate canopy coverage (Figure 13). The percentage of habitat with unsuitable coverage was then calculated by dividing the area of unsuitable habitat by the total area of habitat.

Figure 12. Visual comparison template used to estimate percent canopy cover. Adapted from The USDA, 2003.



GAP Habitat Distribution Comparison

The GAP gopher tortoise distribution map was compared to the final potential habitat map produced by this model. The 44-class Landcover was used to facilitate comparison, as the GAP project utilized the newer 44-class Landcover data.

The GAP habitat distribution grid was clipped to the boundary of SSURGO Survey Area 245. The grid was then converted to a coverage and the total area of habitat calculated and recorded. To examine the degree to which the GAP model predicted habitat concurrent to this model, the PHM was intersected with the GAP habitat distribution map (Figure 14). The area of habitat predicted by both models was divided by the total habitat area predicted by the GAP model to obtain the percent correspondence.

RESULTS

Results are given only for SSURGO Survey Area 245 (Richmond Co.) for simplification. Table 1 summarizes the data sources used in the analyses for the model components. There is a total of 96 counties within the gopher tortoise range. Twenty-four of these counties have SSURGO data available for download; the remaining counties have only STATSGO data (Figure 4). The SSURGO and STATSGO data sources display disparate levels of spatial detail (Figures 5a, 5b). The STATSGO data describe 4 soil classes and 35,537 ha of suitable soils when queried while the SSURGO data return 16 classes and 52,122 ha, indicative of the lower resolution of the STATSGO data.

Comparison of initial gopher tortoise habitat between 1998 and 1988 were made with both the 18 class and the 44 class 1998 Landcover Maps. A large decline in gopher tortoise habitat was indicated in the 44 class data (4285 ha); however, there was an increase of only 441 ha when comparing the18 class data (Table 3). This difference is most likely due to the increased resolution of the classification scheme used in the 44-class data. For this reason, temporal comparisons are made between the 1988 data and the 1998 data derived from 18 classes. Even though the total amount of initial habitat changed very little over time, the amount in each class varies considerably, with the exception of the pasture class. There is a substantial increase in the amount of clearcut land; conversely, there is a large decrease in the amount of evergreen forest. These changes would be indicative of timber harvesting.

Table 3. Habitat component values for survey area 245, Richmond County.

	1988 Landcover Map (ha)	1998 18-class Landcover Map (ha)	1998 44-class Landcover Map (ha)
Xeric Soils	52,122	52,122	52,122
Initial Habitat	38,712	39,123	34,427
Xeric Communities	27,668	26,902	24,608
Potential Habitat	20,238	19,636	10,980

There are relatively few differences between the 18-class and 44-class 1998 Landcover maps; however, the more generalized data likely overestimates habitat due to the coarser classification. The IHM derived from the 1998 Landcover Map of Georgia with 18 classes possesses more habitat than the IHM based on the 1998 data with 44 classes; 39,123 ha of tortoise habitat (Figure 6), compared to 34,427 ha (Figure 7). As would be expected, the 44-class classification identifies less habitat than the generalized 18-class map, a difference of approximately 4,600 ha. The higher resolution data differentiate habitat types within the mixed forest class that would not be suitable tortoise habitat. This allowed the elimination of areas that were previously grouped into the mixed forest category, such as mesic mixed forest types and mesic evergreen areas. Utility swaths, clear cuts, and pasture areas remain the same. There are sandhill and longleaf classes in the 44-class map, both of which are considered optimum tortoise habitat, a noteworthy improvement over the 18-class map.

Differences related to resolution are apparent at every level of analysis. After intersection of the IHM with the XSM, there are 26,902 ha of suitable habitat in the 18 class XCM (Figure 9), compared to 24,608 ha of suitable habitat in the 44 class XCM (Figure 15), a difference of 2,294 ha. The potential habitat map displays the same trend: use of the 18-class landcover map results in 19,636 ha of appropriately sized patches (Figure 10), compared to 10,980 ha when the 44-class landcover map is used (Figure 16).

Table 4 lists total potential habitat area and the amount of habitat considered significant (patches larger than 200 ha) for each county survey area. Potential habitat maps can be found in Appendices A (1998) and B (1988). Although some Survey Areas contain much more habitat than others, it is helpful to remember that some areas contain two or three counties, while only a few contain one county.

Table 4. Final potential habitat values (in hectares) for 1988 and 1998 (18-class data), for each survey area.

Survey Area	**1988**	**Significant Habitat**	**1998**	**Significant Habitat**
33	43,321	14,990	46,487	4,811
107	31,070	3,603	25,514	3,501
245	20,238	18,993	19,636	4,994
277	7,162	0	556	0
602	3,653	0	5,487	0
610	53,627	12,034	48,430	951
616	1,515	0	585	0
620	25,804	6,343	32,687	5,991
631	13,080	2,830	6,686	0
640	32,281	12,319	12,187	0
644	7,911	2,314	7,361	1,029
650	14,443	2,143	14,468	954
683	60,292	32,423	48,176	12,944
Totals	314,397	107,992	268,260	35,175

With the exception of Survey Areas 33, 602 and 620, all areas lost tortoise habitat; even more noteworthy is the loss of significant habitat (Figure 17**).** In 1998, there were only 35,175 ha of significant habitat, down from 107,922 ha in 1988; furthermore only 6,846 ha of tortoise habitat in 1998 were located within public lands (Figure 18). Areas that possess little significant habitat are generally coastal areas with minimal habitat to begin with (Survey Area 616, Camden and Glynn Co.), areas with intense agriculture (Survey Area 277, Tift Co.), or areas that have large cities or an interstate passage (Survey Area 640, Houston and Peach Co.)

Figure 17. Gopher tortoise habitat change, 1988 to 1998.

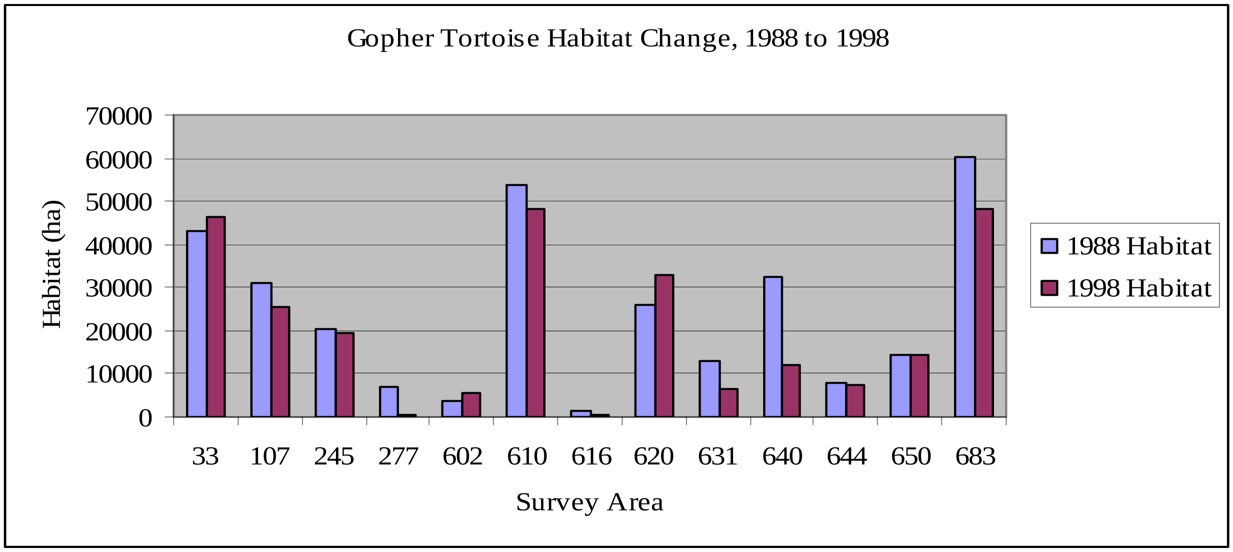
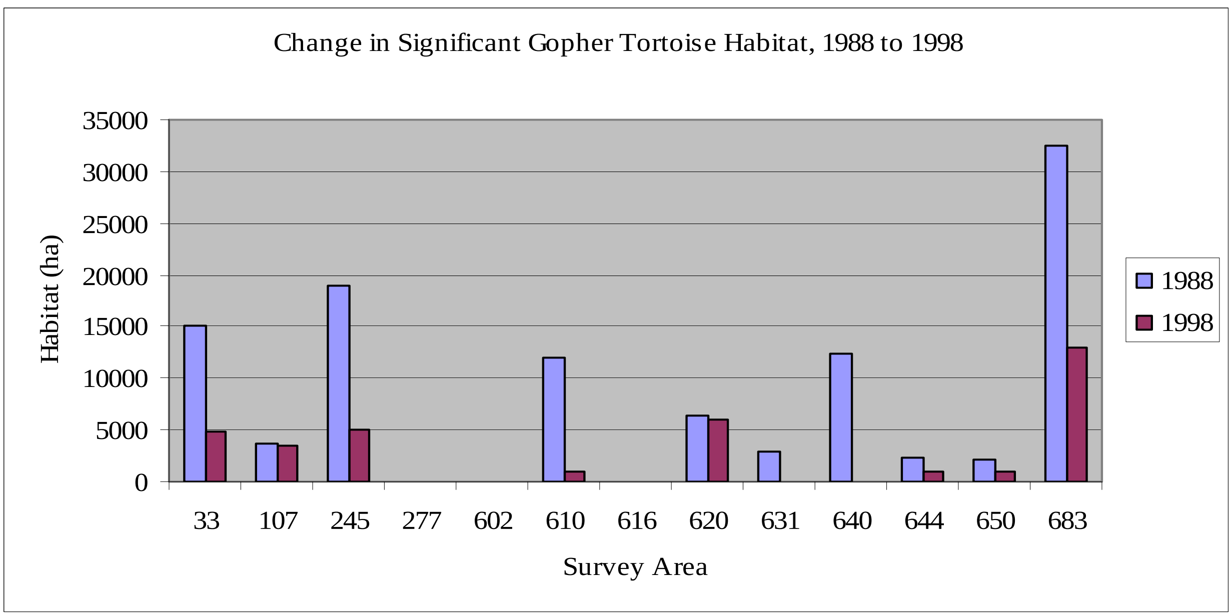


Figure 18. Change in significant gopher tortoise habitat, 1988 to 1998.



Canopy coverage was examined by methods of aerial photo interpretation; four photographs were interpreted (Figure 11). There are 2,032 ha of suitable tortoise habitat contained by these photographs; 31.3% (636 ha) of habitat exceeded the 60% threshold of canopy coverage and were considered unsuitable habitat. As such, it is recommended that once an area is identified as an area suitable for management, acquisition, or reintroduction, either a ground check be performed or aerial photographs be consulted to assess the levels of canopy coverage.

The Georgia Natural Heritage Data were used to perform a cursory accuracy assessment. Sixty-five quadrangles contained tortoise records; only 24 of these were complete quads. This model predicted habitat occurrences in 20 out of 24 complete quads, for a detection rate of 83.4%. Forty-one incomplete quadrangles were excluded from the analysis. However, the model accurately predicted tortoise habitat in 26 of these incomplete quads. It is important to remember that the quadrangles with records are only those that have been reported; the quads with no data do not have any recorded records but that does not equate to tortoise absence.

The GAP gopher tortoise habitat distribution map was compared to the PHM produced by this model within the boundary of SSURGO Survey Area 245 (Figure 19). The GAP model predicted 7,463 ha of habitat, while the model used in this study predicted 10,980 ha. Only 51% of the habitat predicted by the GAP model (3794 ha) coincided with habitat predicted by this model; the remaining gopher tortoise habitat was unique to the GAP model (Figure 14).

DISCUSSION

Soil Data Analysis and Comparison

The original intent of this project was to create a HSM for the entire range of the gopher tortoise within Georgia; however, disparate data sources precluded this. Because soil type is considered the primary limiting factor with respect to habitat selection (Campbell and Christman, 1982), differences of scale should be an important determinant regarding data choice. Other studies have used STATSGO data as a surrogate when SSURGO data are not available (Cox et al., 1994; McCoy et al., 2002), although no study to date has examined the implications of this substitution.

Both SSURGO and STATSGO data were examined to determine their apparent usefulness within a gopher tortoise HSM. A visual assessment clearly reveals the limitation of STATSGO data (Figure 8a) when compared to the SSURGO data (Figure 8b). The STATSGO data describe only 4 soil classes (Orangeburg, Lakeland, Georgeville, and Cecil) whereas the SSURGO data describe 16, most of which are sandy loams, fine sands, and sand. In addition, the STATSGO data underestimate the amount of suitable soil by 16,585 ha due to the smaller scale of the data. Because of the limited capacity of the STATSGO data to accurately distinguish between soil classes, the data are of little use with respect to gopher tortoise habitat prediction. The SSURGO data will be available for all areas by 2005. Until then, the original county surveys in non-digital format can be utilized. Once appropriately sized patches of landcover are isolated, county soil surveys can then be digitized for these areas and the analysis completed. Alternatively, the Tortoise Habitat Distribution Map recently released by the Georgia GAP Analysis Project can be used.

There are many more hectares of suitable soils than landcover, in which case a change in landuse would render the area as suitable habitat. A model that assigns higher priority to the soils based on critical soil factors and distance to suitable habitat would allow more areas to be included as potential habitat. Because these areas are in close proximity to suitable habitat, these areas would be good targets for habitat reclamation.

Landcover/Habitat Analysis

Landcover classes that are considered appropriate tortoise habitat types were extracted from three landcover maps. While classification schemes differed in all three maps there was some correspondence between the maps. The 1988 landcover had four tortoise habitat classes compared to six classes for the 1998 (18-classes) map, while there were twelve habitat classes in the 1998 (44-classes) map. Because of the coarse classification of the 1988 landcover, it is more appropriate to look at temporal changes compared to the 18-class 1998 landcover, as opposed to the highly detailed 44-class map. It should be noted, however, that both the 1988 and the 18-class 1998 data are likely to overestimate habitat compared to the 44-class data.

Differences between classification schemes from 1988 and 1998 do not necessarily prohibit a temporal comparison of the data. For example, there is no beach category in the 1988 classification scheme. This category is included in the cultivated/exposed earth category which largely includes agricultural land and strip mines/quarries; therefore it was excluded from the analysis. The 1988 classification also does not include a class for utility swaths and it is not clear from the metadata where this landuse type belongs.

Upon closer inspection of the omitted classes, it would seem that the exclusion of beaches, which do not occur in most areas, would not impact the results significantly. Only along the coast in areas where dunes and beaches are likely to occur, would the 1988 data slightly underestimate the quantity of tortoise habitat. The same can be said of the utility swaths. Utility swaths comprise less than one percent of the total suitable landcover in the 1998 map of Richmond County, so it appears to be an insignificant component, as are beaches, which do not occur at all. For these reasons, a direct temporal comparison of area values in 1988 and 1998 is possible and the differences can be interpreted as such.

Clearly, the newly released landcover map is preferred to the 18-class data for tortoise habitat location. It is important to note that habitat analysis is scale dependent, not only with respect to data resolution, but also regarding the classification scheme. The highly detailed classification scheme produces a more refined habitat map which reduces the amount of field reconnaissance required before making decisions regarding habitat acquisition. Improving the maps produced by this model would be relatively simple; although time limitations prevented doing so in this study. Either the model could be run with the newer landuse data, or the areas already delineated as tortoise habitat could be examined with the newer data to remove any inappropriate habitat types.

Patch Analysis

Final potential habitat maps for all survey areas are displayed in Appendices A (1988) and B (1998). Excluding patches that are not capable of supporting a tortoise colony (less than 4 ha) refined the potential habitat maps significantly. With small patches excluded, potential habitat decreased by 602 hectares between 1988 and 1998 in Richmond County. The amount of habitat predicted with the use of the 44-class landcover, however, is significantly lower, with only 10,980 ha predicted. This is likely due to the smaller quantity of habitat originally selected as suitable habitat and is an artifact of the data resolution rather than a temporal change in the quantity of suitable tortoise habitat (Table 3). Finer classes and smaller polygons appear to provide more precise information about habitat suitability.

It appears that habitat fragmentation is more apparent when landcover is mapped at a finer scale. Removing smaller patches reduced the xeric communities for both 1988 and 1998 (18-class) by approximately 7,000 ha. The 44-class data was reduced by nearly 14,000 ha, indicative of the degree of habitat fragmentation (Table 3).

The amount of significant habitat, those patches that are 200 ha or larger and are thought to be important to long term tortoise survival, are few, and not much of this falls within the public domain. Survey area 245 is unusual in that it contains a large amount of significant public lands, due to the presence of Fort Gordon military base. Nearly 13% of the total 268,260 ha of mapped tortoise habitat occurs within patches that are significant, a substantial decrease from the 34% significant habitat in 1988. Only 2.5 % of this land is protected as public lands.

Accuracy Assessment

The GDNR Georgia Natural Heritage Data used to perform a cursory accuracy assessment revealed that the model is correct in predicting known occurrences of tortoises with an accuracy of 83%. There were a total of 65 quads that fell completely within the survey areas; because occurrence data could be anywhere within the quadrangle, only complete quads were used to calculate the prediction rate. It is important to remember that actual accuracy may be higher because quadrangles with no data merely have no records and do not conclusively signify that there is no tortoise presence.

Aerial Photo Interpretation

Percent canopy cover is cited in the literature as an important determinant regarding habitat selection because nesting sites must receive adequate sunlight to ensure proper incubation conditions. Canopy coverage cannot be determined from the Landcover data since the landcover forest classed did not include density information. Canopy cover is not evident in 30 m satellite images, but is commonly collected via aerial photo interpretation. This process, however, involves considerable input in the form of time and money. An evaluation was performed for one SSURGO soil survey area (Survey Area 245) in Richmond County to determine the effects of excluding the variable. Approximately 30% of the forest area originally designated potential habitat by the HSM in these photos was found to be unsuitable with canopy cover greater than 60%. These results indicate a substantial amount of potential gopher tortoise habitat can be overestimated if canopy cover is not considered in landcover assessment. Therefore, it would be desirable to perform a check with aerial photographs before any decisions are made regarding tortoise relocation or habitat acquisition.

GAP Habitat Distribution Comparison

The GAP gopher tortoise habitat distribution map is a depiction of habitat based solely upon landcover. In that sense, the GAP map does not progress pass the initial assessment made in this model; it is equivalent to the Initial Habitat Map produced here, except that the landcover types chosen by the GAP project varied somewhat from those used here. All classes used by their model were used by this one. This model, however, included beach, coastal dunes, pasture/hay, open loblolly shortleaf, xeric pine, and loblolly shortleaf classes. Based upon the literature, these are all areas the tortoise has been known to occupy and were therefore included in the model. Due to the inclusion of more habitat classes, this model predicted more overall suitable tortoise habitat than the GAP model (7,463 ha vs. 10,980 ha; Figure 19).

Because the soil variable is the primary limiting factor regarding habitat selection, it is likely to refine this model by selecting for drier areas within all habitat types. Refinement occurs once more as a size limitation rule is used in this model. Approximately 4,000 ha of predicted habitat, (nearly 50%), was common to both models; the remainder of the predicted gopher tortoise habitat for each model was unique (Figure 14). Nearly 50% of the habitat predicted by the GAP model is situated on soils that this model deems inappropriate, which is apt to be of importance regarding habitat selection. In addition, the GAP model does not include a patch analysis, while this model does.

CONCLUSION

The goal of this project was to develop a model of habitat suitability for the gopher tortoise within Georgia. While lack of appropriate data precluded development of the model for the entire range of the species, enough habitat was analyzed to present several conclusions about the status of lands potentially harboring gopher tortoises. Although the results of this thesis are displayed for only one survey area, the Appendices contain Potential Habitat Maps for 13 survey areas, a total of 24 counties.

Georgia's gopher tortoise is threatened; its habitat is in decline and the remaining habitat is becoming increasingly fragmented. Appropriate habitat protection measures should be initiated now to prevent further degradation of gopher tortoise populations and habitat. The fate of Georgia's gopher tortoises is largely dependent upon private landowners (Hermann et al., 2002; Kramer et al., 2004), who possess nearly 98 % of all tortoise habitat mapped in this project.

It is imperative to execute an aggressive campaign to educate landowners about options available to them, including management practices and conservation easements that afford tax relief. Private landowners should be advised of conservation easement opportunities in an effort to perpetuate gopher tortoise survival. In a time when land is becoming increasingly fragmented, conservation easements afford landowners state and federal tax relief to keep land perpetually protected while not restricting the landowner's ability to continue the use of the land as long as it is a reasonable use. For example, a portion of property that is set aside for conservation easement can still be harvested for timber or used agriculturally, as long as the long term status of the land is protected.

Although GIS based habitat suitability models cannot replace survey estimates of habitat due to current data availability, they are nonetheless invaluable tools for providing a quick assessment of overall habitat status and areas of conservation interest. They are useful for indicating potential habitat areas that can then be surveyed with more traditional field survey techniques to determine the status of the existing tortoise population, as well as the feasibility of relocation efforts. With the combined use of innovative management techniques and GIS, suitable habitat that is not currently supporting tortoise populations can be identified as candidate areas for tortoise reintroduction programs. Florida's mitigation program could serve as a role model for similar programs here in Georgia. For example, if a developer wishes to develop an area that is known to contain tortoises, that area must be surveyed to provide information on the population status, and then the appropriate amount of land needed to provide refuge to these tortoises must be preserved. If on-site habitat protection is not possible, the tortoises must be relocated to suitable habitat. A model such as the one developed in this thesis would be helpful in locating suitable areas, even without the refinement of the newly released landcover data. Cox et al., (1987) make detailed recommendations for habitat protection needs on lands slated for development; these, or similar, guidelines should be aggressively pursued in Georgia.

Additional research is needed to identify the remaining habitat within Georgia. The SSURGO soils program plans to have all soil data digitized and available for public use by 2005. Until then, the tortoise distribution map provided by the GAP Analysis Project of Georgia is a suitable substitute. The results of this thesis will be provided to the Georgia Land Trust Service Center, so that they may be redistributed to land trusts that are actively pursuing areas for tortoise conservation. In addition, knowledge that an area may be suitable habitat can provide land trusts with more information when advising land owners with regards to management practices.

