FINAL REPORT

Impacts of Military Training and Land Management on Threatened and Endangered Species in the Southeastern Fall Line Sandhills Communities

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14. ABSTRACT

This research evaluated effects of military training activities and forest management for the federally endangered red-cockaded woodpecker (RCW) on the sustainability of Fall Line sandhills plant communities and associated threatened, endangered and sensitive (TES) plant species. The primary goals were to identify current management conditions for the sandhills communities on military installations and other federal lands, to assess tradeoffs and potential conflicts among species habitat sensitivities, and to provide recommendations to optimize land management objectives. The overall objectives were: (1) at the landscape scale, to assess whether military training and forest management of longleaf pine woodlands to promote RCW habitat (single species management) are appropriate for managing sandhills communities; and (2) at the species level, to determine how combinations of forest management and training activities affect individual TES species, including rare sandhills plants.

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Acronyms and Abbreviations

CEC	cation exchange capacity
cm	centimeter
dbh	diameter at breast height (1.4 meters above ground)
DEM	digital elevation model
DoD	Department of Defense
DOE	Department of Energy
DOQQs	digital orthophoto quarter quadrangles
GA-DNR	Georgia Department of Natural Resources
GIS	geographic information system
GLA	Gap Light Analyzer software
Landsat-7 ETM+	Landsat-7 enhanced thematic plus imagery
NMDS	non-metric multidimensional scaling ordination
m	meter
NRCS	Natural Resource Conservation Service
PC-ORD	PC ordination software
SRS	Savannah River Site (Department of Energy)
RCW	red-cockaded woodpecker
SC-DNR	South Carolina Department of Natural Resources
SERDP	Strategic Environmental Research and Development Program
TES	threatened, endangered or sensitive
TNC	The Nature Conservancy
TWINSPAN	two-way indicator species analysis
USFS-SR	United States Forest Service – Savannah River
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

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1. Executive Summary

In the southeastern United States, the Department of Defense (DoD) has numerous land holdings in the Fall Line ecoregion, along the interface between the Coastal Plain and Piedmont provinces. Throughout this region, there are extensive areas of sandhills and related xeric forests, which are nutrient-poor habitats with sandy soils. Extending from the Carolinas, through Georgia and into Alabama, these Fall Line sandhills support a unique flora and fauna, including a suite of threatened, endangered and sensitive (TES) plant and animal species. Forests on military installations along the Fall Line are managed to promote open pine woodlands as habitat for the federally endangered red-cockaded woodpecker (RCW, *Picoides borealis*). Also occurring on many of these installations is the gopher tortoise (*Gopherus polyphemus*), which is currently listed as threatened only in the western part of its range but is declining elsewhere. It is not known whether management efforts directed towards RCW populations are also beneficial, or possibly harmful, for other sandhills TES species. The DoD must address simultaneously the demands associated with military training and other land-use activities along with the habitat sensitivities of these species. This complex challenge requires the integration of diverse information with understanding of processes operating at multiple spatial and temporal scales.

This research evaluated effects of military training activities and forest management for RCW habitat on the sustainability of Fall Line sandhills plant communities and associated TES plant species. The primary goals were to identify current management conditions for the sandhills communities on military installations and other federal lands, to assess tradeoffs and potential conflicts among species habitat sensitivities, and to provide recommendations for adaptive management to optimize land management decisions. The overall objectives were: (1) at the landscape level, to assess whether military training and forest management of longleaf pine (*Pinus palustris*) woodlands to promote RCW habitat (single species management) are appropriate for managing sandhills communities; and (2) at the species level, to determine how combinations of forest management and training activities affect individual TES species, especially rare sandhills plants.

This project has developed landscape-level and species-based habitat models, and combined them with field surveys and experiments, to evaluate potential conflicts among management scenarios for selected TES plant species. The research has focused upon three federal installations with contrasting land use practices: (1) Fort Benning, Georgia, which has light to heavy disturbance from military training activities, (2) Fort Gordon, Georgia, where disturbance from military training is light, and (3) the Department of Energy's Savannah River Site (SRS), South Carolina, which has no military training. Pine forests at each of these installations are managed for RCW habitat. In addition, gopher tortoises occur naturally at Fort Benning and Fort Gordon and have been successfully reintroduced to the SRS. All three sites have sandhills and related xeric forest communities with populations of TES plants.

At the landscape level, research under Objective 1 combined field ecological surveys with geographic information systems (GIS) data and landscape-level spatial models to capture, analyze, and interpret diverse types of information within a common environment. Initial GIS-based spatial analyses were conducted to discriminate potential Fall Line sandhills and related xeric woodlands from adjacent hardwood and managed pine forests. Since sandhills and these forests are arrayed along gradients of topography, soil, and other environmental conditions, extensive field surveys were conducted at geo-referenced sampling sites chosen at each installation. Multivariate statistical analyses were used to group sites based upon vegetation characteristics and to relate the groups to environmental characteristics. These analyses distinguished sandhills and closely related xeric woodland communities (including scrub barrens, dry mixed-pine hardwoods, dry hardwoods and dry pine savannas) from adjacent pine and hardwood forests. In the GIS analyses, the statistical relationships that best delineated these sandhills and xeric woodland communities were determined by a variety of techniques, and maps of these communities were generated for each of the three installations based upon Landsat-7 enhanced thematic mapper plus (ETM+) imagery and soils information. These maps were then validated through additional field sampling and reconnaissance and were overlain with information on forest management and military activities (where applicable) at the three installations.

Also at the landscape level, a field experiment was conducted to evaluate the effects of specific forest management practices for RCW habitat on xeric sandhills woodland communities. Treatments used to control hardwood understory species and maintain open pine forests for RCW habitat may include combinations of burning, herbicide application, and mechanical shredding. Composition and structure of the canopy, subcanopy, and ground cover vegetation of a sandhills site were determined prior to the experiment and over three years following management treatments. The canopy and subcanopy retained their species composition under all treatment combinations, although stem density and basal area of all species, including longleaf pine, declined as a result of the loss of smaller individuals. By the end of the third growing season, there was relatively little overall effect of burning alone on woody or herbaceous species composition or cover. The shredding and the herbicide treatments resulted in an initial decline of most woody and herbaceous plants, although by the third year there was extensive regrowth. The combination of burning, shredding, and herbicide application removed all herbaceous plants and there was little recovery by the third growing season. Two TES plant species that occurred at this site were little affected by the burn only and the burn plus shredding treatments, resprouting from surviving rootstocks. Overall, use of herbicides resulted in extensive initial loss of ground cover vegetation. As management tools for maintaining RCW habitat, burning and shredding appeared to have relatively similar effects on canopy and subcanopy species, and on understory forbs, grasses and woody seedlings.