The findings of this study indicate that habitat analysis is scale dependent, not only with respect to data resolution, but also regarding the classification scheme. Finer classes and smaller polygons appear to provide more precise information about habitat suitability. Clearly, the STATSGO data are of little use with respect to gopher tortoise habitat prediction due to data resolution. Additionally, the newly released Landcover Map with 44 classes is preferred to the 18-class data for tortoise habitat location. These results indicate a substantial amount of potential gopher tortoise habitat can be overestimated if canopy cover is not considered in landcover assessment. Finally, the GAP gopher tortoise habitat distribution map is a suitable substitute in areas where no data are available. However, this study shows that the addition of the soil variable, the primary limiting factor regarding habitat selection, improves the model substantially.

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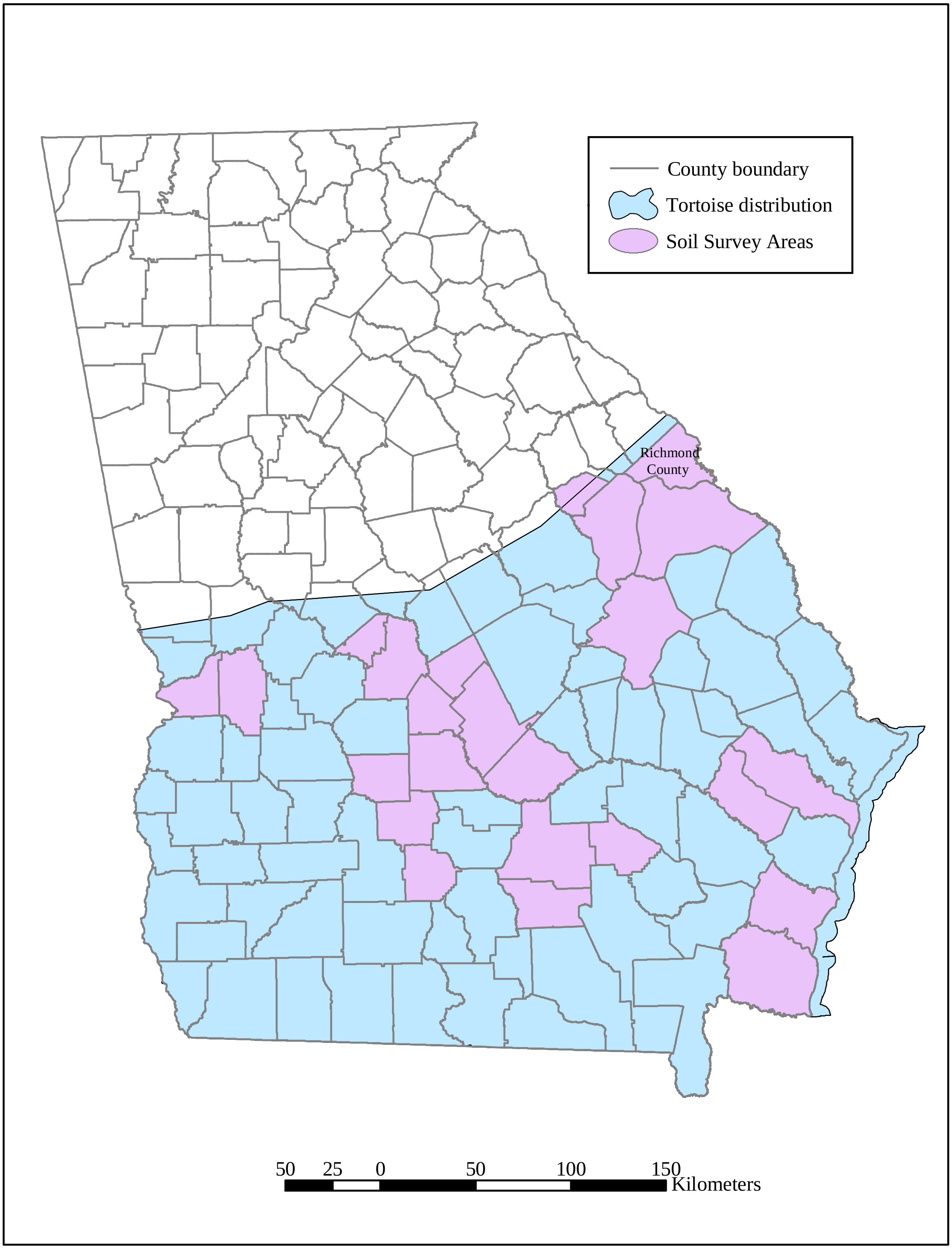

Figure 4. Gopher tortoise range distribution; SSURGO soil survey areas.

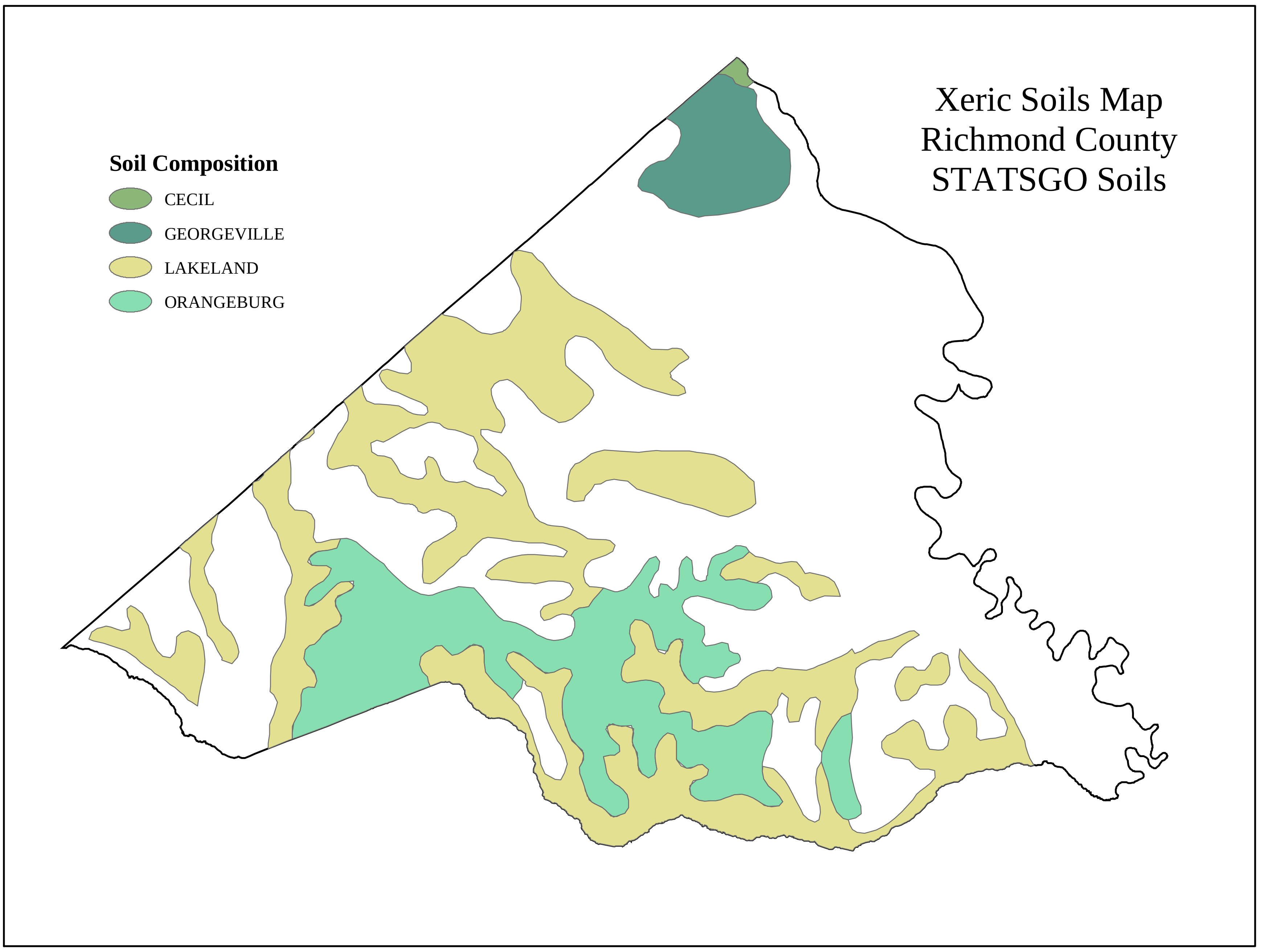

Figure 5a. Soils suitable for gopher tortoise habitation, derived from STASTGO data.

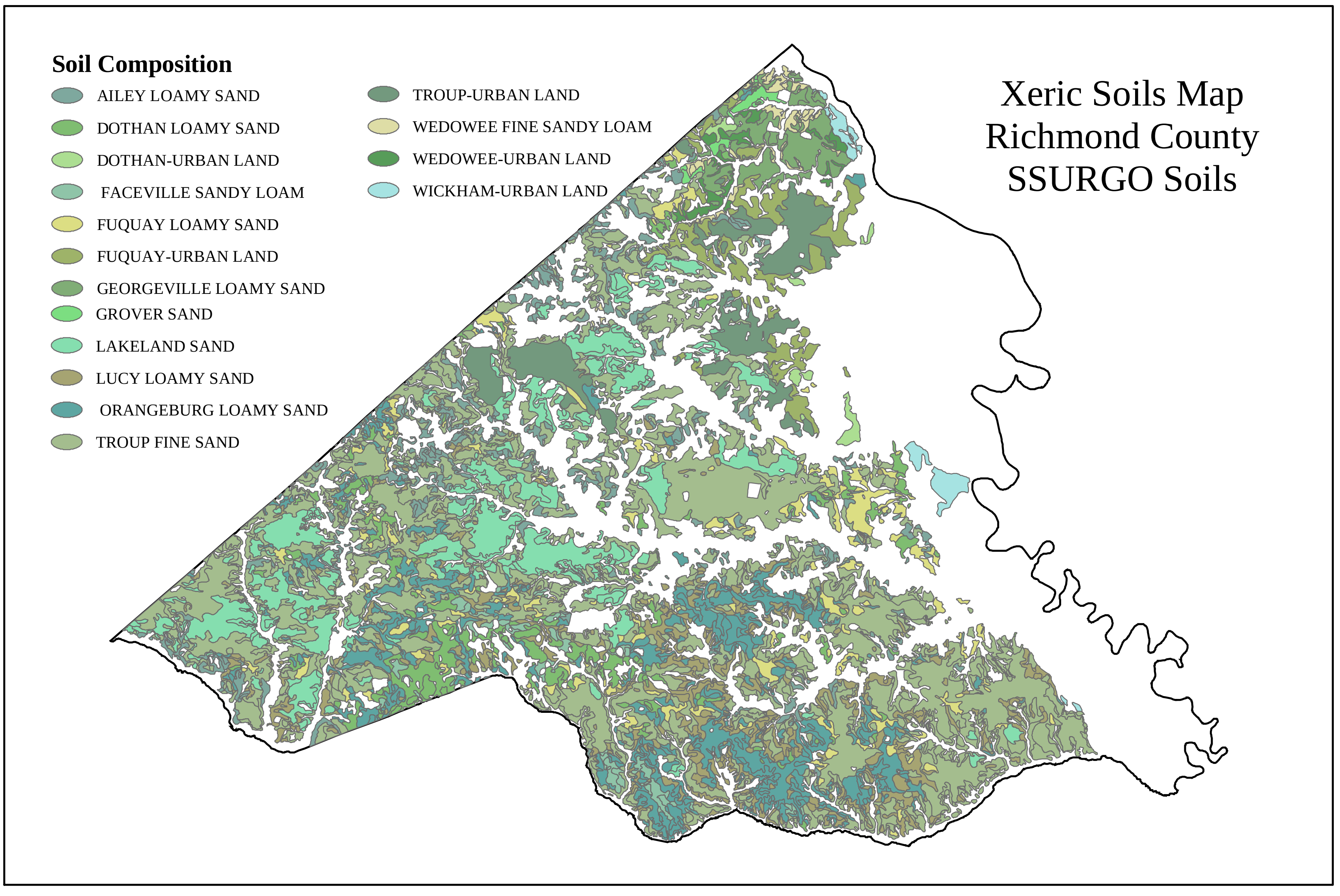

Figure 5b. Soils suitable for gopher tortoise habitation, derived from SSURGO data.

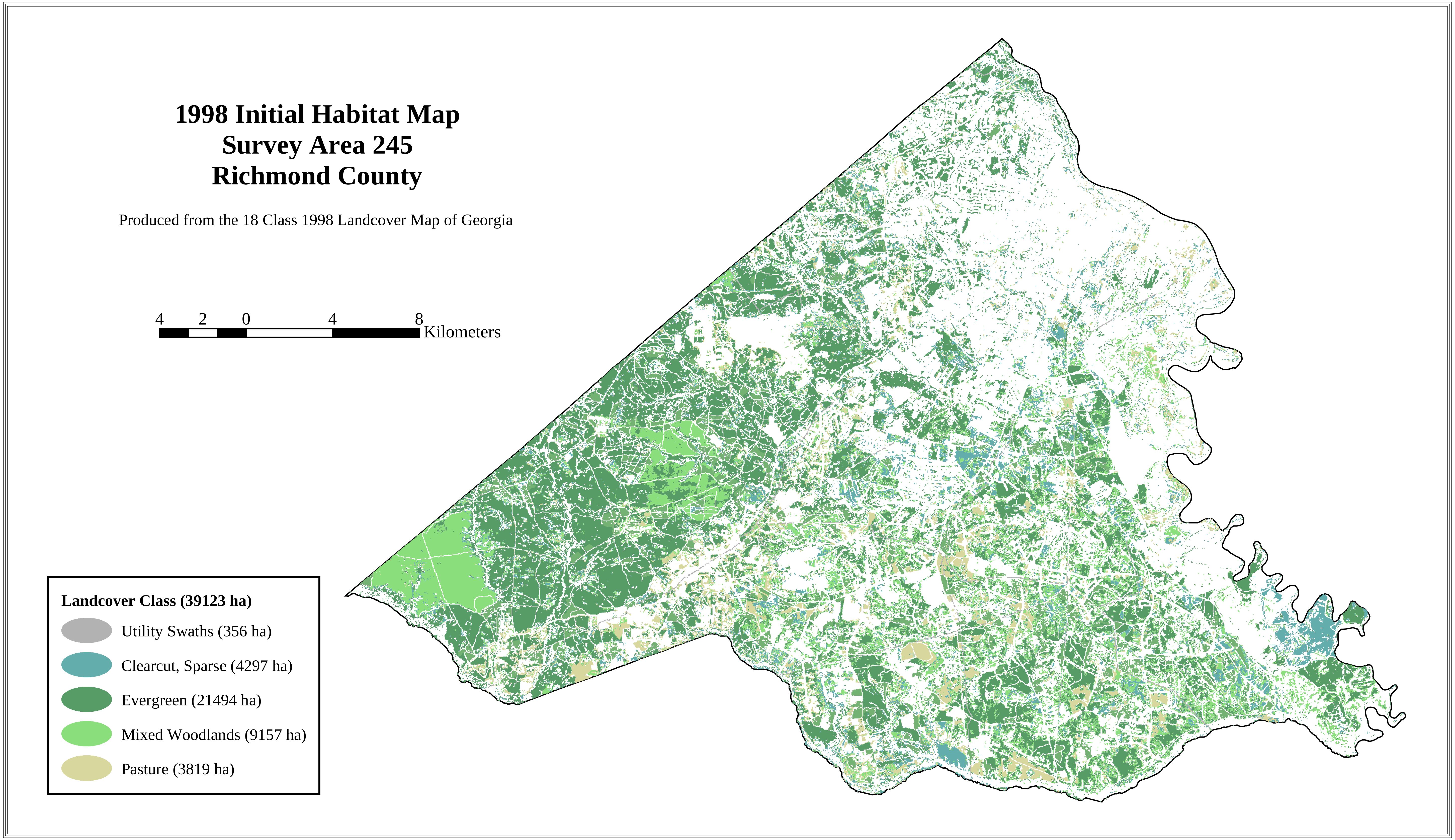

Figure 6. Initial Habitat Map produced from the 18 Class 1998 Landcover Map of Georgia.

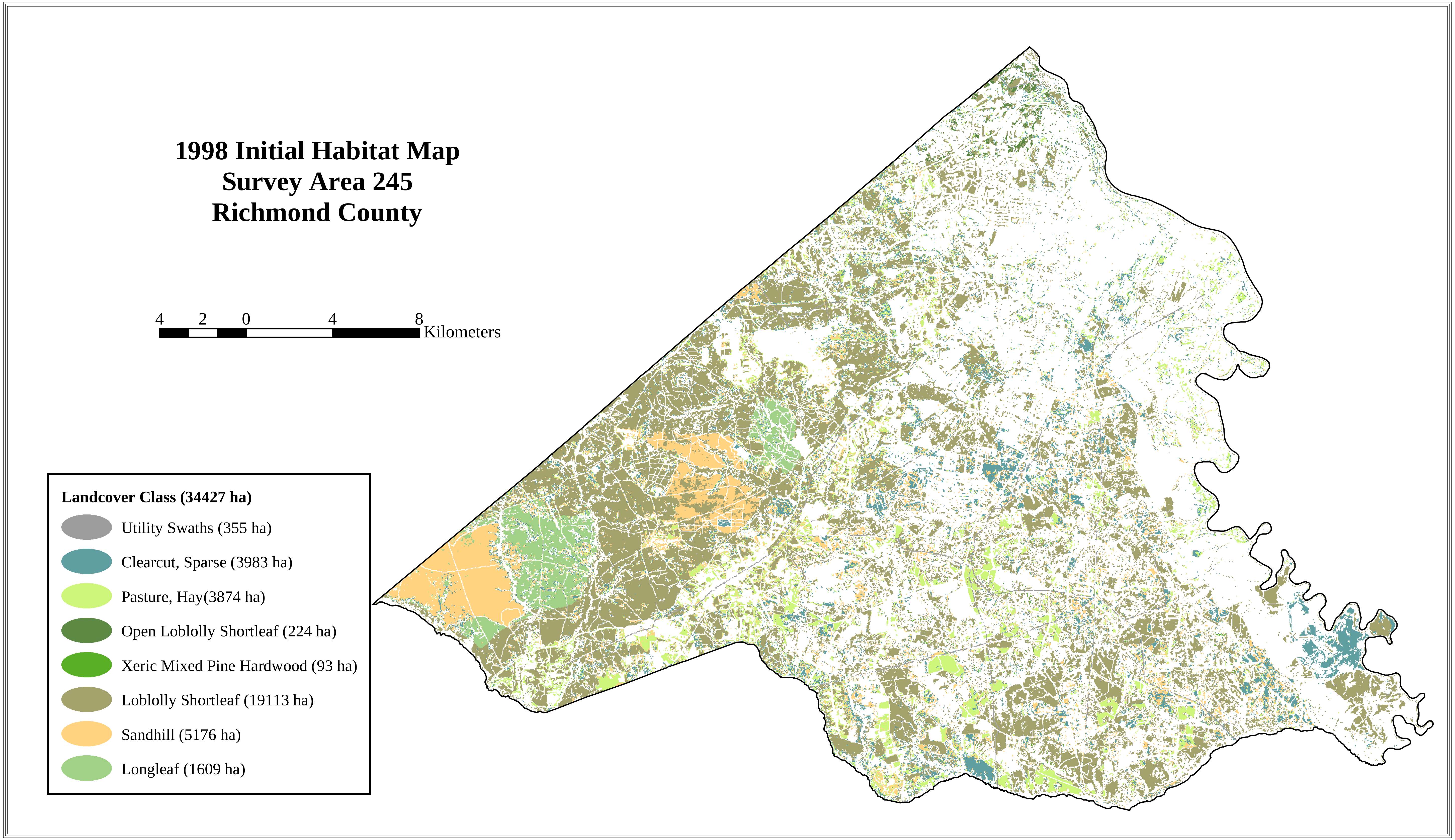

Figure 7. Initial Habitat Map produced from the 1998 44 Class Landcover Map of Georgia.

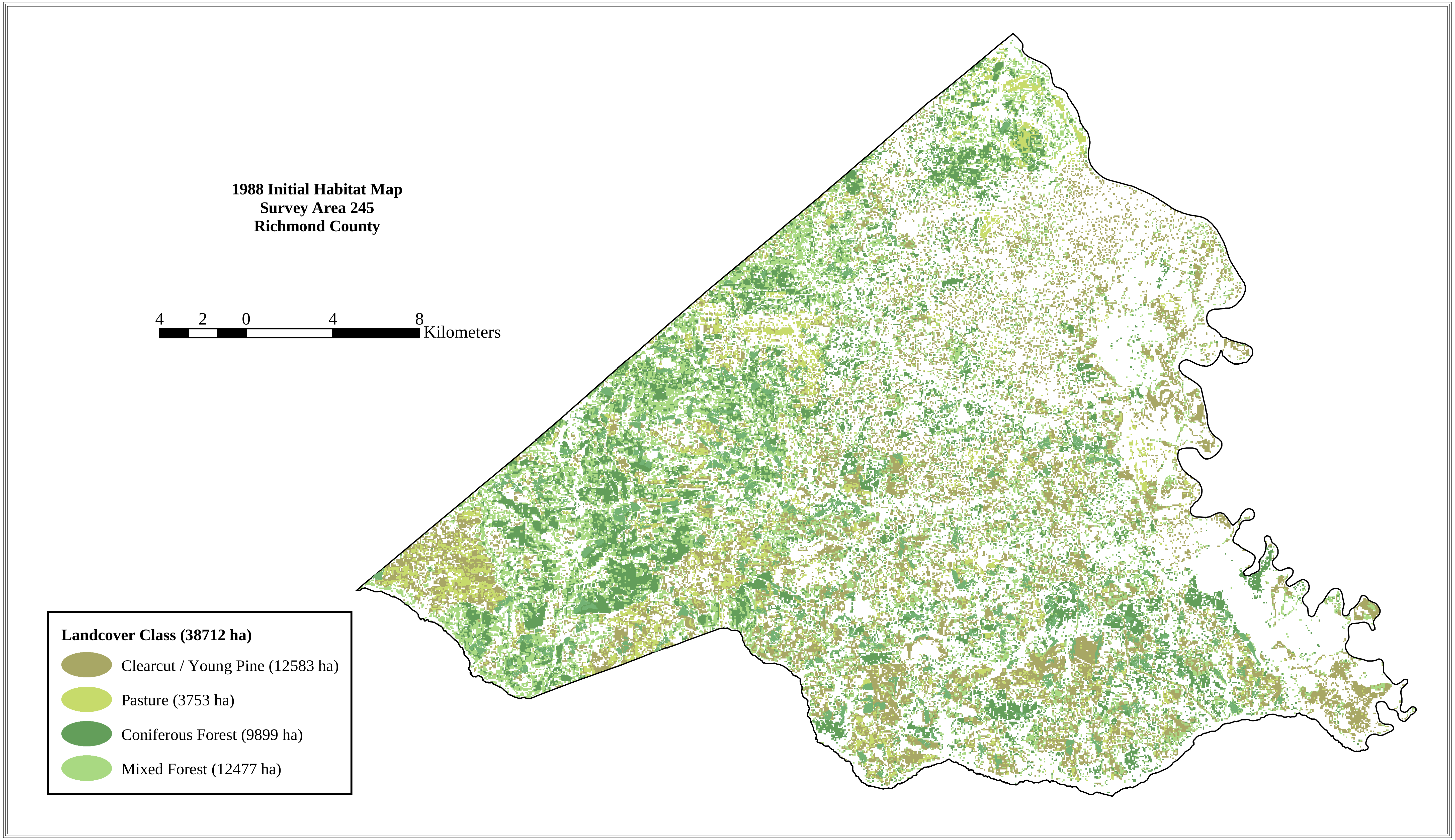

Figure 8. Initial Habitat Map produced from the 1988 Landcover Map of Georgia.

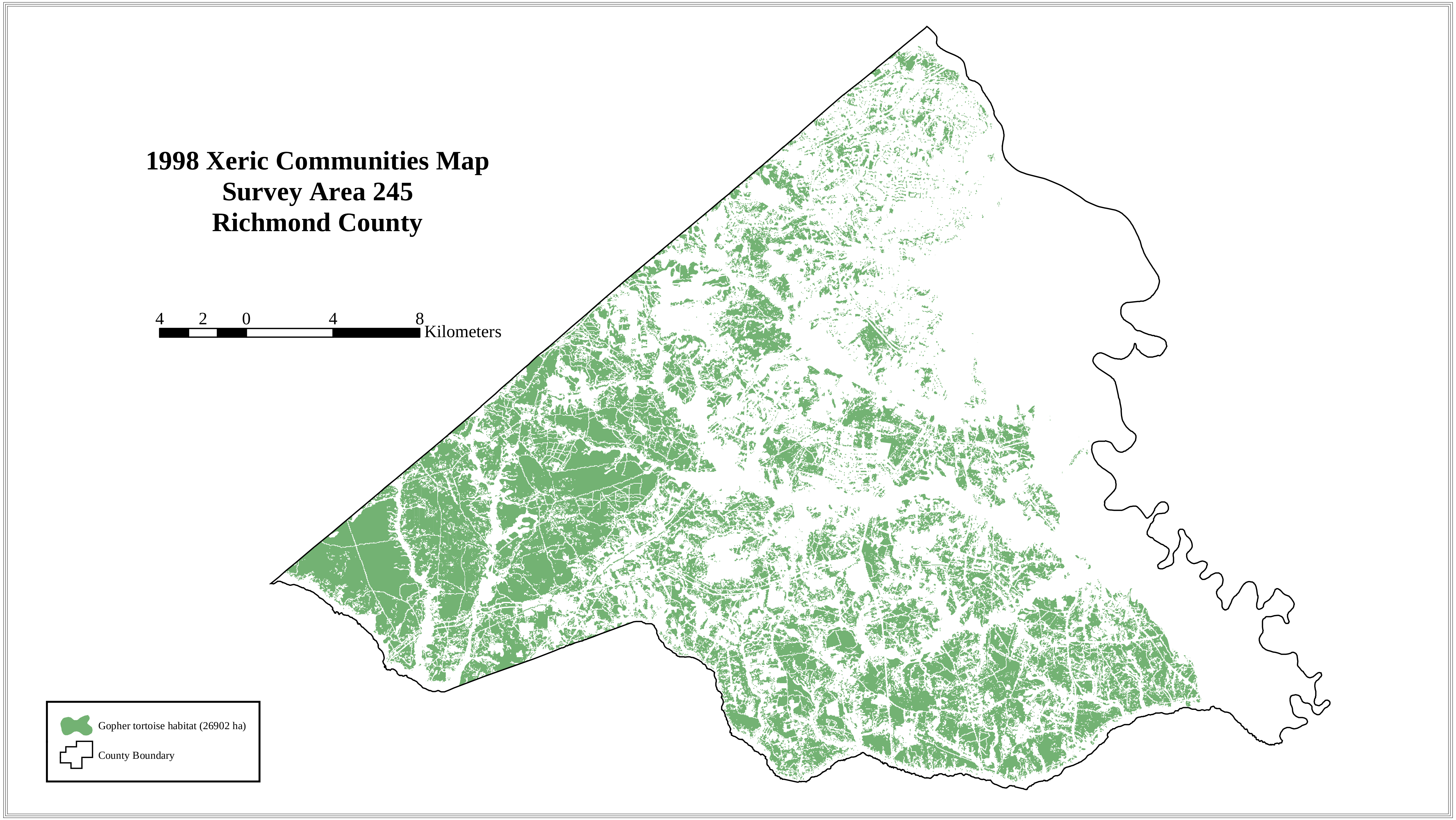

Figure 9. Xeric Communities Map produced by intersecting the Initial Habitat Map and the Xeric Soils Map.

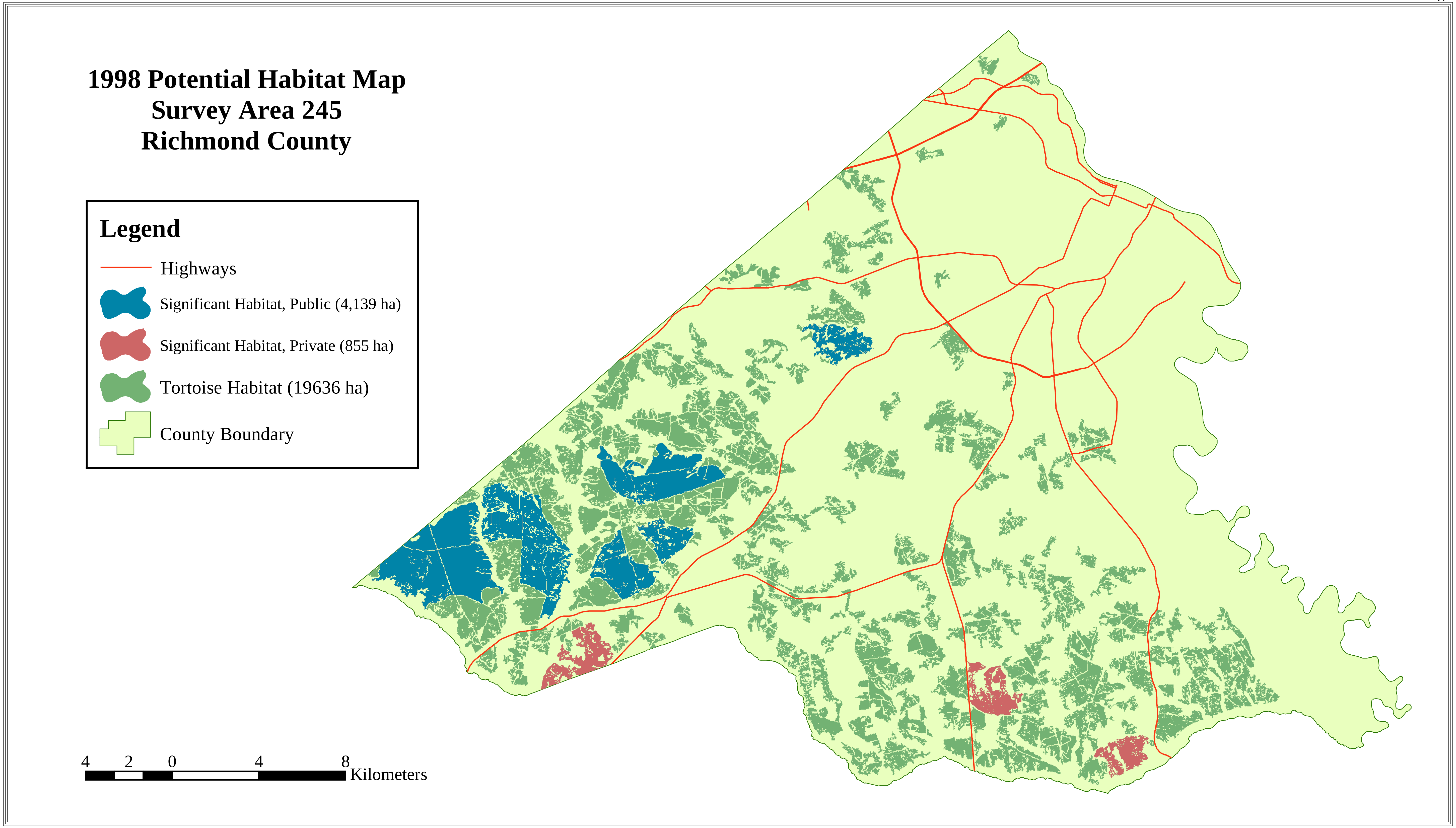

Figure 10. 1998 Potential Habitat Map, Richmond County

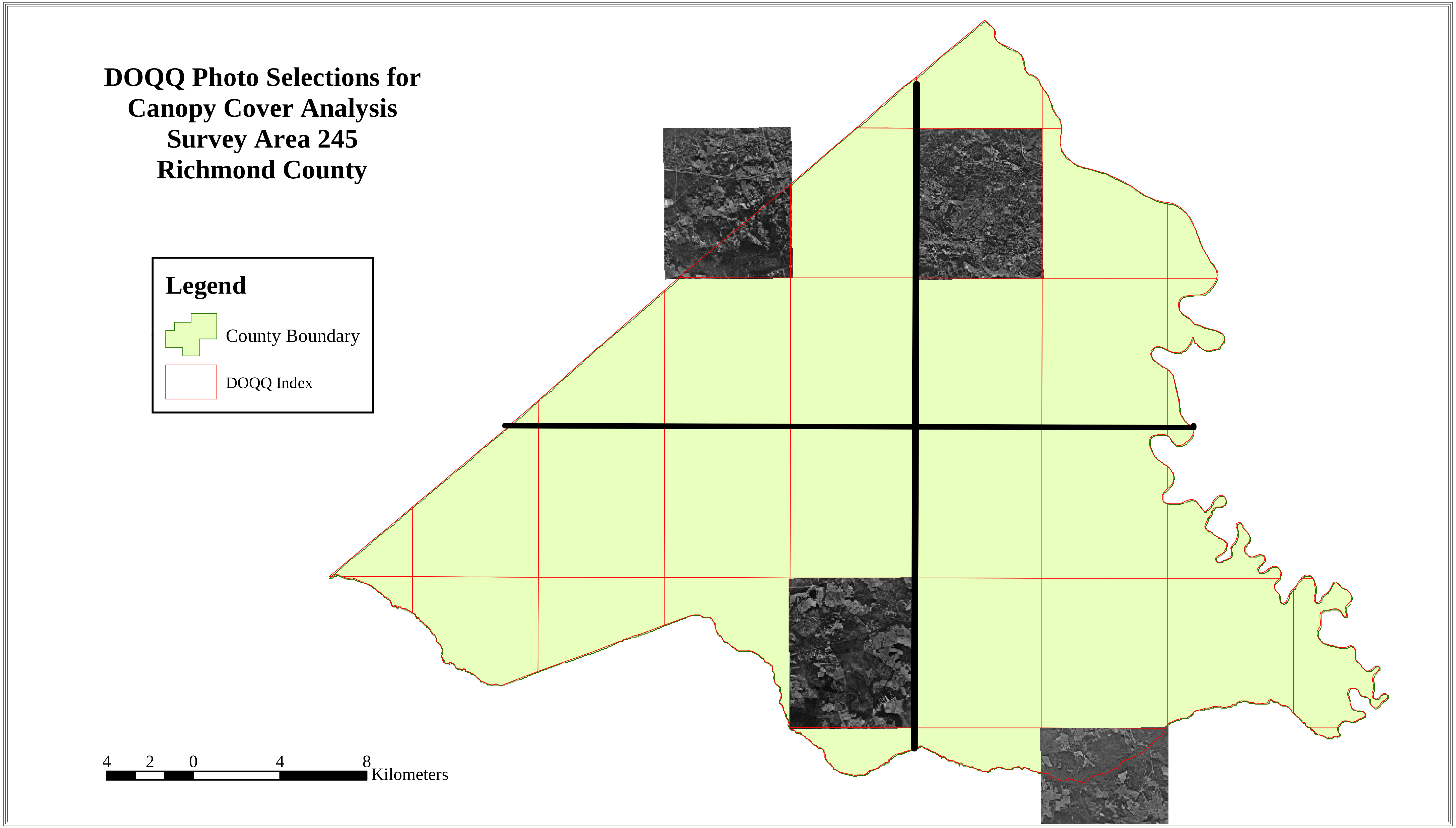

Figure 11. Distribution of Digital Orthophoto Quarter Quads used in canopy cover analysis.

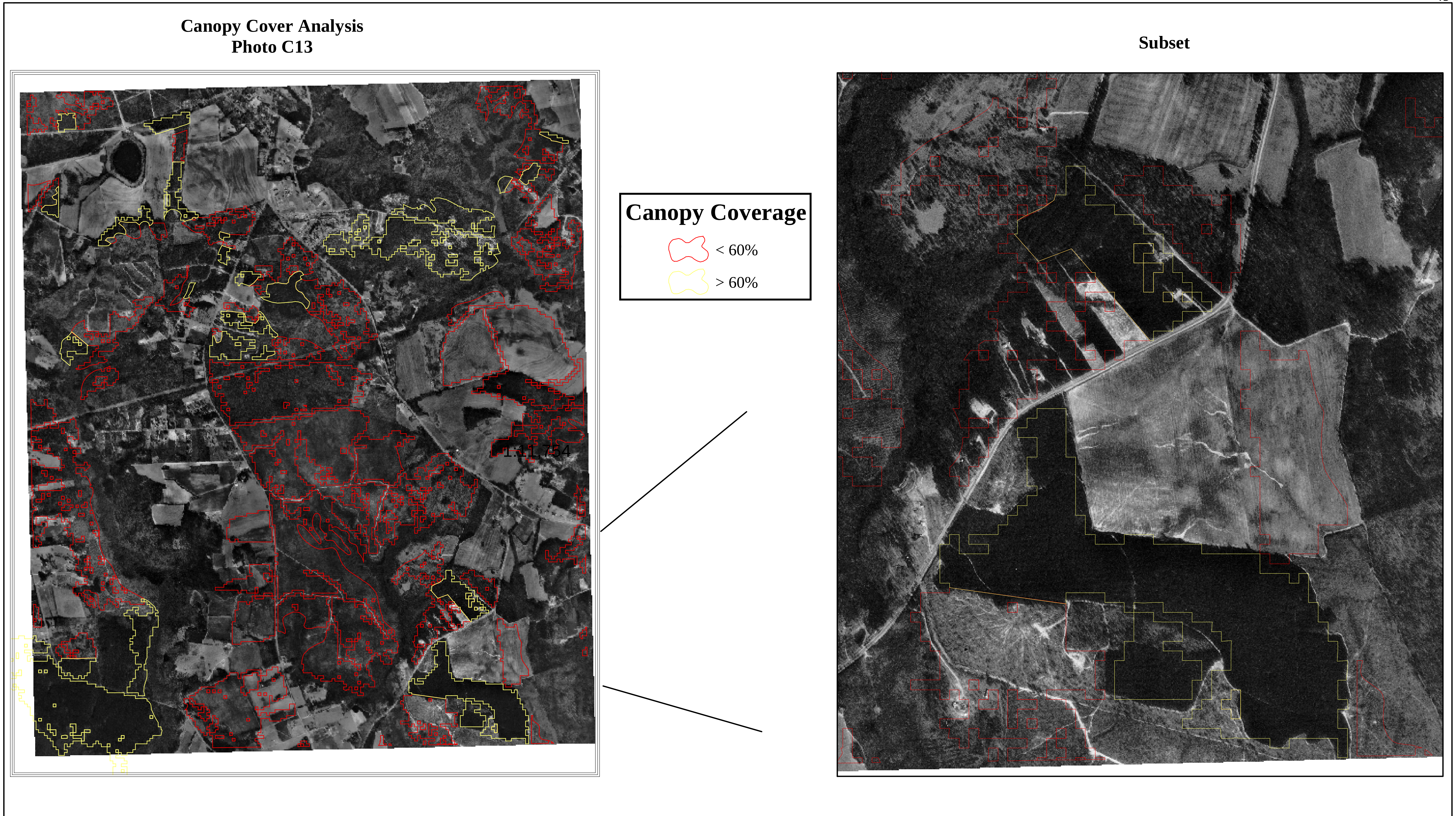

Figure 13. Example of aerial photo interpretation. Areas in red are habitat areas predicted by the HSM. Areas in yellow have more than 60% canopy coverage and are excluded from the final analysis.

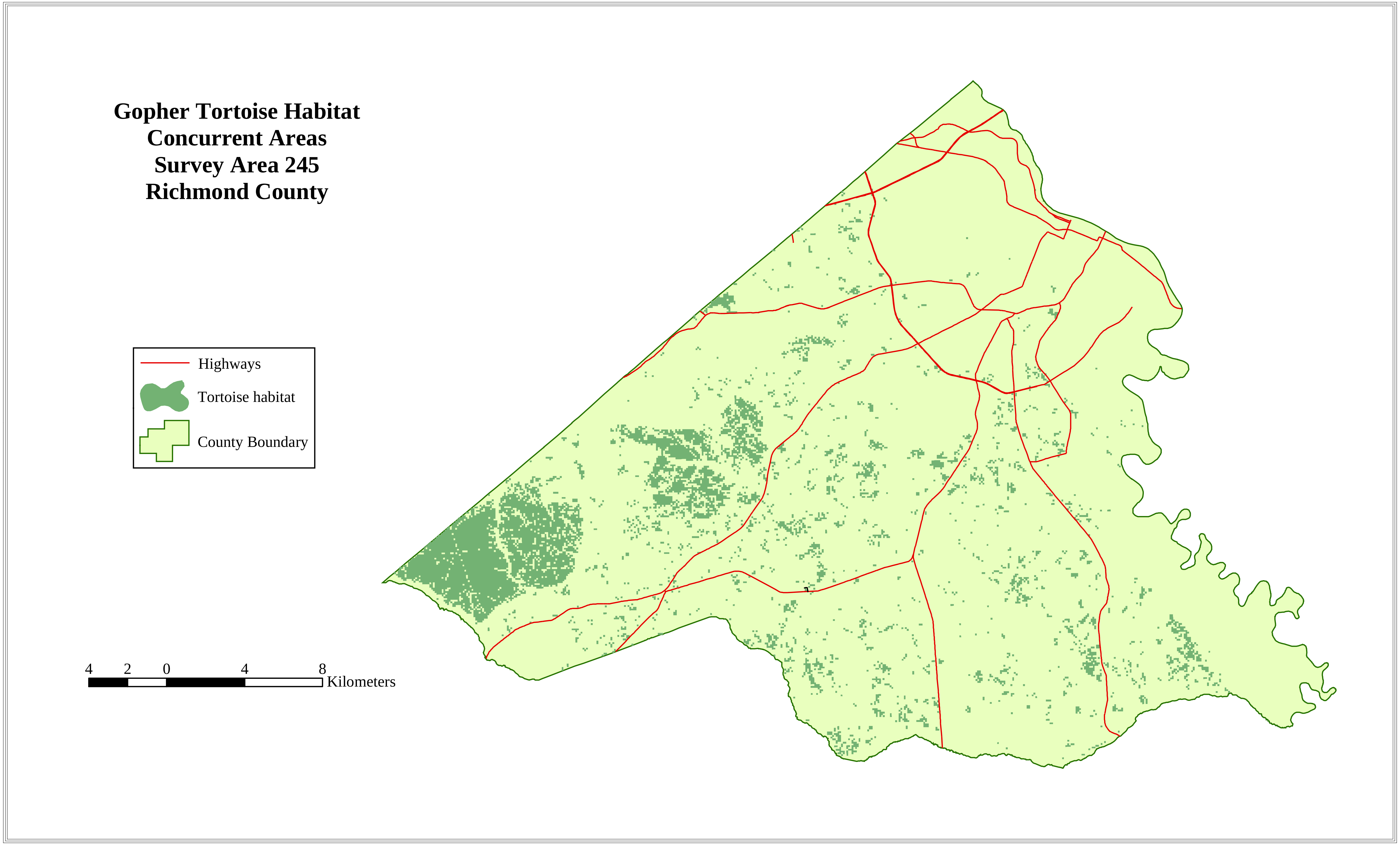

Figure 14. Habitat areas concurrent to both the GAP distribution map and the potential habitat map.