At the TES species level, research under Objective 2 assessed whether the combination of frequency and timing of burning to promote RCW habitat (single species management), and military use, also provides suitable conditions for individual TES plant species. Populations of nine sandhills plants listed as Species of Conservation Concern in Georgia and South Carolina were sampled and their habitat conditions characterized. Population sizes were inventoried and habitat variables such as canopy openness, soil characteristics (moisture, texture and fertility), occurrence and density of other species, and spatio-temporal patterns of disturbance were measured. From these data, species-specific probability-based habitat models have been developed. The models weigh disproportionate affinities of species to specific combinations of habitat characteristics against the proportional occurrence of these combinations across the landscape. Performance of the models in predicting TES plant occurrence varied among the species. Occurrence of light-seeded species was less accurately predicted than occurrence of heavier-seeded species or ultra-xeric site species. Generally, predictions tended to somewhat over-estimate species occurrences and habitat suitability, but only a very few sites actually contained TES plant populations without their predicted occurrence. Over-estimation of suitable habitat was highest for the SRS and lowest for Fort Benning; these differences may be due to differences in fire management and military disturbances. These models that characterize the frequency of suitable sites for TES species on the landscape are important for restoration and conservation as well as for the implementation of successful survey and monitoring programs.

In addition, sandhills sites on the three installations with habitat characteristics similar to those that support the TES species populations were identified and mapped for each species using Landsat-7 enhanced thematic mapper plus (ETM+) imagery and soils information. These species-specific maps were validated by additional surveys and combined into potential TES species richness maps for each installation. These maps can be used to identify areas with habitat conditions that could support multiple TES plant species and thus might be priority conservation sites. They may also be compared with information on forest management or military activities to identify areas where conflicts among species habitat and management activities may occur. Finally, combining these TES plant habitat maps with information on populations of protected (or potentially protected) animal species such as the gopher tortoise revealed considerable habitat overlap. Such maps may support a more holistic approach to conservation of at-risk and declining sandhills species.

Experimental gardens were established in spring 2005 to test specific responses of several of the TES plants to habitat disturbances associated with military training and forest management, as well as to examine their potential for transplantation and population restoration. Twelve gardens were located on sandhills soils in areas of high disturbance, low disturbance and no disturbance, simulating military training (heavy, light, none) and forest management (understory control by burning and mechanical shredding). Four perennial herbaceous sandhills TES species (*Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana,* and *Stylisma pickeringii*) were planted as seedlings into the gardens. Survival and growth were assessed at the end of the first, second, third and fourth growing seasons post-disturbance. In general, TES plants had moderately high survival and growth in sites that had been disturbed, and lower survival and growth in undisturbed closed-canopy sites. Three of the species also reached reproductive maturity in disturbed areas within two to three years, and the other (*Nolina georgiana*) flowered in the fourth season after transplantation. Thus, preliminary results suggest that conservation of at least some of the sandhills TES plant species may be accomplished on sites that are burned to maintain an open understory or that are used for military training, and that transplantation may be an option where conflicting land uses may require destruction of TES plant habitat.

This research has provided information on the occurrence and distribution of southeastern Fall Line sandhills and related xeric woodland communities, on the occurrence of rare plants in these communities, and on the effects of forest management practices and disturbances that may be associated with military activities. Results suggest that burning at intervals of several years to maintain an open understory for RCW habitat is compatible with the occurrence of most sandhill plant species, but other understory control treatments (especially herbicide application) are detrimental. In general, rare plants of the sandhills persist under moderate disturbances associated with forest management and military activities. Furthermore, habitat models and GIS maps of potential suitable habitat for TES plants are useful in conservation efforts and in identifying sites for transplantation if conflicts in land use and TES species occurrence arise.

The development of management plans and implementation of management techniques for TES species have historically been conducted on a species-by-species basis. Within the DoD, however, there has been a shift toward ecosystem-based management, and emphasis is being placed on managing lands for multiple species conservation rather than single species of interest. The federal lands along the southeastern Fall Line are critical to the conservation of sandhills and related xeric woodland communities and the TES plants they contain. Future steps to be considered include: 1) More complete surveys should be conducted on federal lands to locate additional populations of sandhills TES plants (including the species examined in this study and others). Potential habitat maps developed through this research should aid surveys on Fort Benning, Fort Gordon and the SRS. 2) Protocols should be developed for transplanting populations of TES plants to other suitable sites (identified from soils maps and other resources such as aerial imagery) if necessary to protect the species when land use conflicts arise. 3) Since these TES plants are not officially protected and do not receive the attention or public awareness that at-risk animal species such as the gopher tortoise or RCW receive, areas of habitat overlap of rare plant and animal species should be identified and given high priority for conservation efforts.

2. Objectives

SERDP Sustainable Infrastructure (Conservation) SON (CCSON-02-05) requested research to "develop or apply methods and technologies that evaluate the effects of, and possible interrelationships between, military operations and species/habitat sensitivities on the occurrence and vitality of threatened or endangered species (TES)." This research has evaluated effects of military training activities and forest management to promote habitat for the federally-endangered red-cockaded woodpecker (RCW, *Picoides borealis*) on the sustainability of Fall Line sandhills plant communities and associated TES plant species on military installations and other federal lands in the southeastern United States. The primary goals have been to identify current management conditions for the sandhills communities, to assess tradeoffs and potential conflicts among species habitat sensitivities, and to provide recommendations for adaptive management to optimize land management decisions. The overall objectives were: (1) at the landscape level, to assess whether military training and forest management of longleaf pine woodlands to promote RCW habitat (single species management) are appropriate for managing sandhills communities; and (2) at the species level, to determine how combinations of forest management and training activities affect individual TES species, especially rare plants.

Research under the first objective included 1) field surveys to characterize sandhills and related xeric woodlands and discriminate them from adjacent forests, 2) spatial analysis and mapping of sandhills communities and comparison of these maps with spatial information on forest management and military activities at the three installations, and 3) an experimental examination of the effects of forest understory control practices that are used to maintain appropriate RCW habitat on the sandhills plant communities. Research under the second objective included 4) habitat characterization of selected TES plant species, 5) development of habitat models for TES plants and identification of potential additional suitable habitat, and 6) an experimental garden study to examine responses of four TES plants to disturbances related to military training and forest management and their potential for translocation.