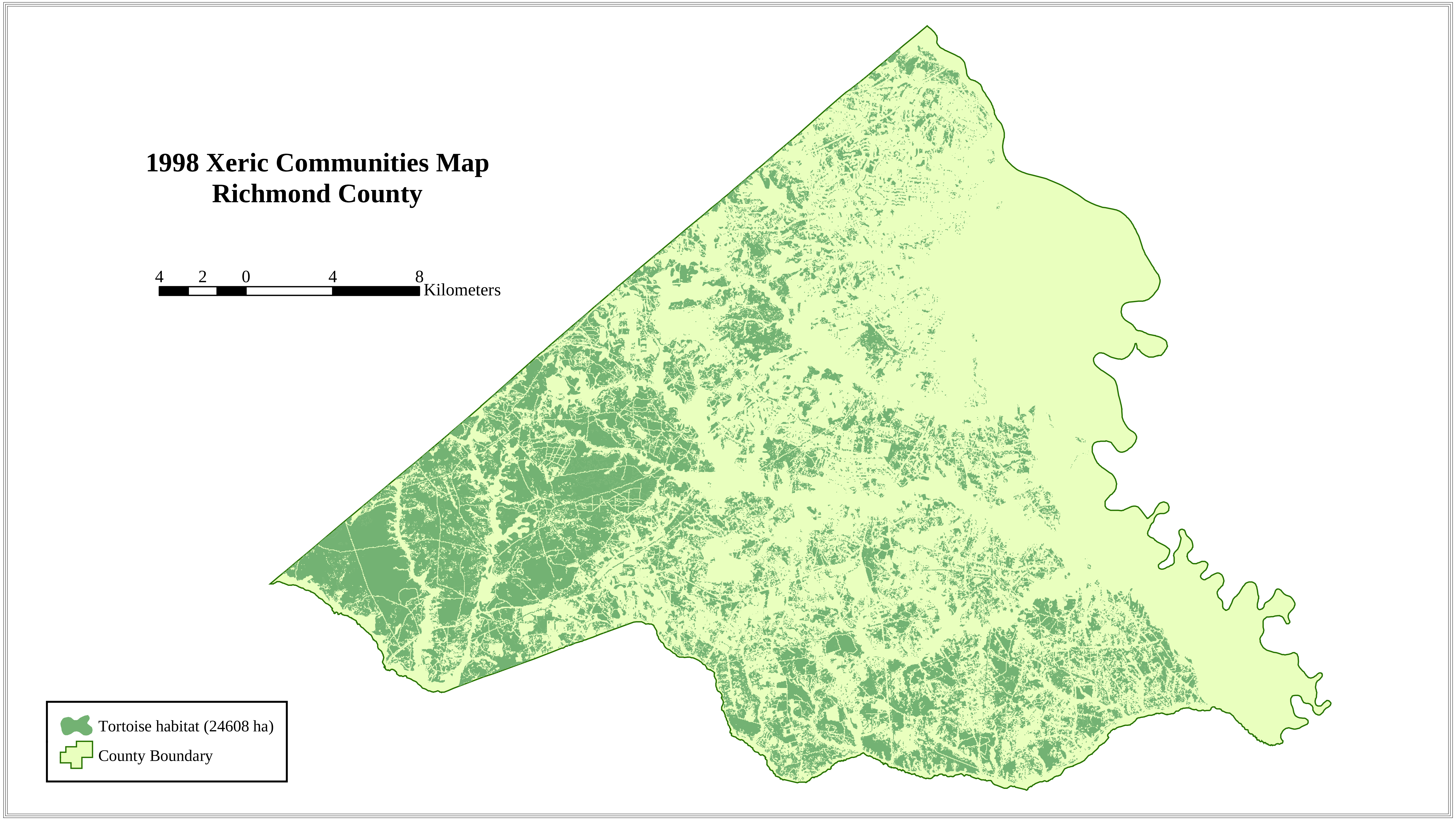

Figure 15. 44 class Xeric Communities Map produced by intersecting the Initial Habitat Map and the Xeric Soils Map.

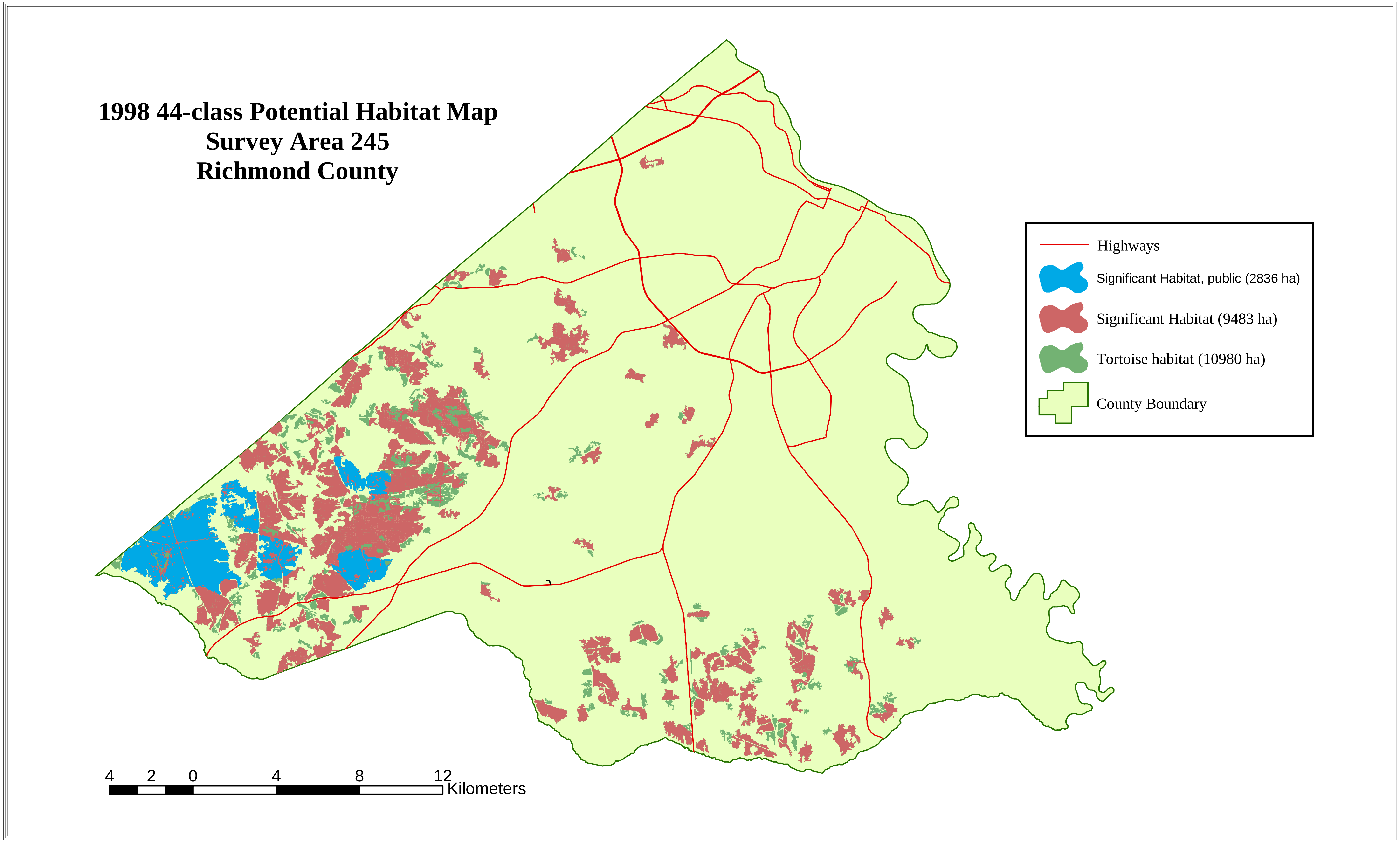

Figure 16. 1998 Potential Habitat Map derived from the 44-class Landcover Map of Georgia.

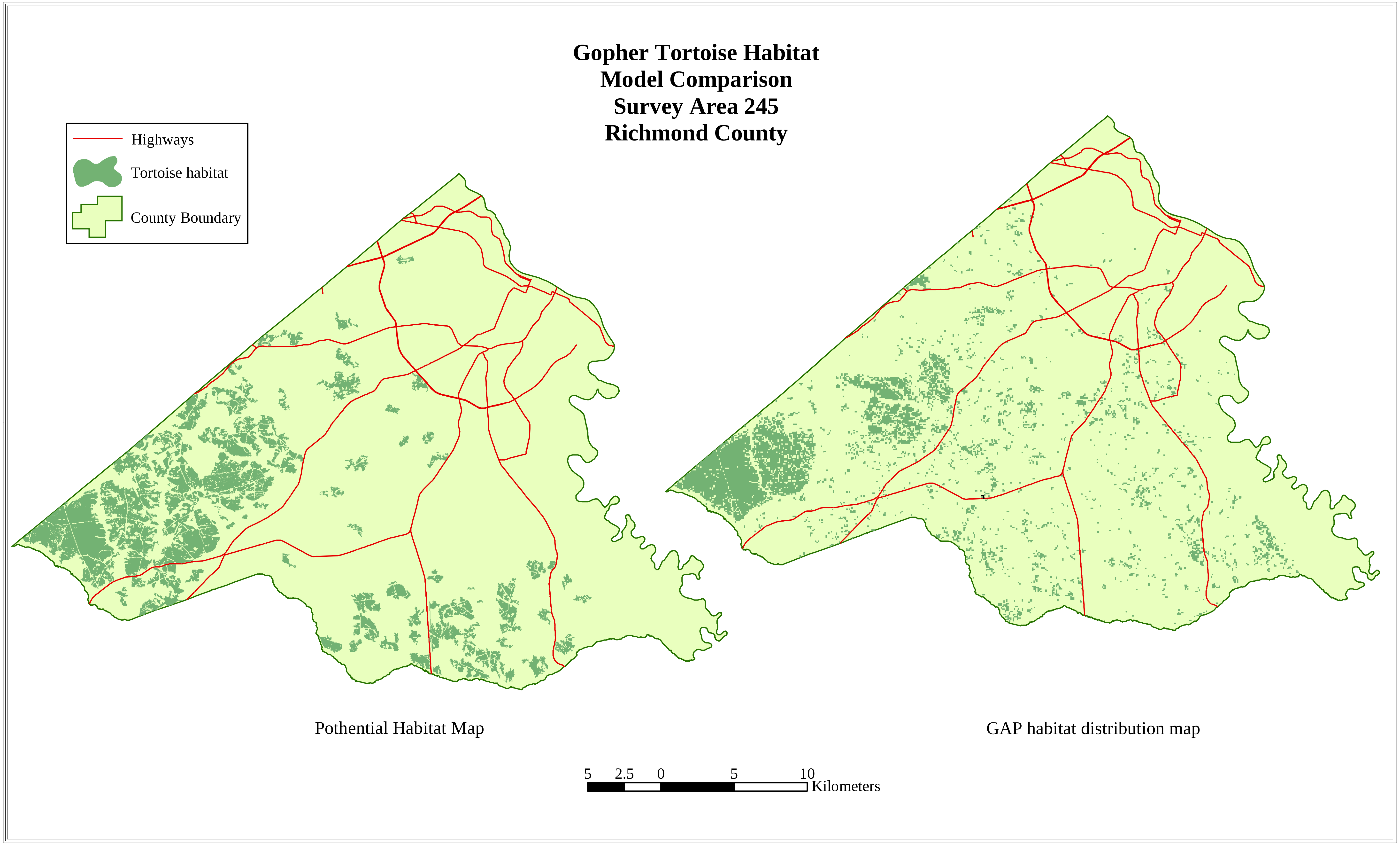

Figure 19. A comparison of the GAP gopher tortoise distribution map and the Potential Habitat Map.

APPENDIX A

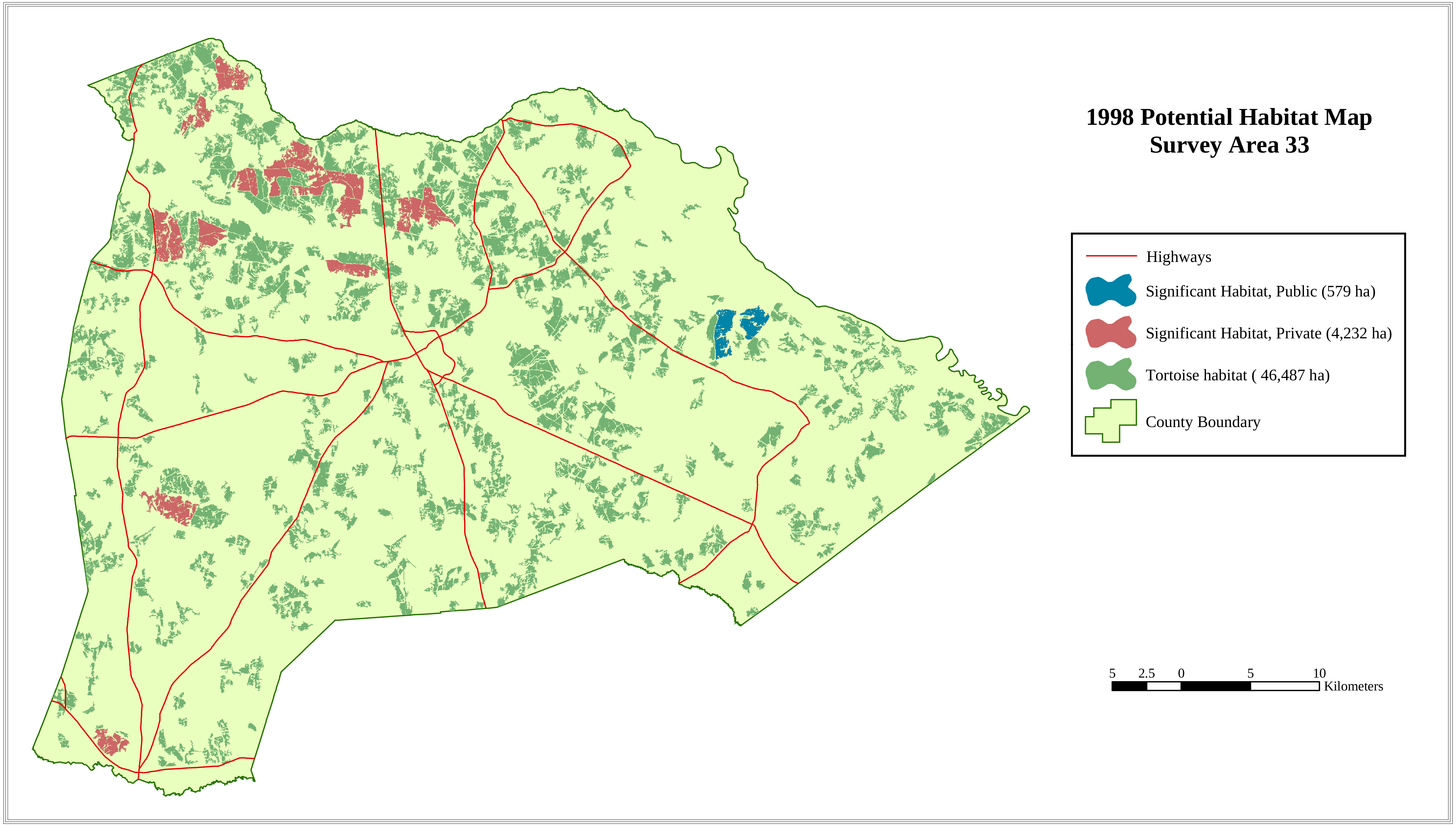

Figure A1. 1998 Potential Habitat Map. Burke County.

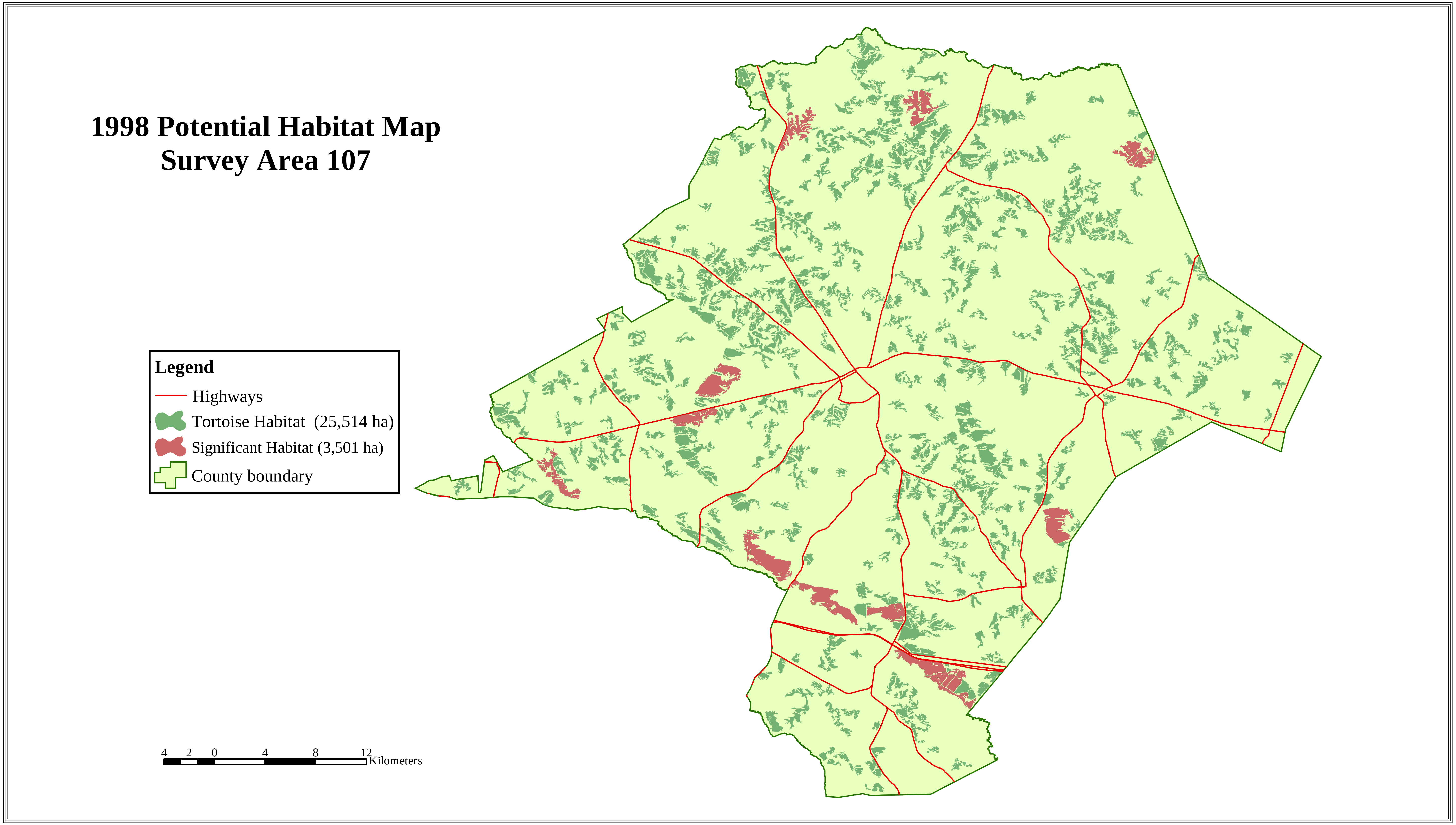

Figure A3. 1998 Potential Habitat Map, Emmanual County

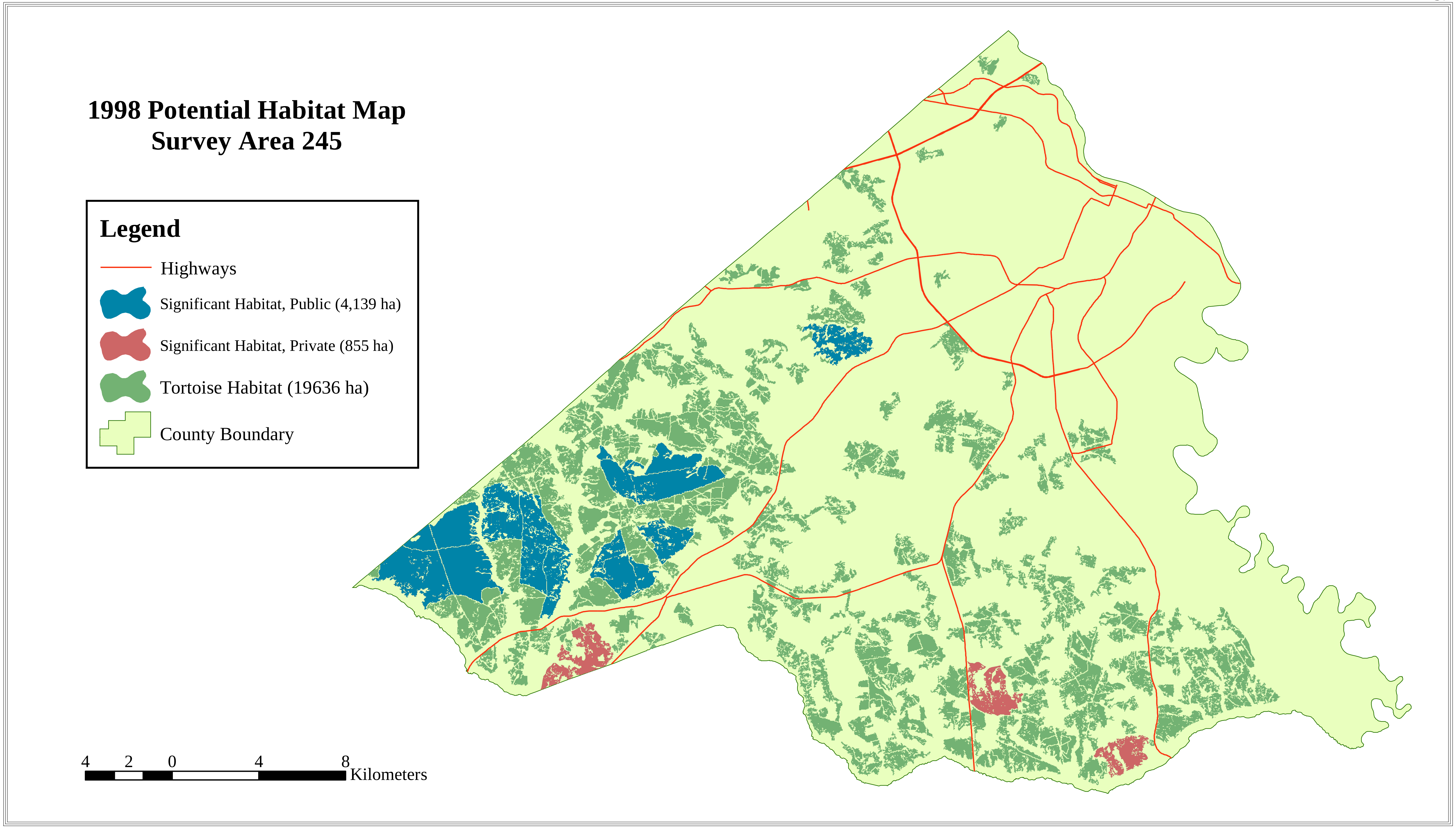

Figure A3. 1998 Potential Habitat Map, Richmond County

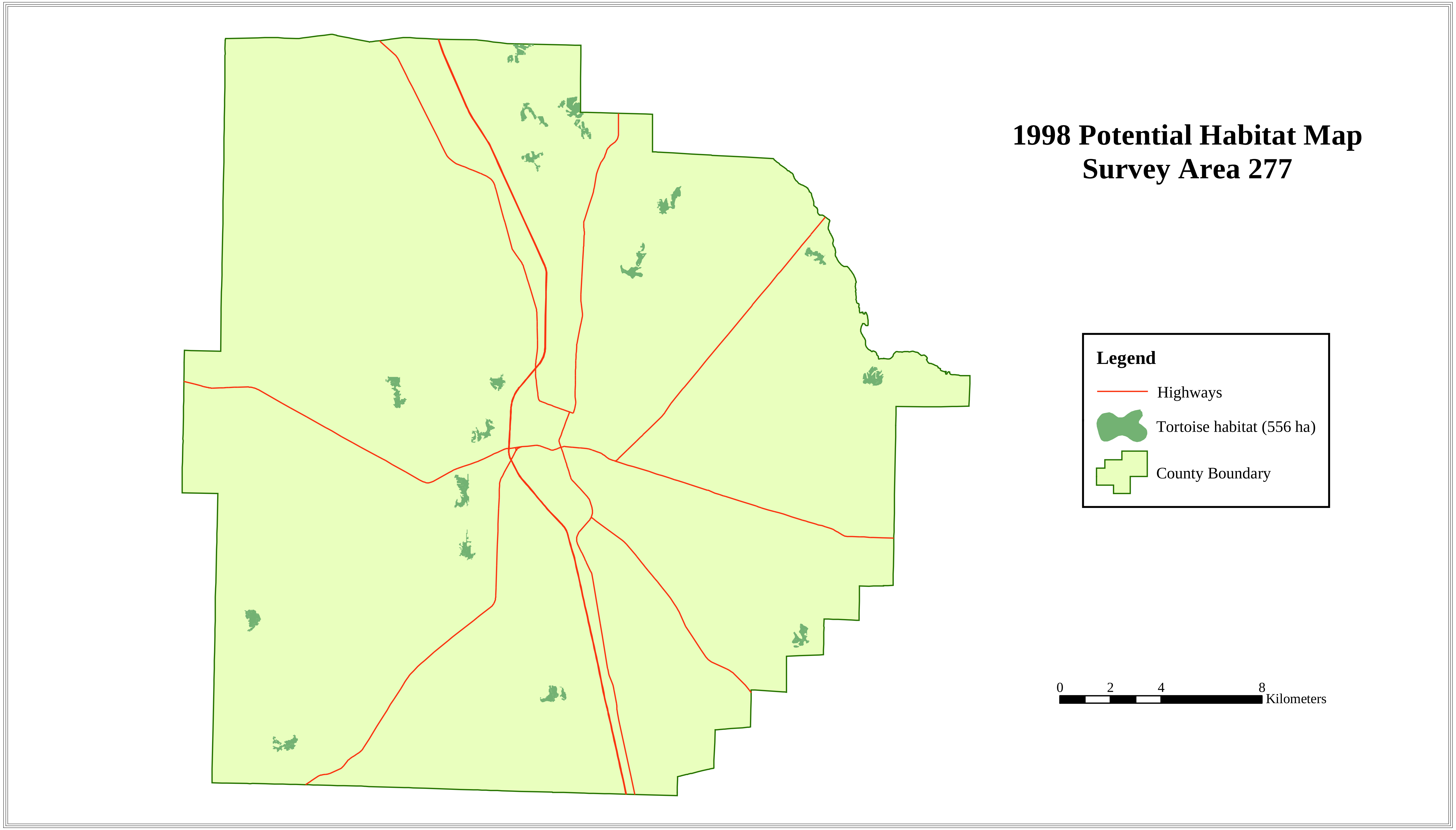

Figure A4. 1998 Potential Habitat Map, Tift County

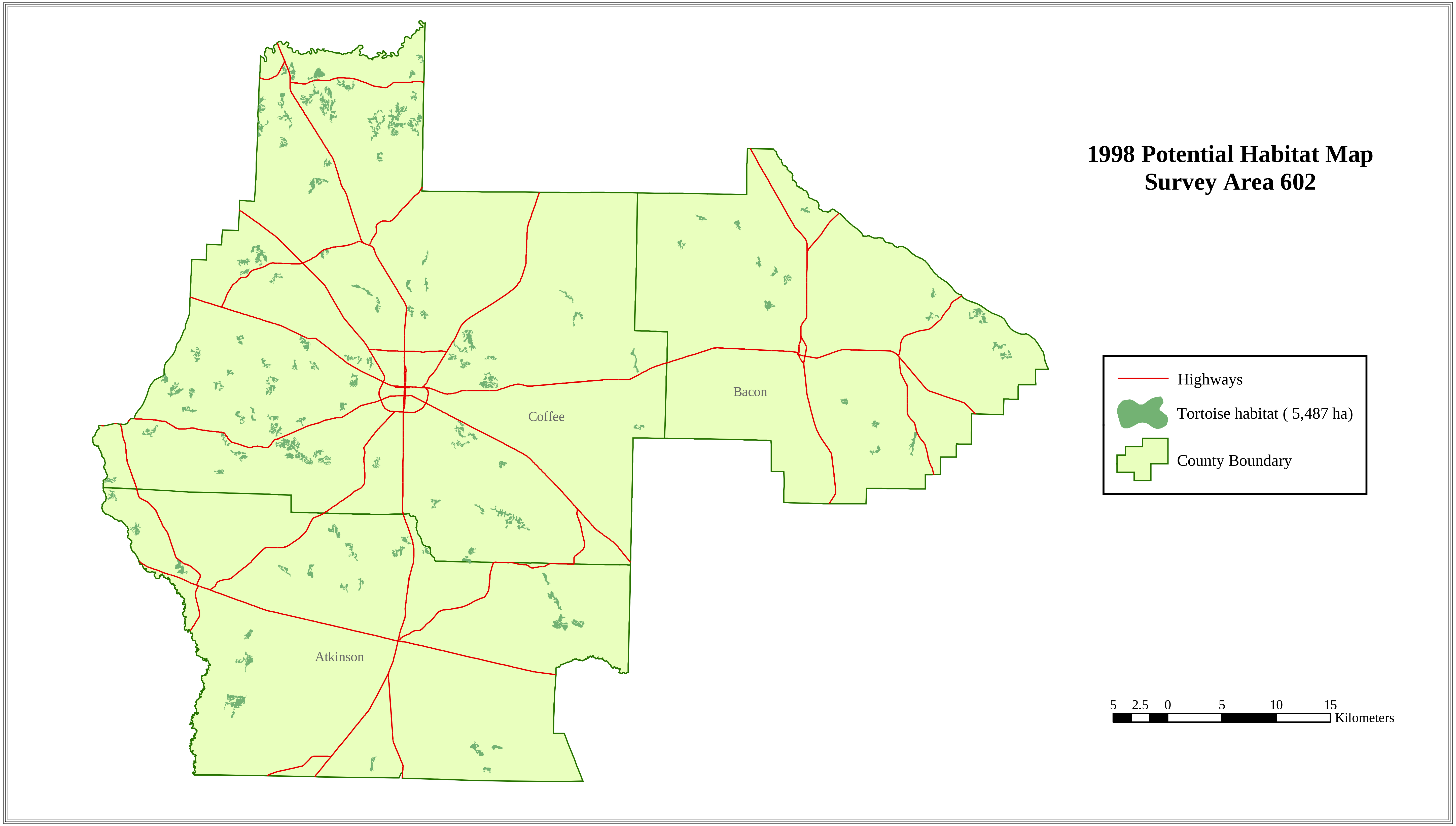

Figure A5. 1998 Potential Habitat Map, Atkinson, Bacon, and Coffee Counties.

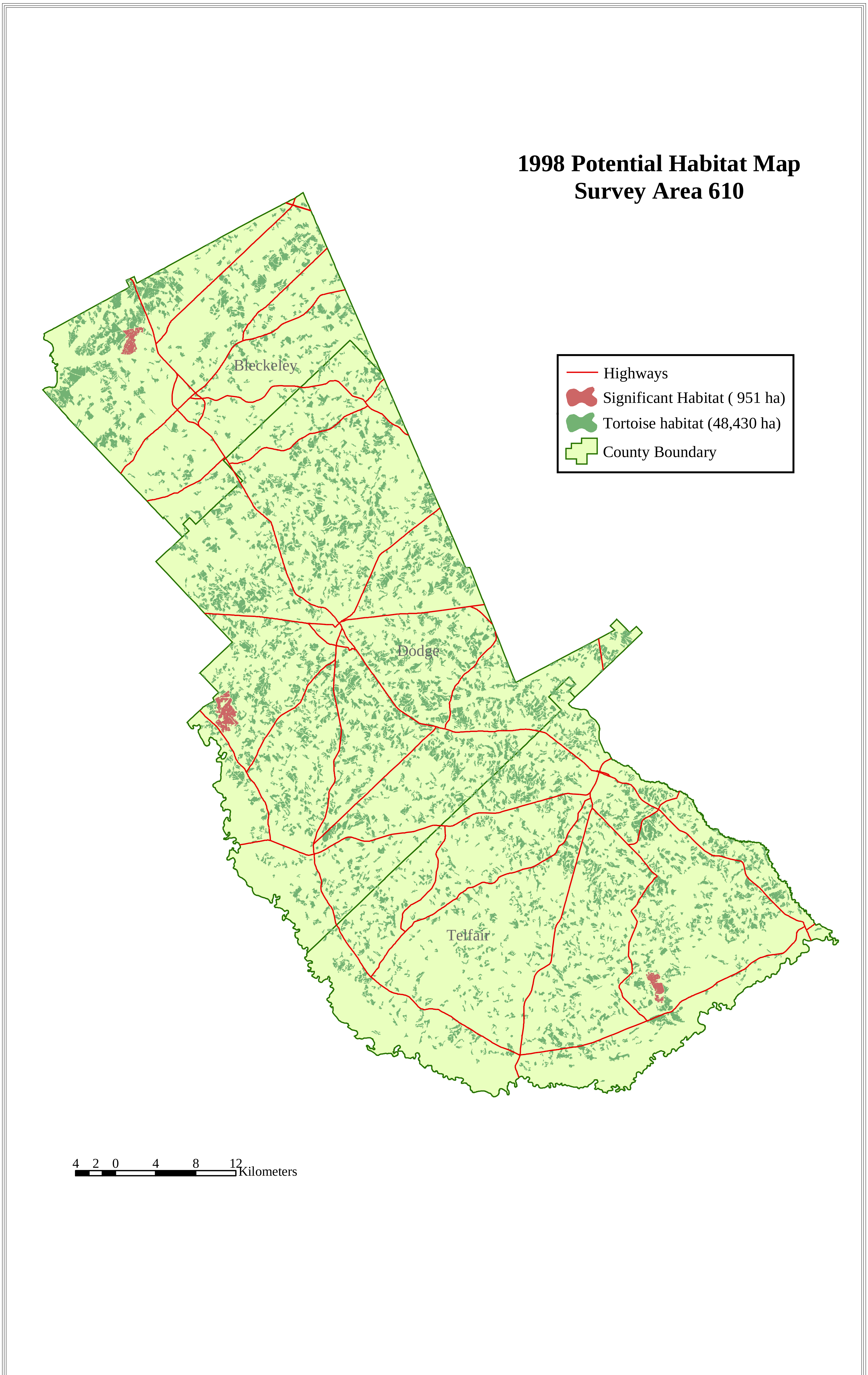

Figure A6. 1998 Potential Habitat Map. Blekely, Dodge, and Telfair Counties

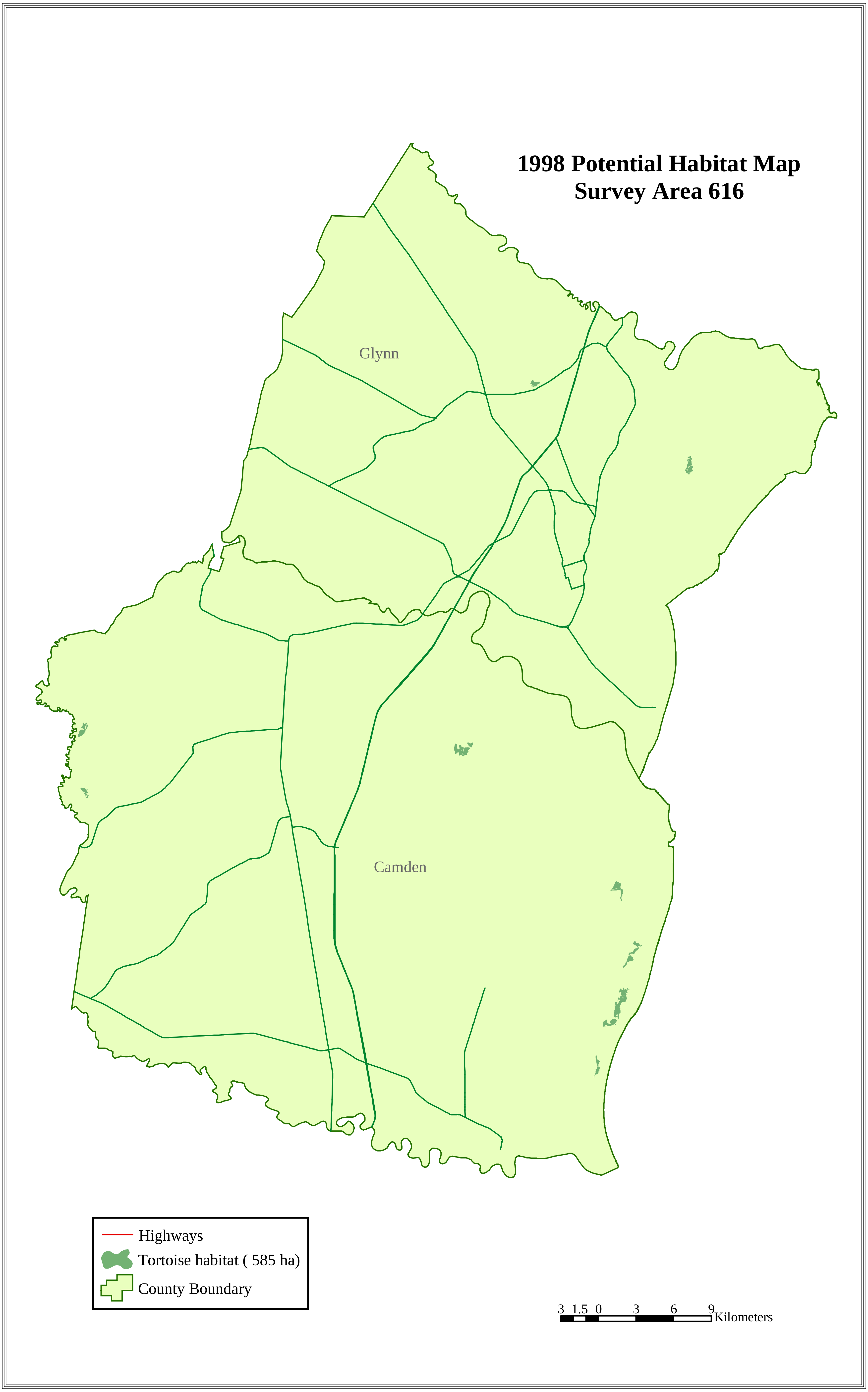

Figure A7. 1998 Potential Habitat Map. Camden and Glynn Counties

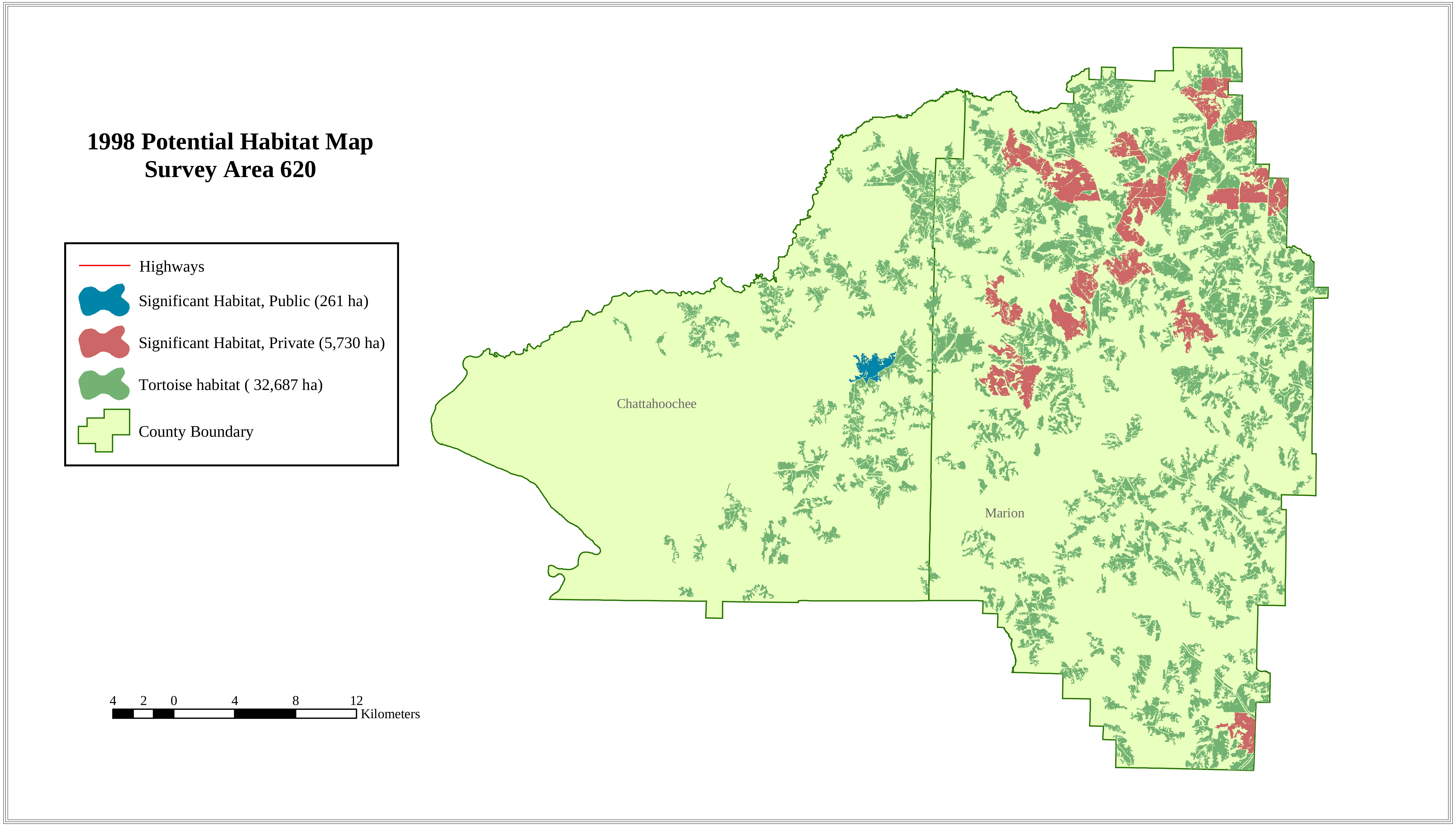

Figure A8. 1998 Potential Habitat Map. Chattahoochee and Marion Counties.

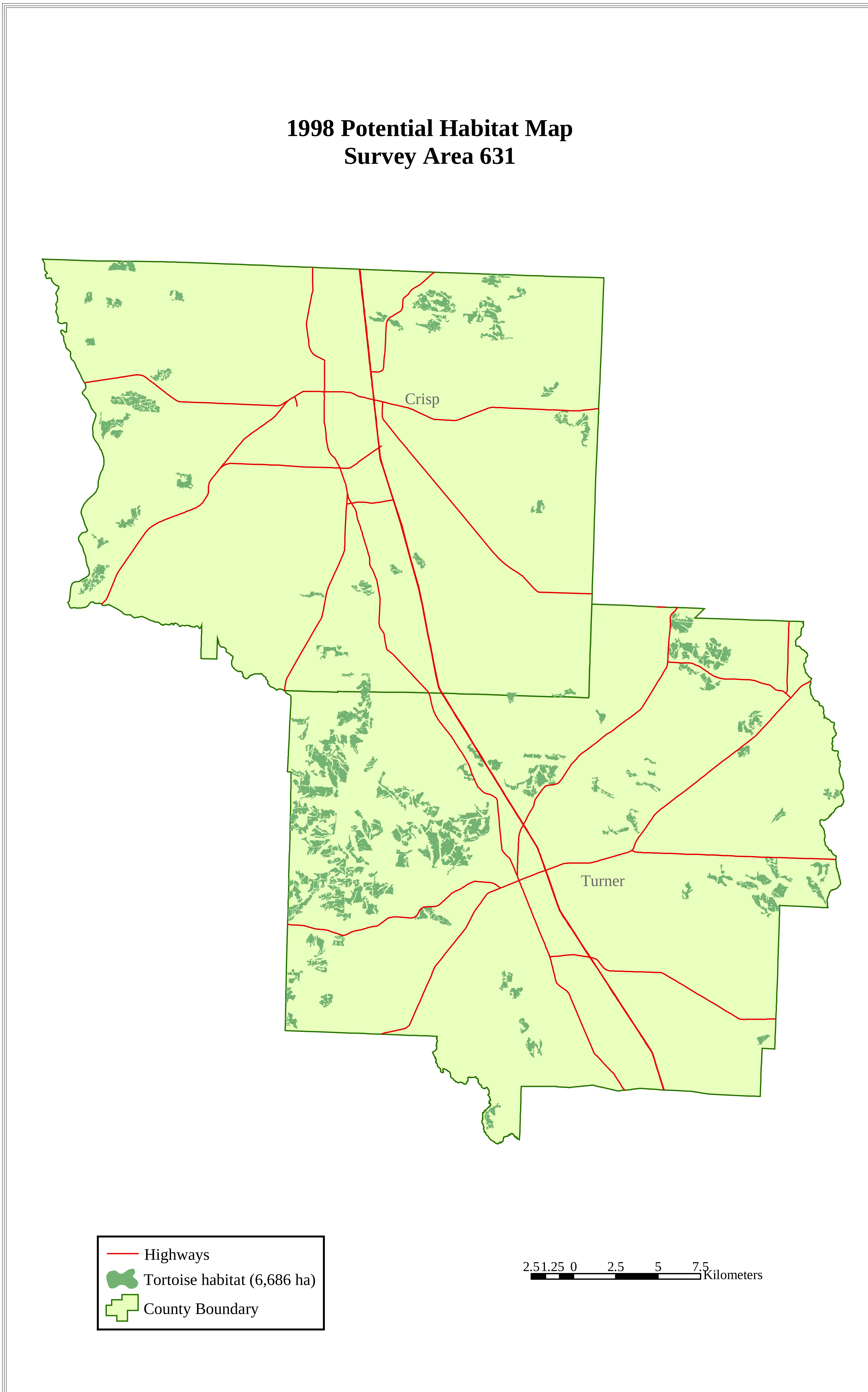

Figure A9. 1998 Potential Habitat Map. Crisp and Turner Counties.