3. Background

In the southeastern United States, the Department of Defense (DoD) has numerous land holdings in the Fall Line ecoregion, along the interface between the Coastal Plain and Piedmont provinces. Throughout this region, there are extensive areas of sandhills and related xeric woodlands, which are nutrient-poor habitats with sandy soils. Extending from the Carolinas, through Georgia and into Alabama, the Fall Line sandhills support a unique flora and fauna, including a suite of threatened, endangered and sensitive (TES) plant and animal species. These xeric woodland communities are dominated by longleaf pine and turkey oak (*Quercus laevis*), with frequent associations of sand post oak (*Q. margaretta*) and bluejack oak (*Q. incana*) as well as other woody species (Wells and Shunk 1931, Laessle 1958, Monk 1960).

Forests on military installations along the Fall Line are managed to promote open pine woodlands as habitat for the federally endangered red-cockaded woodpecker (RCW, *Picoides borealis*). Also occurring on many of these installations is the gopher tortoise (*Gopherus polyphemus*), which is federally listed as threatened only in the western part of its range (western Alabama, Louisiana, Mississippi) but is declining elsewhere. In addition, numerous TES plants are found associated with these woodland habitats, including more than a dozen species of conservation concern, most of which are state listed as vulnerable or imperiled. It is not known whether management efforts directed specifically towards RCW populations are also beneficial, or possibly harmful, for other sandhills TES species, especially rare plants.

Army-wide management guidelines for maintaining RCW habitat call for prescribed burns at least every three years if possible, or other forms of hardwood midstory control if needed, to maintain the open pine woodlands (Jordan et al. 1997). How these management treatments may affect sandhills communities that occur along with these pine lands, and rare sandhills species, is unknown. A 1997 assessment of the potential effects of these management guidelines on associated rare animals and plants on military installations in the southeast acknowledged that while habitat requirements for many TES animals have been poorly studied, detailed autecological information for the rare plant species that may occur in these habitats is especially limited (Jordan et al. 1997).

Although habitat management for rare species historically has been conducted on a species-by-species basis, within the DoD there has been a shift toward ecosystem-based management, and emphasis is being placed on managing lands for multiple species conservation rather than for single species of interest. A series of SERDP reports addressed needs for regional guidelines for managing TES species on military installations in the southeastern U.S. (e.g., Martin, et al. 1996, Trame and Harper 1997), and several focused on longleaf pine woodlands (Harper et al. 1998, Martin et al. 2001). Recommendations from the 2001 report, *A Community-Based Regional Plan for Managing Threatened and Endangered Species on Military Installations in the Southeastern United States* (Martin et al. 2001), included determining the life history and habitat requirements of TES species inhabiting each community of concern (such as the longleaf pine and sandhills communities) and also determining existing and potential impacts resulting from military activities and other land use practices.

Military training and testing mission requirements are the highest priority land uses on DoD lands. However, as described in the above-mentioned report, the military mission and TES species management can be compatible and should not be thought of as mutually exclusive interests (Martin et al. 2001). Furthermore, an ecological community approach has been recommended in the conservation of rare and threatened species on military lands (Leslie et al. 1996), since protection of representative communities also captures the broad-scale level of biodiversity. The recommendations from these previous SERDP studies and reports provided the background for this research to evaluate effects of military training activities and forest management for RCW habitat on the sustainability of Fall Line sandhills plant communities and associated TES plant species on military installations and other federal lands.

4. Materials and Methods

This research to evaluate effects of military training activities and forest management for RCW habitat on the sustainability of Fall Line sandhills plant communities and associated TES plant species has focused on two objectives. At the landscape scale (objective 1), studies assessed whether military training and forest management of longleaf pine woodlands for RCW habitat are appropriate for managing sandhills communities. Sandhills and related xeric woodlands were characterized, discriminated from adjacent pine and hardwood forests, mapped, and their distributions compared with spatial information on forest management and military training activities. In addition, a field experiment examined the effects on sandhills communities of forest understory management practices used to maintain RCW habitat. At the species level (objective 2), studies examined how forest management and training activities affect TES species. Habitats of nine TES plant species were characterized, habitat models were developed, and additional potential suitable habitat for these species was identified and mapped. In addition, four TES species were transplanted to experimental gardens to examine survival and growth responses to disturbances associated with military training and forest management.

4.1. Characterize sandhills and related xeric woodlands and discriminate from adjacent forests

In order to develop strategies for management of sustainable sandhills and related xeric woodland habitats, it is necessary to discriminate them from surrounding longleaf pine and hardwood communities. Existing images and maps for Fort Benning, Fort Gordon, and the SRS were provided by GIS personnel from each installation. U.S. Geological Society (USGS) 1999 digital orthophoto quarter quadrangles (DOQQs) were purchased to complete full coverage of Fort Benning. Additional GIS-coverage was provided by the U.S. Forest Service-Savannah River (USFS-SR), The Nature Conservancy (TNC), U.S. Fish and Wildlife Service (USFWS), South Carolina Department of Natural Resources (SC-DNR), and Georgia Department of Natural Resources (GA-DNR). This compilation of extensive spatial data provided the necessary background information for selection of study areas across a gradient of forest management and military training activities.

From the aerial imagery, sites were selected at all three installations that appeared similar to known sandhills on the SRS. In addition, soil maps were used to identify areas confined to the Lakeland classification (excessively drained, rapidly permeable soils on ridge tops and adjacent slopes). A total of 42 sites, 11 at the SRS, 14 at Fort Benning, and 17 at Fort Gordon were chosen for field characterization. Within each of these 42 sites, ten points at least 30 meters (m) apart were randomly selected for vegetation and soil sampling. Trees and large shrubs were sampled in a circle around each of these points using a prism, and species identification and diameter at breast height (dbh) were recorded. The prism (5x) method is a plotless technique and was chosen because it is efficient, widely used in forest management, and provides more information at a point than other plotless method (Husch et al. 1982, Thompson et al. 2006). In addition, hemispherical photographs were taken 1 m above the forest floor at each point to assess canopy openness, and three soil cores were extracted (to a depth of 50 centimeters or deeper).

Soils were analyzed for moisture, texture, pH, and nutrient content. Additional site variables included slope and aspect, obtained from digital elevation models (DEM).

Vegetation data from the 42 field sites were grouped by means of cluster analysis; similar results were received using PC-ORD (McCune and Medford 1999) software and PROC CLUSTER (SAS 1999). The clustering, a Sorensen (Bray-Curtis), centroid method was based upon similarities in individual woody species importance values. A second analysis of tree basal area values using a two-way indicator species analysis (TWINSPAN, PC-ORD, McCune and Medford 1999) gave a slightly better discrimination among groups. Discriminant analysis (PROC DISCRIM, SAS 1999) was used to validate the accuracy of these groupings, and Duncan's Multiple Range Tests (PROC ANOVA, SAS 1999) were used to identify significant differences among groups with regard to tree species abundance, soil characteristics, and other measured environmental variables. Non-metric multidimensional scaling (NMDS, PC-ORD, McCune and Medford 1999) also was used to display the relationships among the vegetation groups. PROC REG (SAS 1999) tested for significant relationships between the clusters revealed by NMDS ordination axis 1 and axis 2 scores and the environmental variables.

4.2. Spatial analyses and mapping of sandhills and related xeric woodland communities and comparison with spatial information on forest management and military activities

Landsat-7 enhanced thematic mapper plus (ETM+) satellite scenes covering the three installations were purchased for two time periods (December 2002 – leaf-off and April 2003 – leaf-on). Only ETM+ bands were used because these data are regularly available over a broad spatial extent. Supervised and unsupervised classifications were conducted to identify and distinguish distinct woodland types using the Feature Analyst Professional (Visual Learning Systems 2004) extension to ArcMAP (ESRI 2004). In this approach, groups of pixels, rather than individual pixels, were classified as objects. This allowed both spectral and contextual information to be incorporated while reducing inherent pixel-based noise. Maps of the Fall Line woodland communities were constructed for each of the installations (Harper and Sharitz 2005).

The maps were validated by field examination of 64 map polygon locations distributed across the three installations. Surveys included extensive walk-through that covered at least 10% of the selected polygon area, and canopy and subcanopy species and ground cover plants were recorded and compared with previous vegetation survey data (objective 1.1). Following map validation, GIS layers were acquired or developed for each installation to describe the spatial extent and intensity of forest management practices and military activities (if applicable). The maps of sandhills and related xeric woodlands were then overlain with these land management maps to determine potential conflicts in management needs of the installations and conservation of these woodland communities.

4.3. Effects of forest understory control practices used to maintain RCW habitat on sandhills plant communities

Management of habitat for the red-cockaded woodpecker, which prefers open pine savannas with a dense ground cover containing a diversity of grass, forb and low shrub species (Jordon et al. 1997), may require a frequent fire return interval or even mechanical or chemical control of understory hardwood species. These management practices may have different effects on sandhills communities and populations of rare plants. An experiment was conducted to evaluate the effects of forest understory management practices, including burning, mechanical shredding, and herbicide application, on a sandhills forest on the SRS. Twenty permanent transects, 30 m apart, were established in the summer of 2004, and the canopy and subcanopy layers were sampled at 30 m intervals along each transect using the point-quarter method. Shrubs greater than 2.5 cm in diameter and taller than 4 m were included in the subcanopy measurements. At these same points, 2 x 2 m plots were established to determine shrub and vine cover and the number of woody seedlings, and 1 x 1 m plots were used to estimate ground cover including herbs, mosses, woody debris and bare ground. Hemispherical photographs were taken at each sample plot 0.5 m above the forest floor for a measure of canopy openness.

The entire area was burned in early March of 2005. Shortly thereafter, each transect was equally split into four treatments ranging in intensity of disturbance to mimic forest management practices. Treatments included 1) burn only, 2) burn and mechanically shred, 3) burn and herbicide, and 4) burn, shred and herbicide. Shredding of the understory was conducted in the early spring of 2005 and the herbicide was applied in the summer due to rainy spring weather conditions. The canopy, subcanopy and ground layer vegetation were sampled after treatment applications in late summer 2005 and again after the second and third growing seasons in late summer of 2006 and 2007. Basal area, density and importance values (relative basal area, density and frequency summed to 100) were calculated for each canopy and subcanopy species and relative cover for all ground layer species was calculated. Percent canopy openness was determined from the hemispherical photographs using Gap Light Analyzer software. In addition, the effects on two TES plants, *Carphephorus bellidifolius* and *Liatris secunda*, were examined where they occurred.

4.4. Habitat characterization of selected TES plant species

Nine sandhills TES plant species were selected for survey purposes**:** *Astragalus michauxii, Baptisia lanceolata, Carphephorus bellidifolius, Chrysoma pauciflosculosa, Liatris secunda, Nolina georgiana, Phaseolus polystachios* var. *sinuatus, Stylisma pickeringii* var. *pickeringii,* and *Warea cuneifolia* (Table 1). Sixty-three populations of these plants were surveyed during 2003 and 2004. Boundaries of the TES populations were delineated with a Trimble GPS unit, and transects were established in a 30 x 30 m grid design (100 x 30 m for large populations) extending across the populations and beyond into areas without TES plants. At each grid location, density of TES plants and general observations of plant health and reproductive status were recorded. In addition the following were determined using standard sampling methods: 1) understory herbaceous plant cover, bare ground, and woody debris in 1 x 1 m plots; 2) understory shrub and vine cover in 2 x 2 m plots; 3) canopy tree composition using the point-quarter method; and 4) canopy openness using hemispherical photographs taken 0.5 m above the forest floor. Soil samples were also collected to determine texture (percent sand, silt, and clay), soil moisture, organic matter, and nutrient content.

Population densities of TES plants were generated based upon distance measurements at each of the surveyed TES field sites. NMDS ordination of vegetation data was used examine whether the TES population sites were similar in canopy and ground cover composition. Means of measured vegetation and environmental parameters included data for plots with and without TES plants present. In addition, during the early fall of 2004, vegetation data at selected gopher tortoise burrows on several federally- and state-owned lands including Fort Gordon were obtained (Tuberville et al. 2007). These data sets were used to compare habitat conditions for the gopher tortoise and the sandhills TES plants.

Table 1. Sandhills TES plants listed as Species of Conservation Concern for Georgia and South Carolina and chosen for study.

TES Species	Common Name	Global[1] Status	State Status[1]
Astragalus michauxii	sandhills milkvetch	G3	GA-S2, SC-S3
Baptisia lanceolata	lanceleaf wild indigo	G4	GA-S4, SC-S3
Carphephorus bellidifolius	sandy woods chaffhead	G4	GA-S1, SC-SNR
Chrysoma pauciflosculosa	woody goldenrod	G4G5*	GA-S3, SC-S1
Liatris secunda	sandhill gay feather	G4G5*	GA-S1, SC-SNR
Nolina georgiana	Georgia beargrass	G3G5*	GA-SNR, SC-S3
Phaseolus polystachios	sand bean	G5, T3	GA-S2, SC-SNR
Stylisma pickeringii	Pickering's dawnflower	G4, T3	GA-S2, SC-S2
Warea cuneifolia	sandhill cress	G4	GA-S3, SC-S1

[1]1= critically imperiled, 2 = imperiled, 3 = vulnerable, 4 = apparently secure, 5 = secure SNR = species not ranked, T = sub-taxon. *Numeric range rank is used to indicate the range of uncertainty about the exact global status of the species. Status from NatureServe, December 2008