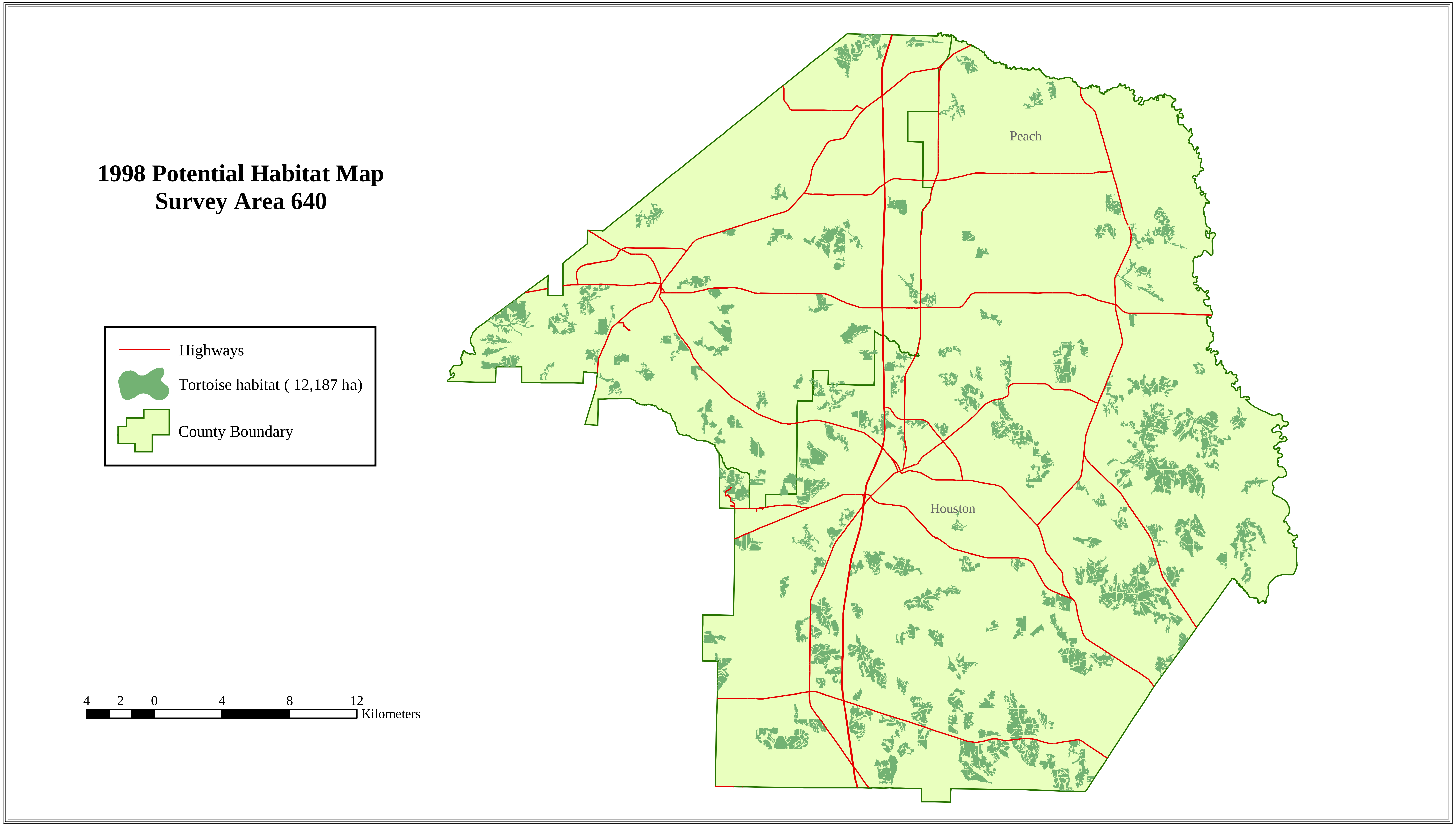

Figure A10. 1998 Potential Habitat Map. Houston and Peach Counties.

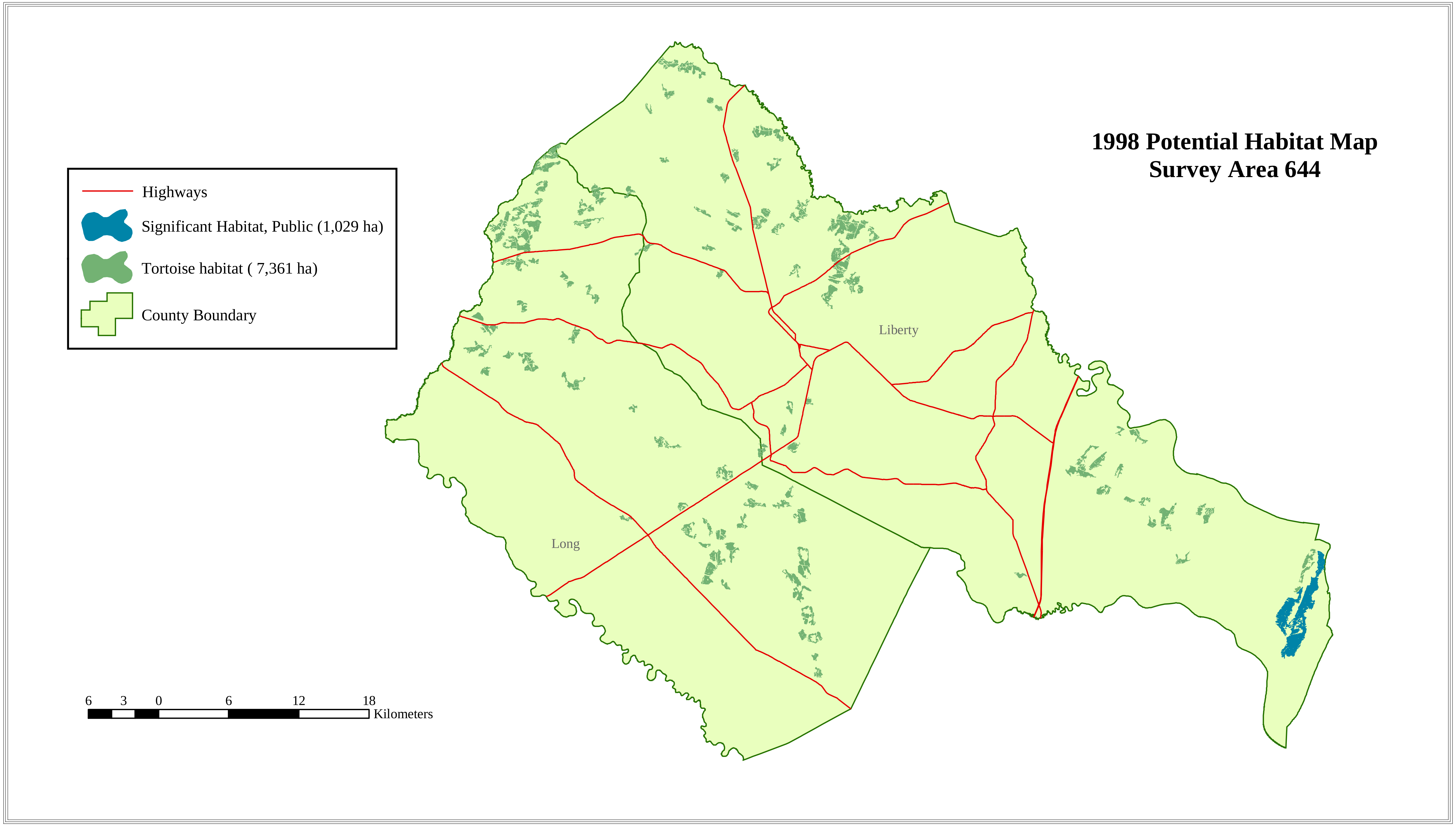

Figure A11. 1998 Potential Habitat Map. Liberty and Long Counties.

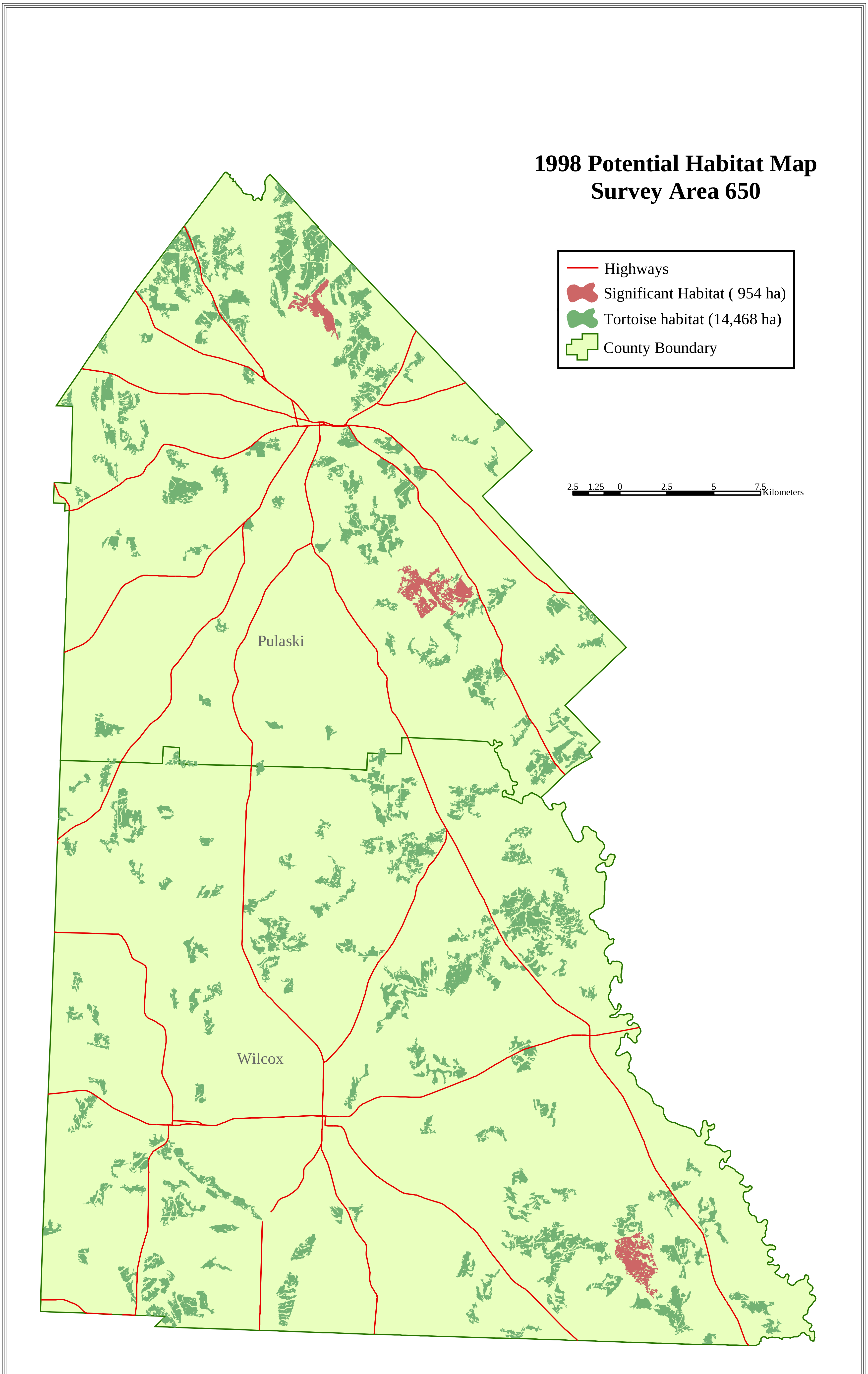

Figure A12. 1998 Potential Habitat Map. Pulaski and Wilcox Counties

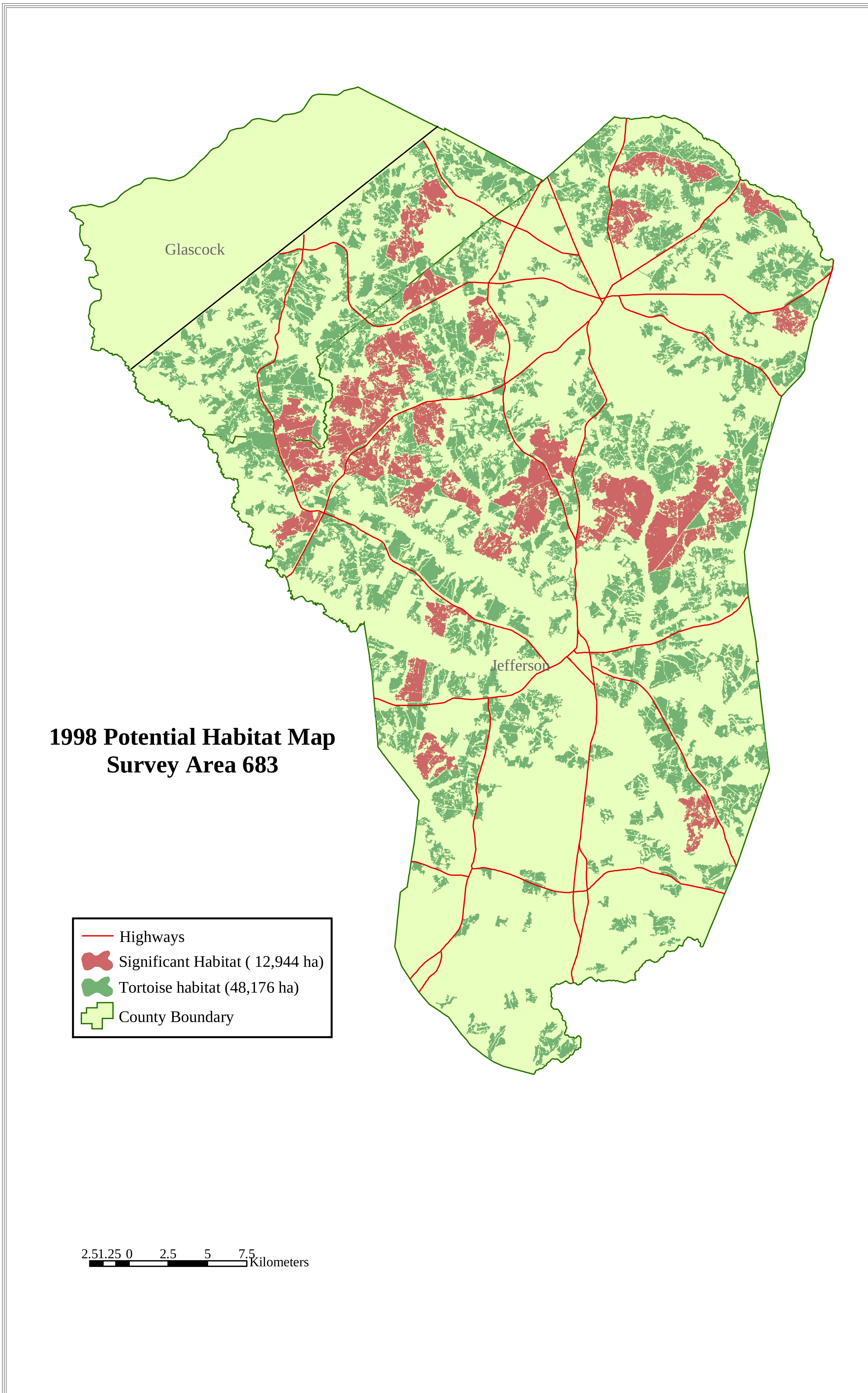

Figure A13. 1998 Potential Habitat Map. Glascock and Jefferson Counties

APPENDIX B

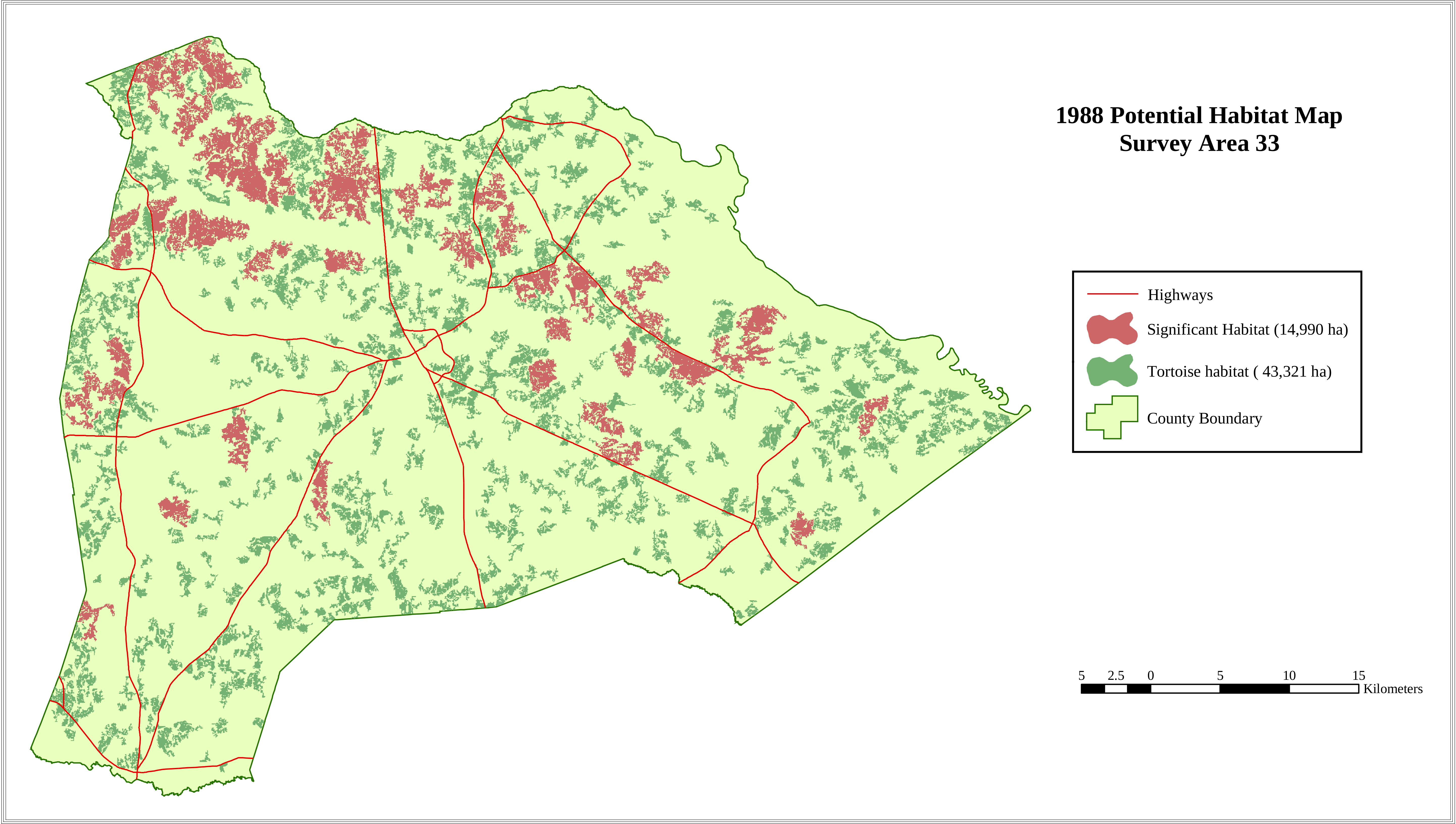

Figure B1. 1988 Potential Habitat Map. Burke County.