4.5. Development of habitat models for TES plants and identification of potential additional suitable habitat

Two approaches were taken to develop habitat models for TES plants and to identify areas of potential suitable habitat on the three installations where additional populations might occur or where plants might be relocated in the event of habitat use conflicts. Probability-based habitat suitability models were developed based upon the data from the habitat analysis of the TES species. These models were based upon species-specific affinities to habitat characteristics and their underlying factors. Direct and indirect relationships between environmental parameters and individual species occurrences were assessed and prioritized. The approach included the following steps: 1) Variation in environmental parameters as distance increased from points where the target TES species were sampled was calculated. 2) A standard spline routine was used to estimate environmental conditions between sample locations. 3) Covariance among environmental parameters was assessed (for example, soil moisture is correlated with soil texture) and independent residuals were calculated for each parameter. 4) Step-wise regression equations for species-environmental relationships were developed and variables that did not contribute significantly to the model were eliminated. 5) The frequencies of plants of the TES species for each cell in a spatial grid were predicted using splined information and the equations. 6) Predicted and observed frequencies in each cell were compared to identify spatial patterns and assess model performance. The outcome from these models is a fairly specific range of conditions under which a TES species occurs and its likelihood of occurrence at broader landscape scales that may be correlated with GIS-level information.

In addition to developing predictive mathematical models of TES species habitat, GIS maps of potential species occurrences were based upon Landsat-7 ETM+ imagery and soils associated with known population locations. The maps were validated by surveys of 64 locations across the installations (see Objective 1.2 above). These maps may be useful not only in locating sites where additional TES populations may occur, but also in identifying potential suitable sites for population translocation if needed. The maps were then compared with information on forest management and military training (if applicable) at the three installations. In addition, the maps of potential habitat were combined for all TES species to provide guidance regarding priority areas for conservation of multiple species. These maps of potential habitat for multiple TES plants were compared in a GIS format with known gopher tortoise burrow locations on Fort Benning to identify potential TES plant habitat that might be protected through conservation efforts directed toward the gopher tortoise (Balbach et al. 2007).

4.6. Experimental garden study of selected TES plant responses to disturbances related to military training and forest management

Experimental gardens were established in spring 2005 to test specific responses of several of the TES plant species to habitat disturbances associated with military training and forest management, as well as to examine their potential for population relocation. Twelve gardens (six on Fort Gordon and six on the SRS) were located on sandhills soils (Lakeland/Troup) in areas of contrasting forest management and disturbance treatments. High disturbance sites included two burned and shredded forest areas (typical of forest management practices) and two logging decks (mimicking tank and motorized vehicle training). Low disturbance sites included two areas in which fox-hole digging was mimicked and two areas in which troop movements were mimicked. In addition, four gardens (two on each installation) with no disturbance treatment served as controls. Canopy openness at each garden was determined from hemispherical photographs, and soil cores were collected for determination of soil texture and nutrient levels.

Four perennial herbaceous sandhills TES plants (*Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana,* and *Stylisma pickeringii*) were selected because they occur in natural populations throughout both installations and their life forms are characteristic of many of the sandhills TES plant species. Seedlings were raised in a greenhouse until planting conditions were appropriate. In the spring of 2005, an equal number of each species was planted into each of the gardens. A week after planting, all dead or dying seedlings were replaced; each garden was watered every other day for the first month to promote seedling establishment. Mortality, size (height, vine length, rosette width or leaf length), and observations of general health (and reproductive status if appropriate) were recorded one month after planting and again in the late summer of 2005. The experimental populations were censused again at the end of the second, third and forth growing seasons (late summer 2006, 2007, 2008); survival and plant growth were measured and reproductive status was determined.

5. Results and Accomplishments

At the landscape level (objective 1), analysis of vegetation and environmental data collected from field sites at the three installations resulted in discrimination of eight groups which were collapsed into five woodland community types based upon similarities in dominant species composition. These sandhills and related xeric woodlands were mapped, and their distributions compared with forest management and military training activities. Hardwood understory control practices of burning, shredding and herbicide applications were examined and found to have little long-term effect on groundcover vegetation in the sandhills, although cover of both herbaceous and woody species was substantially reduced by a combination of the three treatments. At the species level (objective 2), habitats of sandhills TES plants were characterized by vegetation cover and soil conditions, and these data were used to generate habitat models and to identify potential additional suitable habitat for TES species in a GIS framework. Composite maps of potential TES species habitat were developed for each installation to identify areas for conservation priority. TES species were successfully transplanted and grown in experimental gardens across a range of disturbance conditions, demonstrating the potential for translocation of populations as a conservation tool if necessary to avoid land use conflicts.

5.1. Characterize sandhills and related xeric woodlands and discriminate from adjacent forests

Twenty-six woody species were identified across the 42 sites, of which two are considered shrub species but were large enough in diameter to be sampled with the prism technique. Cluster analysis of the vegetation data resulted in eight groups, and the discriminant analysis indicated that sites were grouped accurately. There was much similarity in species composition among the groups, but there were significant differences in importance of key species, especially longleaf and loblolly pine (*P. taeda*), turkey oak, sand post oak, sand laurel oak (*Quercus hemisphaerica*) and bluejack oak, hickories (*Carya* spp.), and slash pine (*P. elliottii*). Collectively, longleaf pine, loblolly pine, turkey oak, bluejack oak, sand post oak and southern red oak (*Quercus falcata*) accounted for more than half of the woody species basal area in all groups except one (Table 2).

There also was strong similarity of environmental factors among the groups; however, Duncan's Multiple Range Test results indicated significant differences in soil particle size, soil moisture, and soil nutrient content, with a general trend toward increasing sand content along with decreasing soil moisture and decreasing nutrient content (Table 3). Canopy openness ranged from 25-37% in all sites except those in group 8

The NMDS ordination displayed the relationships among the groups and illustrated the gradients in community types in relation to environmental variables (Figure 1). Those sites with higher basal area of turkey oak had higher soil sand content and greater canopy openness. As soil moisture and clay content increased, there was a higher importance of dry hardwood species. An increase in mixed pine and hardwood species was also related to increasing soil silt content.

Scrub barrens were associated with sandy soils of low moisture content. Regression analyses of NMDS axis 1 and axis 2 scores with environmental variables resulted in R^2 values of 0.51 and 0.67, respectively.

Table 2. Cluster analysis of field sites into groups, based upon woody species basal area (m^2/ha). Letters indicate significance differences between groups. *indicates species present but basal area <0.01m^2/ha.

Group Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of Sites	3	3	3	10	6	10	2	5
Scientific (common) name								
Pinus palustris (longleaf pine)	4.02^{ab}	4.69^{a}	3.85^{ab}	3.78^{b}	0.96^{d}	1.90^{c}	0.97^{d}	0.39^{d}
Pinus taeda (loblolly pine)	0.37^{c}	0.13^{c}	0.15^{c}	0.08^{c}	3.14^{a}	1.98^{b}	0.43^{c}	0.14^{c}
Quercus laevis (turkey oak)	0	0.05^{d}	1.09^{b}	1.04^{b}	0.76^{bc}	0.34^{cd}	0.26^{cd}	1.79^{a}
Quercus margaretta (sand post oak)	0	*	0.39^{b}	0.24^{bc}	0.04^{bc}	0.07^{bc}	1.15^{a}	0.06^{bc}
Quercus hemisphaerica (sand laurel oak)	0	0	0.53^{a}	0.08^{b}	0.08^{b}	0	0	0.15^{ab}
Quercus incana (bluejack oak)	0	0.02^{b}	0.04^{b}	0.04^{b}	0.12^{b}	0.06^{b}	0	0.53^{a}
Carya spp. (hickory)	0	*	0	*	0	0.06^{b}	1.89^{a}	0
Quercus falcata (southern red oak)	0.03^{b}	0	0.12^{ab}	0	0.03^{b}	0.27^{a}	0.01^{b}	0.02^{b}
Quercus stellata (post oak)	0	0	0	0.01^{a}	0	0.16^{a}	0.03^{a}	0.11^{a}
Diospyros virginiana (persimmon)	*	0	0	0.01^{a}	0	*	0	0
Nyssa sylvatica (black gum)	0	*	0	0.05^{a}	0	0.05^{a}	0	0
Vaccinium arboreum (sparkleberry)	0	0.01^{a}	0	*	0	*	0	0
Crataegus flava (hawthorn)	0	0	0	*	0	*	*	0.11^{a}
Pinus echinata (shortleaf pine)	0.02^{b}	0	0	0.06^{b}	0	0.08^{b}	0.33^{a}	0
Pinus elliottii (slash pine)	0.63^{a}	0	0	0	0	0	0	0.01^{b}
Quercus nigra (water oak)	0.01^{a}	0	0	0	0.03^{a}	0.11^{a}	0	0
Quercus velutina (black oak)	0	0	0	0	0	0.06^{b}	0.22^{a}	0
Cornus florida (dogwood)	0	0	0	*	*	0.01^{b}	0.09^{a}	0
Quercus marilandica (blackjack oak)	0.04^{b}	0	0	0.02^{b}	0	0.01^{b}	0.16^{a}	0
Prunus spp. (cherry)	0	0.42^{a}	0	*	0.02^{b}	0.01^{b}	0	0.02^{b}
Sassafras albidum (sassafras)	0	*	0	*	*	0	0	0
Quercus alba (white oak)	0	0	0	0	0	0.01^{a}	0	0
Acer spp. (maple)	*	0	0	0	0	0	0	0
Ilex opaca (American holly)	0	0	0	0	*	0	0	0
Liquidambar styraciflua (sweetgum)	0	0	*	0	0	0	0	0
Oxydendrum arboreum (sourwood)	0	0	0	0	0	*	0	0
Total Basal Area (m^2/ha)	5.12	5.34	6.19	5.48	5.20	5.16	5.55	3.33

Table 3. Means of environmental variables associated with the xeric woodland communities identified by the cluster analysis of vegetation data (Table 2). Letters indicate significance differences between groups.

Group Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of Sites	3	3	3	10	6	10	2	5
Environmental Variables								
% Canopy Openness	30.3^{cd}	29.4^{cd}	37.4^{b}	33.8^{bc}	31.9^{bc}	36.1^{b}	25.0^{d}	67.7^{a}
% Soil Moisture	9.3^{a}	5.5^{bcd}	5.9^{bc}	5.1^{cd}	4.6^{d}	6.7^{b}	6.1^{bc}	5.4^{cd}
% Silt	2.5^{ab}	1.4^{d}	1.6^{d}	1.9^{cd}	1.9^{cd}	2.2^{bc}	2.9^{a}	1.9^{cd}
% Clay	9.4^{a}	4.1^{bcd}	3.4^{d}	3.0^{d}	3.8^{cd}	5.8^{bc}	6.0^{b}	3.9^{cd}
% Sand	88.1^{c}	94.5^{a}	95.0^{a}	95.1^{a}	94.3^{a}	92.0^{b}	91.1^{b}	94.2^{a}
% Slope	5.2^{d}	4.7^{d}	6.5^{bcd}	8.7^{ab}	10.1^{a}	8.4^{abc}	4.8^{d}	5.8^{cd}
Soil pH	4.5^{b}	4.5^{b}	4.7^{ab}	4.5^{b}	4.7^{ab}	4.8^{ab}	4.9^{a}	5.0^{a}
Soil Nutrients (0-20 cm)								
Phosphorus (ppm)	3.0^{ab}	2.0^{ab}	1.4^{ab}	2.2^{ab}	1.4^{b}	1.6^{b}	3.7^{a}	1.3^{b}
Potassium (ppm)	10.9^{ab}	8.9^{b}	7.7^{b}	9.2^{b}	7.6^{b}	10.3^{ab}	13.4^{a}	10.8^{ab}
Calcium (ppm)	34.7^{b}	25.1^{b}	17.0^{b}	16.1^{b}	17.2^{b}	30.2^{b}	81.0^{a}	29.0^{b}
Magnesium (ppm)	5.8^{b}	3.2^{c}	2.6^{c}	2.8^{c}	2.8^{c}	2.8^{c}	13.6^{a}	3.4^{bc}
Manganese (ppm)	6.1^{b}	3.0^{b}	1.9^{b}	2.1^{b}	2.3^{b}	4.2^{b}	12.1^{a}	3.8^{b}
Nitrogen (%)	0.023^{bc}	0.017^{c}	0.023^{bc}	0.022^{bc}	0.030^{ab}	0.024^{bc}	0.035^{a}	0.020^{bc}
Carbon (%)	0.843^{ab}	0.403^{b}	0.653^{ab}	0.604^{ab}	0.910^{a}	0.855^{ab}	1.040^{a}	0.594^{ab}

Based upon the similarities in woody species composition and soil characteristics among the field sites, the eight groups were further collapsed into five community types consistent with other descriptions of southeastern xeric mixed pine and hardwood ecosystems (Wells and Shunk 1931, Laessele 1958, Monk 1960, Christensen 1988). Collectively these comprise a system of sandhills and related xeric woodlands:

- Dry pine savannas (groups 1 and 2): These communities were strongly dominated by longleaf pine with a rather limited presence of hardwood species.