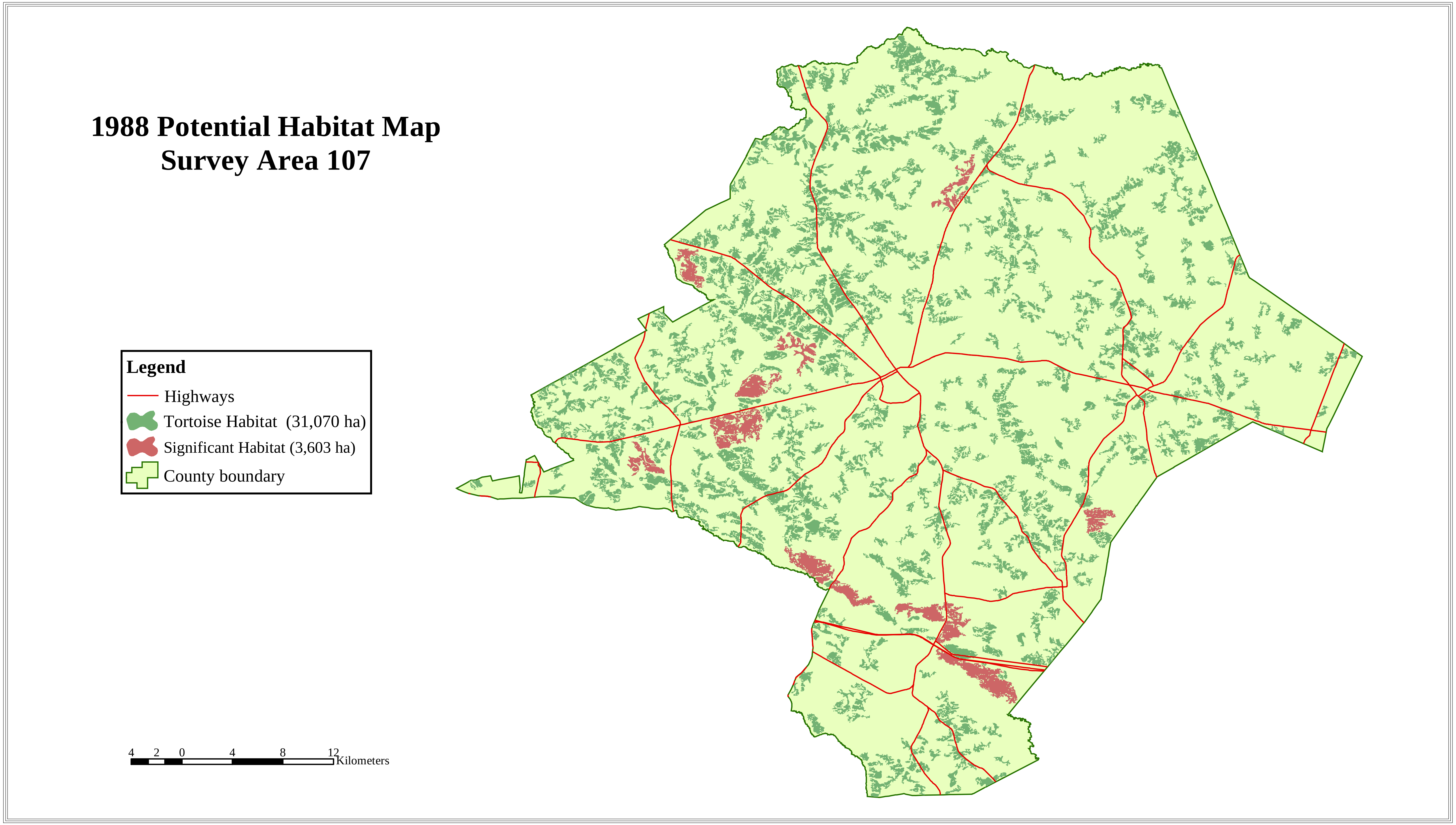

Figure B2. 1988 Potential Habitat Map, Emmanual County

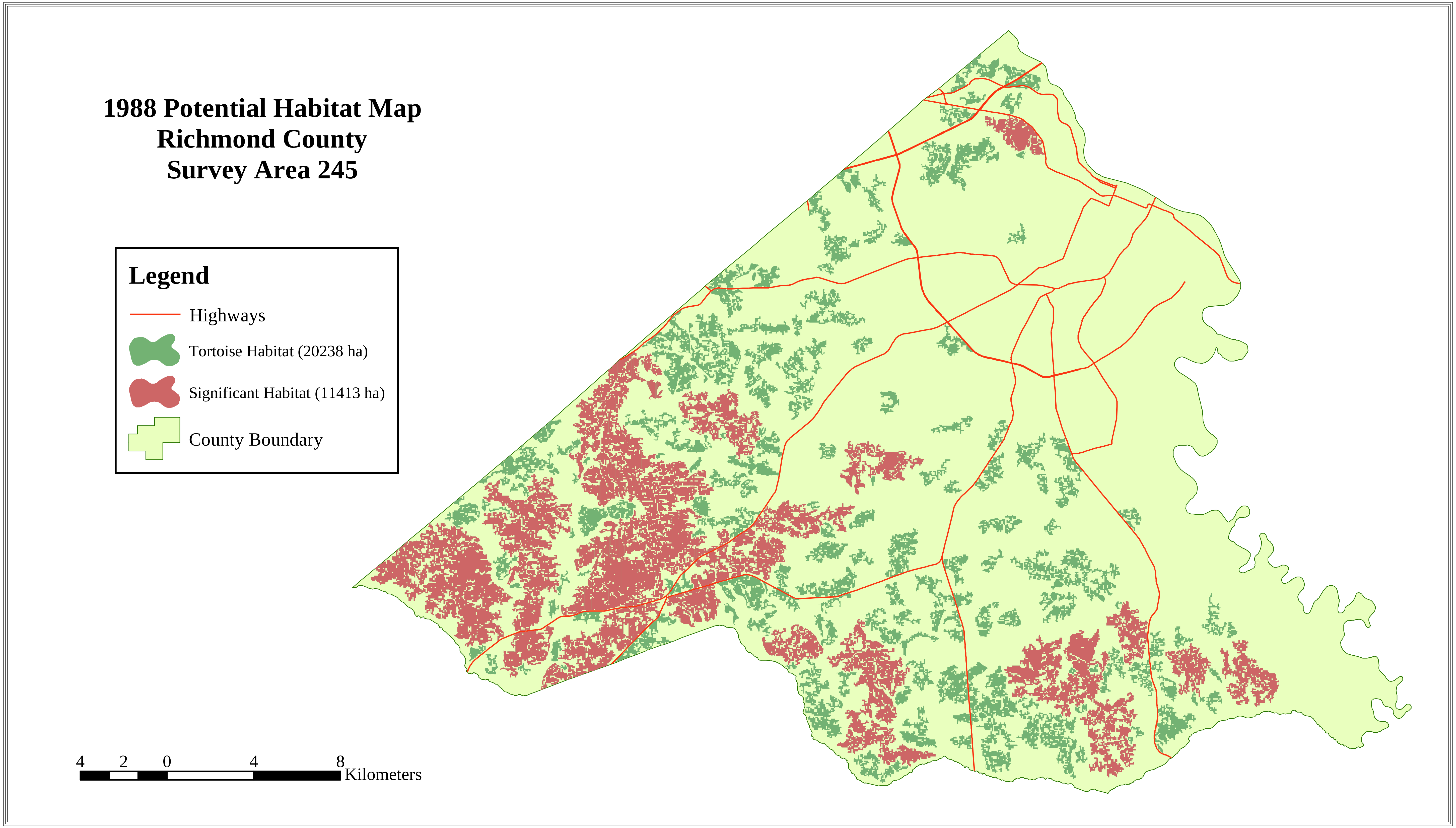

Figure B3. 1988 Potential Habitat Map, Richmond County

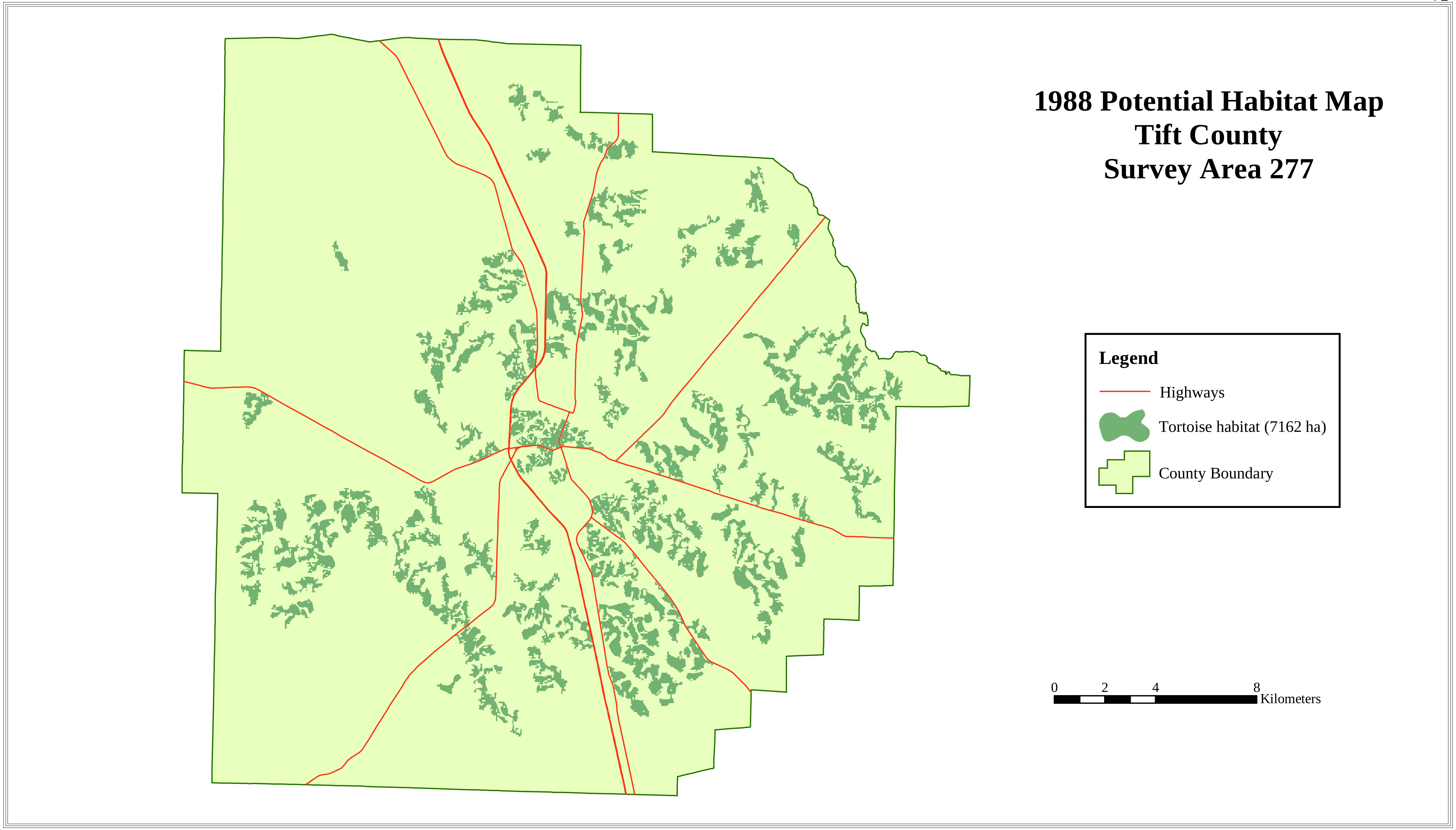

Figure B4. 1988 Potential Habitat Map, Tift County

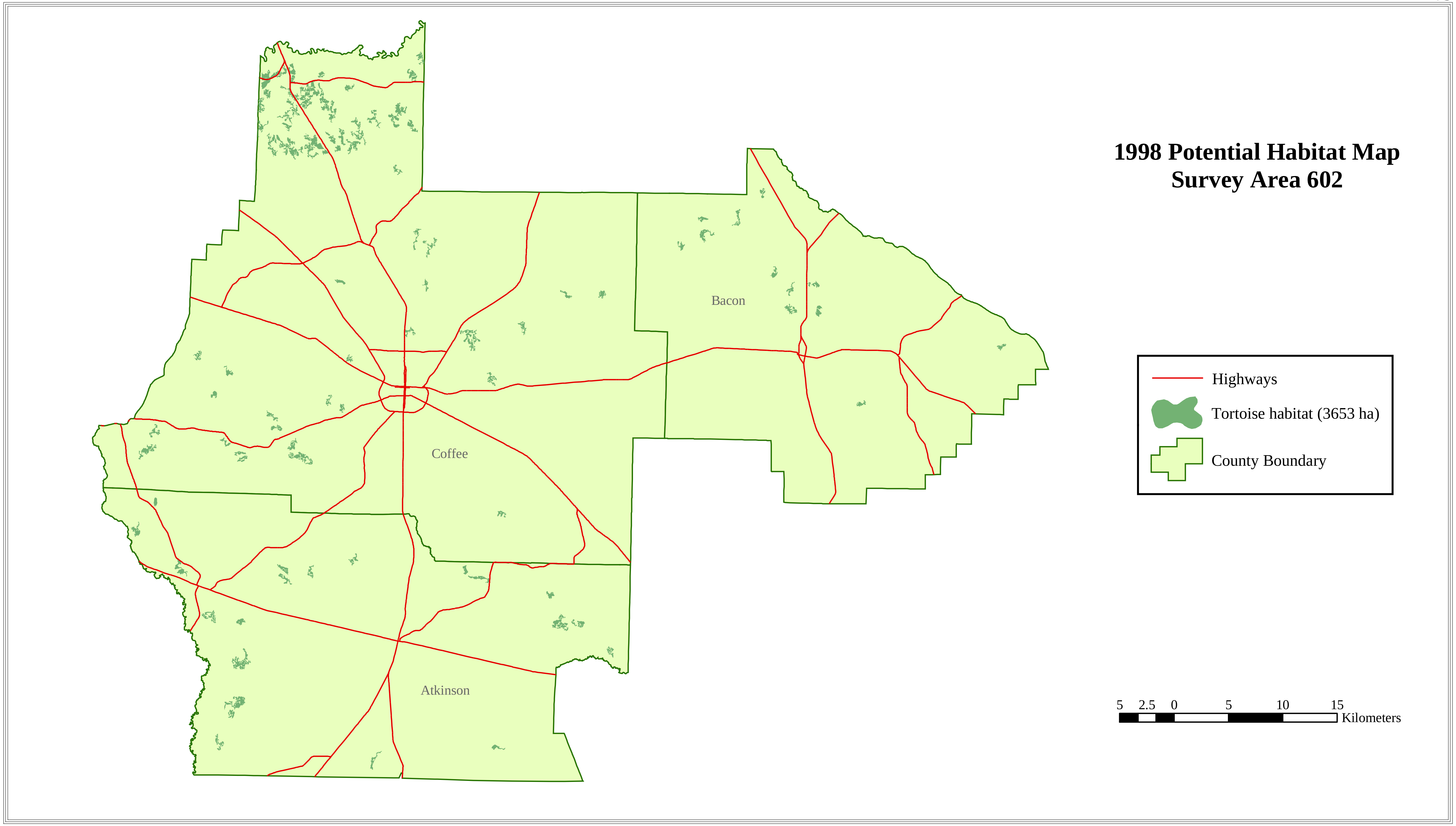

Figure B5. 1988 Potential Habitat Map, Atkinson, Bacon, and Coffee Counties

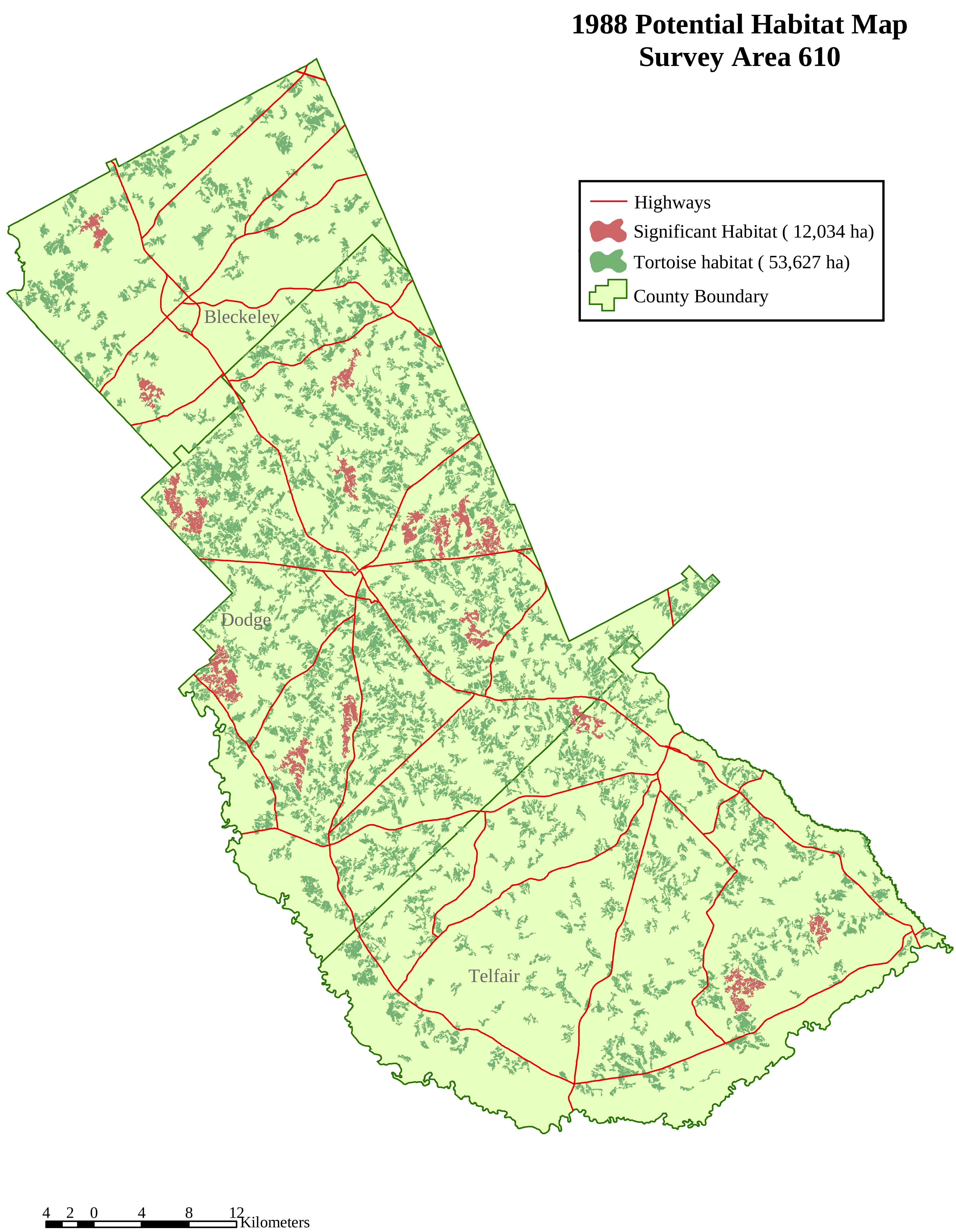

Figure B6. 1988 Potential Habitat Map. Blekeley, Dodge, and Telfair Counties

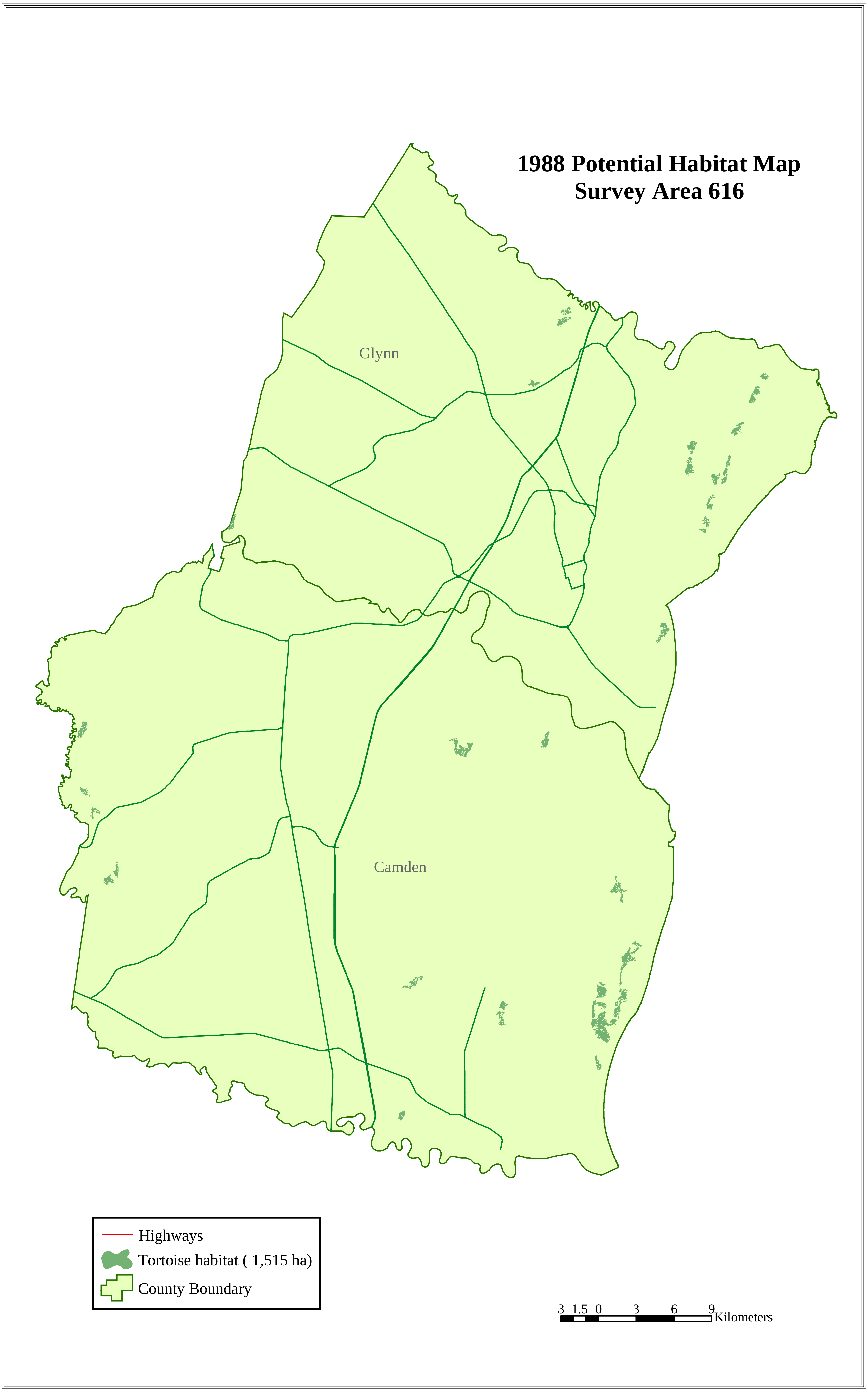

Figure B7. 1998 Potential Habitat Map. Camden and Glynn Counties

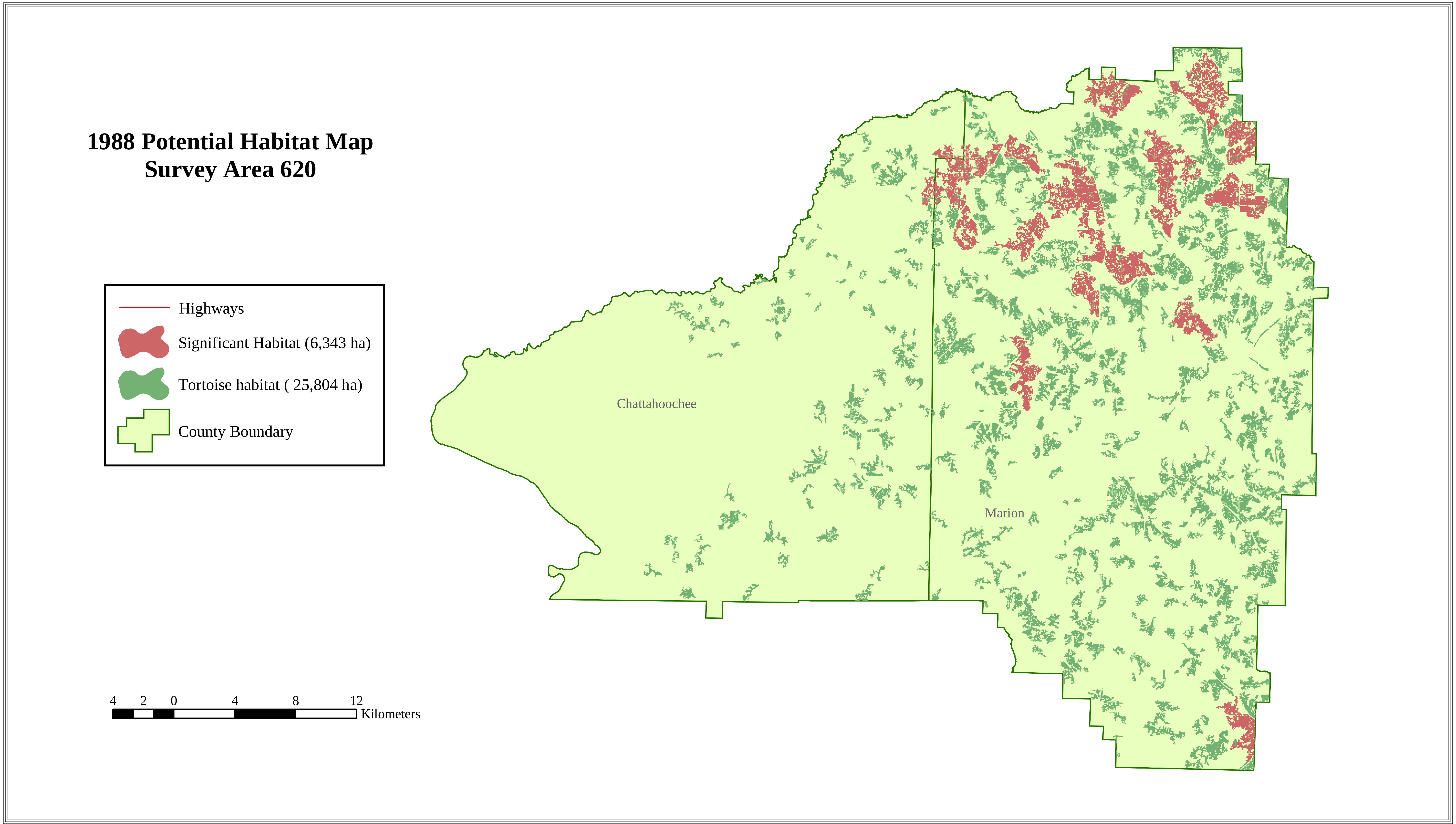

Figure B8. 1988 Potential Habitat Map. Chattahoochee and Marion Counties.