- Xeric sandhills (groups 3 and 4): These woodlands have canopies of longleaf pine and sandhill oaks (turkey oak, sand post oak, sand laurel oak and bluejack oak).

- Dry mixed pine hardwoods (groups 5 and 6): These forests had a greater presence of loblolly pine, along with longleaf pine and several of the sandhill oaks. There was also a greater presence of other hardwood species at these sites.

- Dry hardwoods (group 7): These sites contained more hickories (*Carya* spp.) as well as several other more mesic species such as dogwood (*Cornus florida*). The canopy was more closed and soils were generally higher in nutrients.

- Scrub barrens (group 8): These sites had very open canopies of mixed sandhill oaks as well as longleaf and loblolly pine at low basal area.

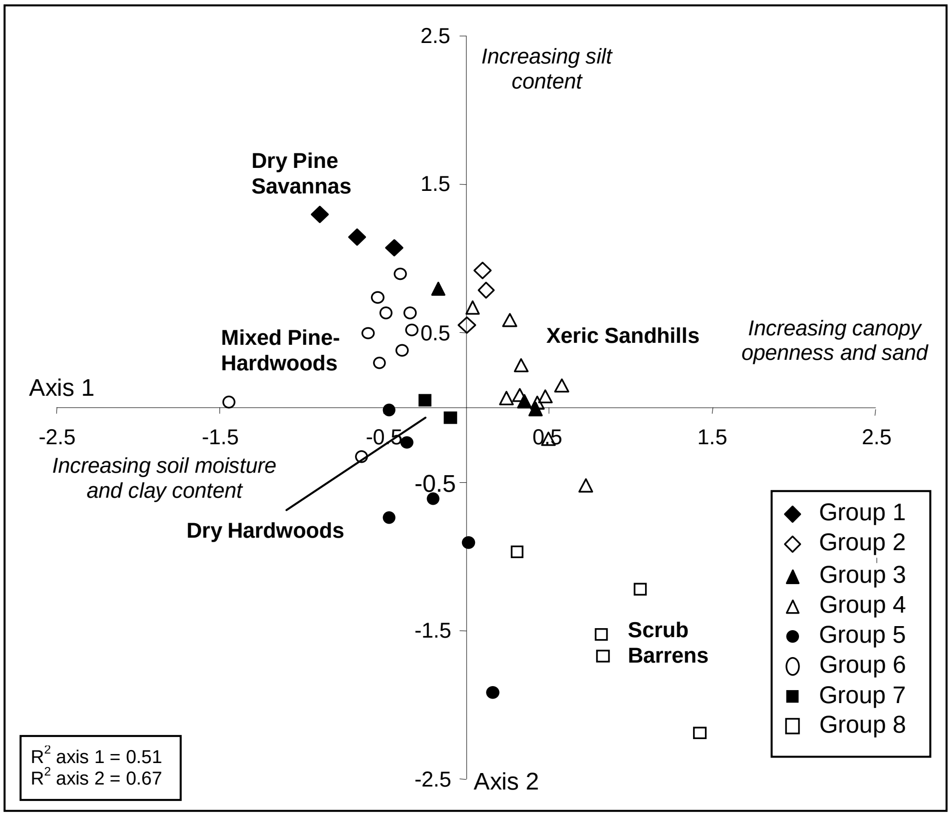
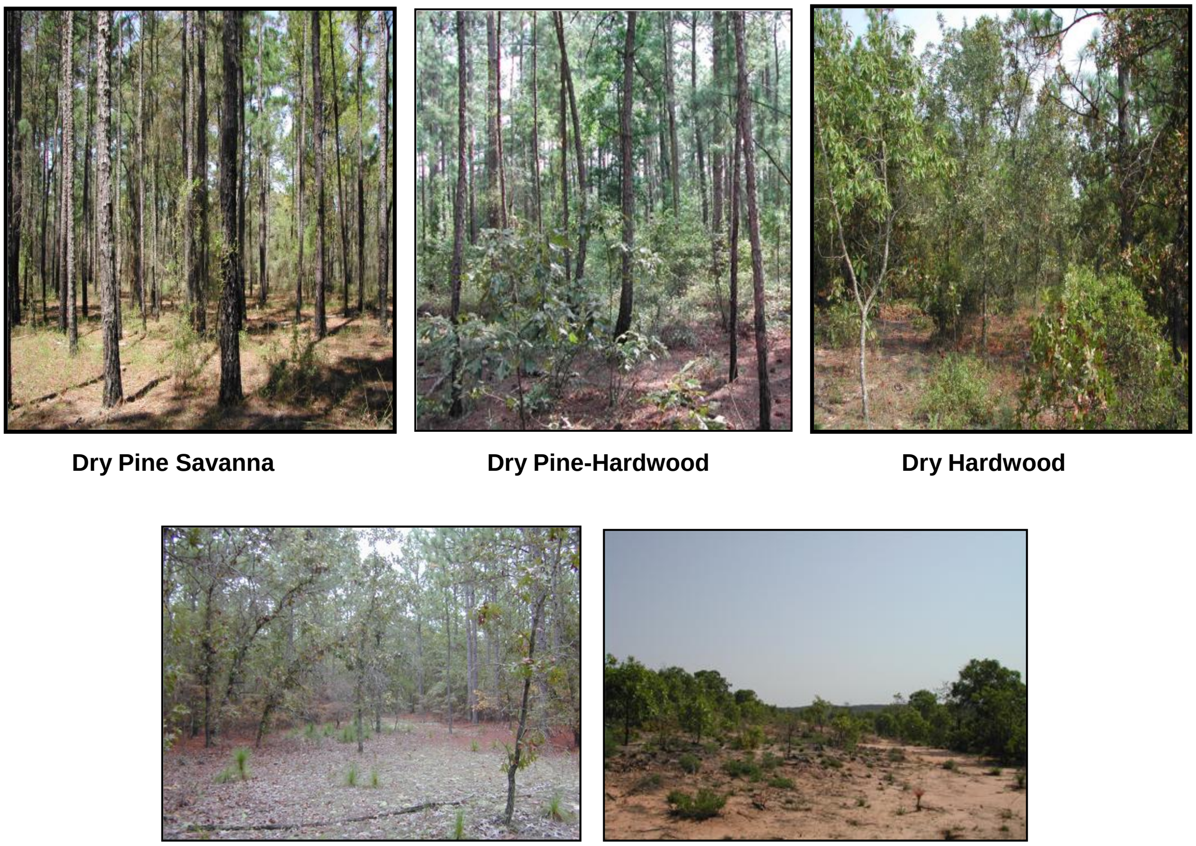


Figure 1. Non-metric multidimensional scaling ordination of canopy species basal area from xeric woodland sites with community types indicated. Axis 1 is significant with increasing canopy openness and sand content of the soil (to the right) and with increasing soil moisture and clay content (to the left); axis 2 is significant with increasing soil silt content (to the top).