1988 Potential Habitat Map
Survey Area 631

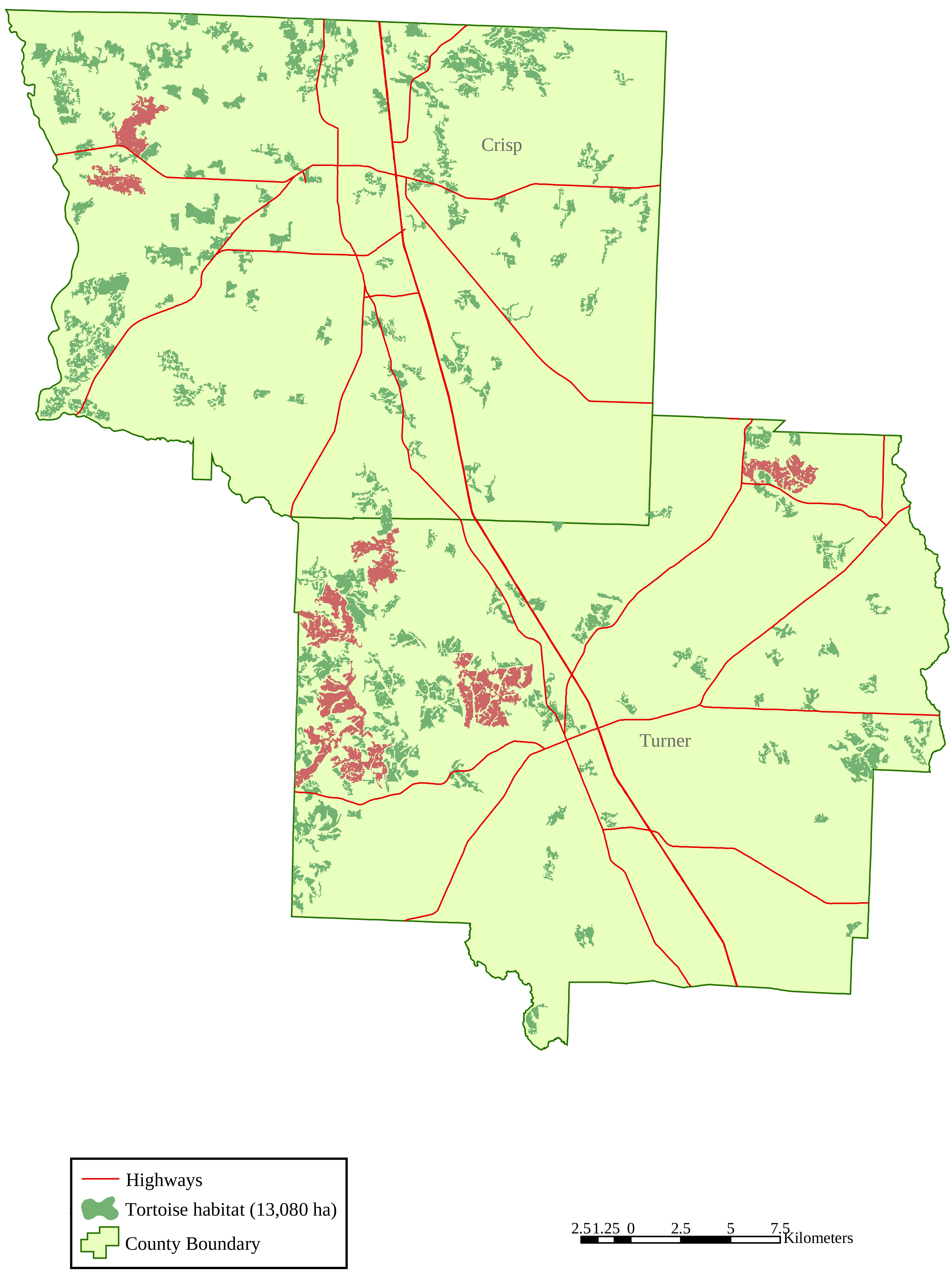

Figure B9. 1988 Potential Habitat Map. Crisp and Turner Counties.

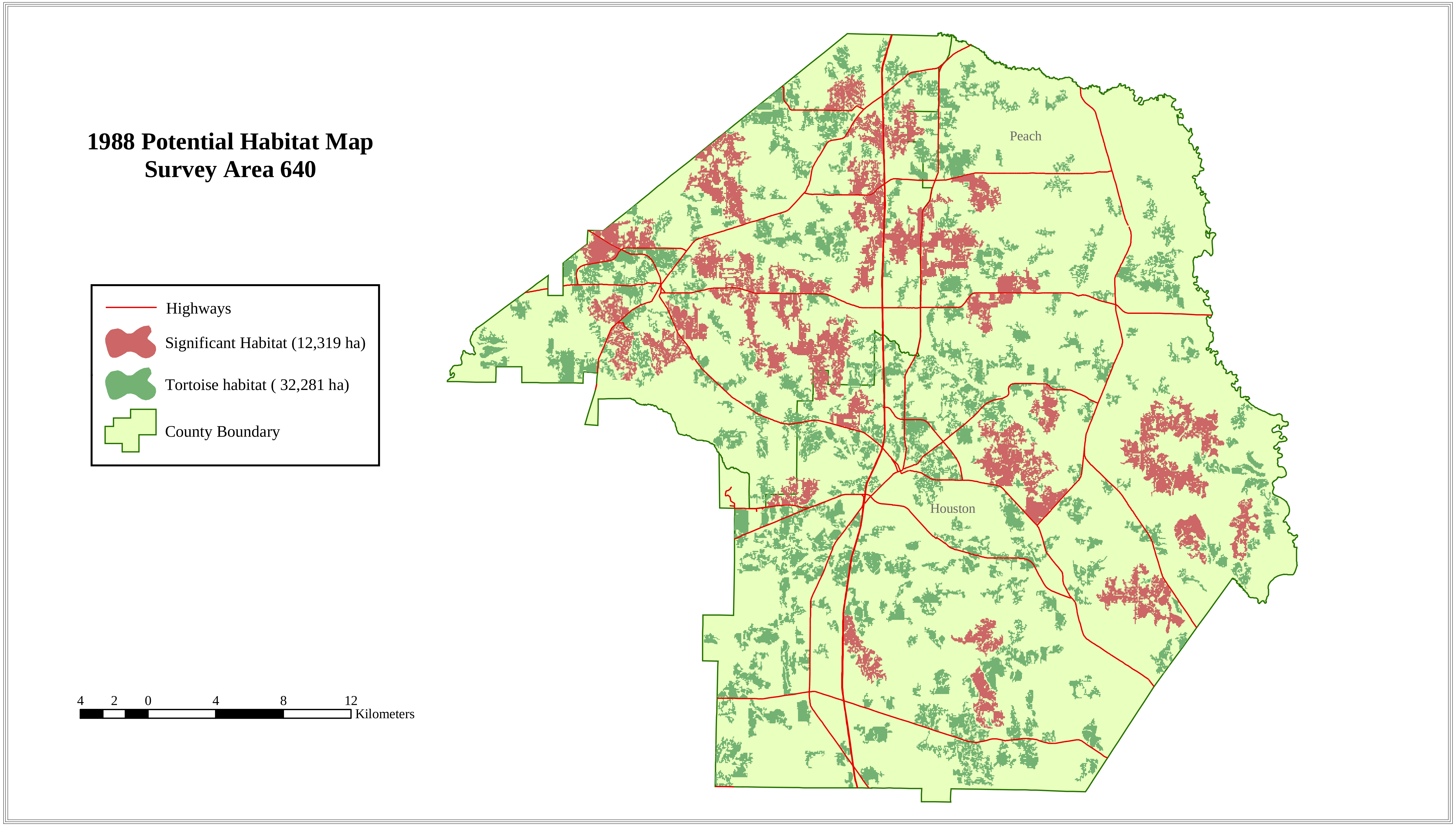

Figure B10. 1988 Potential Habitat Map. Houston and Peach Counties.

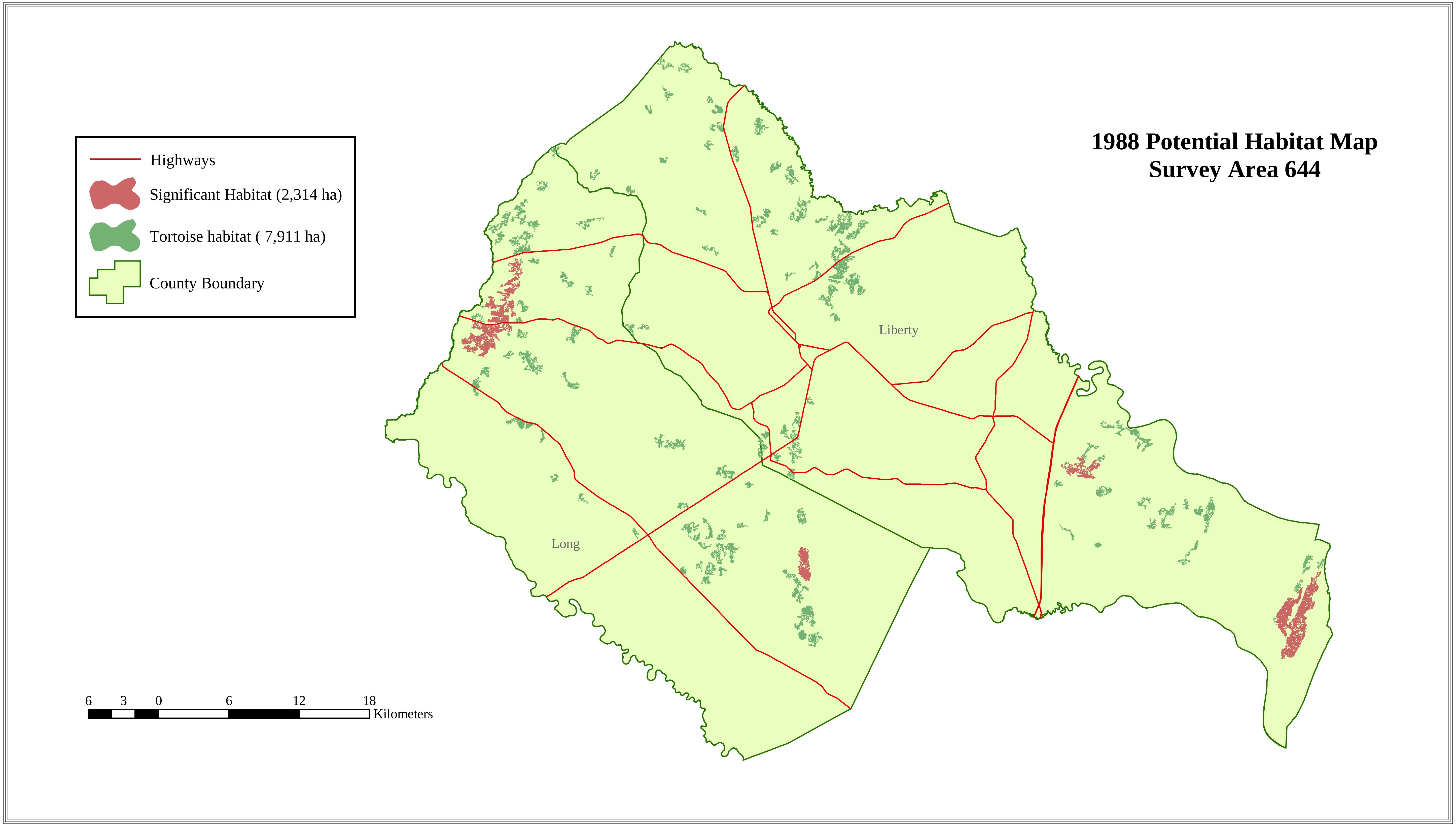

Figure B11. 1988 Potential Habitat Map. Liberty and Long Counties.

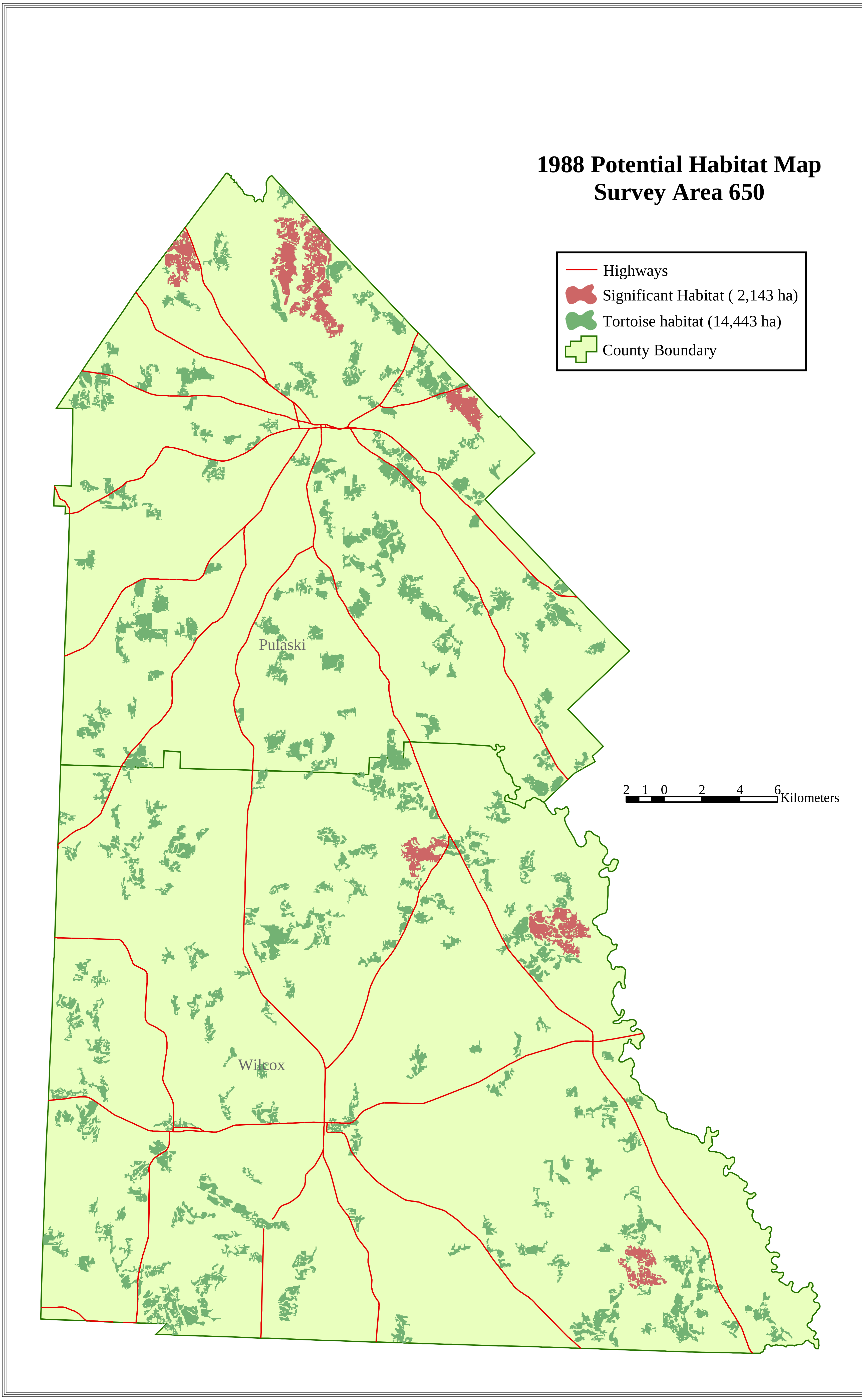

Figure B12. 1988 Potential Habitat Map. Pulaski and Wilcox Counties

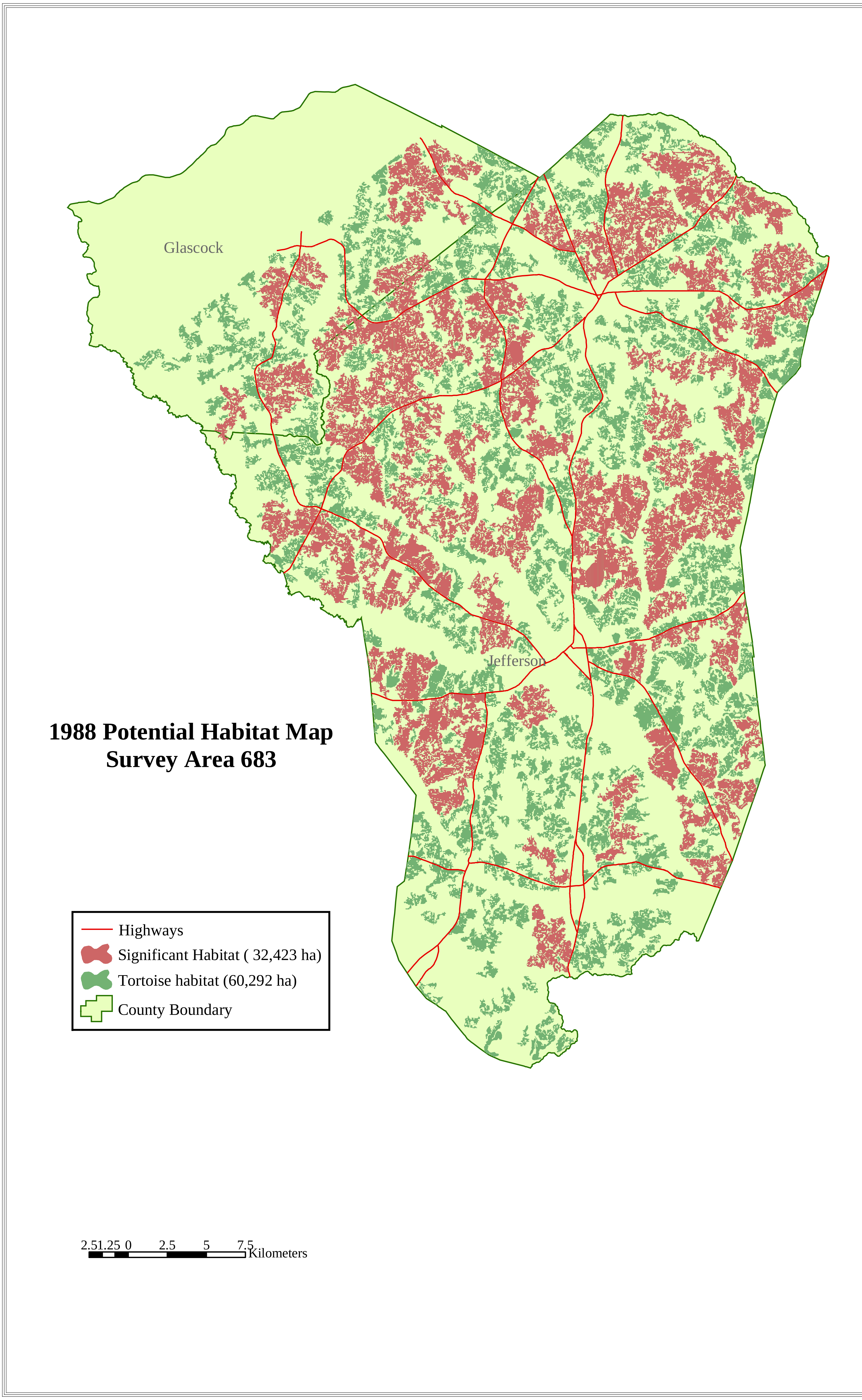

Figure B13. 1988 Potential Habitat Map. Glascock and Jefferson Counties