These communities are associated with gradients of soil moisture, soil texture (Figure 1), and soil nutrient content. Although xeric sandhills communities occur on sites with deep sand and with low soil nutrient levels, there are gradients in woody vegetation composition across the array of environmental conditions and the sandhills share many species with the other groups in xeric woodland complex (Figure 2). From a management and conservation perspective, many of these sites with similar species composition and environmental conditions should be managed similarly.

Of these five xeric woodland communities, xeric sandhills, dry mixed pine-hardwoods, and dry pine savannas were sampled on all three installations. Dry hardwood sites were found only on Fort Benning and the SRS, and scrub barrens were sampled only on Fort Benning. The gradients of soil moisture, soil texture, and soil nutrient content likely influence tree species composition. However, some of the variation among sites may also be attributed to past land-use activities that may have altered and fragmented these woodland areas, as well as to current land management and military training activities.



Dry Pine Savanna **Dry Pine-Hardwood** **Dry Hardwood**

Xeric Sandhill **Scrub Barren**

Figure 2. Sandhills and related xeric woodland communities of the southeastern Fall Line region.

5.2. Spatial analyses and mapping of sandhills and related xeric woodland communities and comparison with spatial information on forest management and military activities

The multivariate analyses of field data showed that the five woodland community types could be discerned based upon canopy composition and species abundance. However, in sequential supervised and unsupervised classifications of the Landsat imagery, the five communities could not be unambiguously delineated from one another. While 60% to 70% of cells classified were identified as belonging to a single community type, other locations were classified as belonging to more than one type (Harper and Sharitz 2005).

Although difficulty in the classification process may have arisen from the input data or the classification approach used, it is more likely that the inherent similarity of these woodland communities make them especially difficult to discern remotely. This was suggested from the NMDS analysis that revealed that sample plots, while clustered, were distributed along environmental gradients (objective 1.1, Figure 1). It is also possible that forest management and military training activities may have resulted in changes to forest composition that make it difficult to discern community types. However, Landsat ETM+ imagery alone can be used effectively to distinguish sandhills and related xeric woodlands from the surrounding pine forest matrix, and may serve as a first level of screening in the identification of potential xeric sandhills sites. Maps of these woodland communities were developed for each installation (Figure 3).

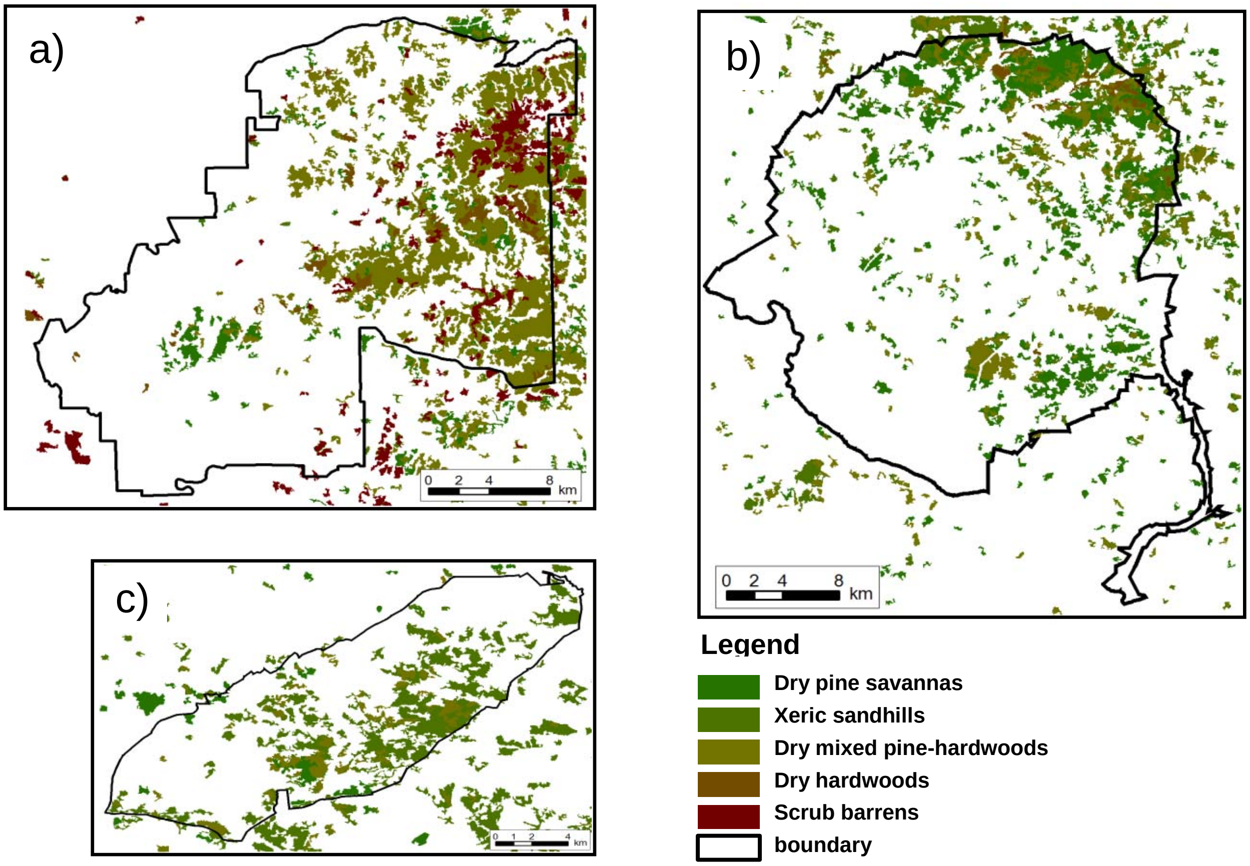


Figure 3. Sandhills and related xeric woodlands as determined from supervised classifications of Landsat imagery for a) Fort Benning, GA, b) the Savannah River Site, SC, and c) Fort Gordon, GA (Harper and Sharitz 2005.

Of the 64 locations visited to validate the maps, 80% were determined to be a sandhills community or related woodland type. Canopies were dominated by longleaf or loblolly pine and sandhills oaks (turkey oak, sand post oak, bluejack oak) with sparse hickory species. Locations determined not to be of the sandhills type were recent clearcuts, planted pine forests, or open areas used for military activities such as drop zones or ranges. Overall map accuracy was high at Fort Gordon and the SRS (>90%), whereas at Fort Benning the accuracy was 67%. The more heavy military land use at Fort Benning tended to obscure the identification of sandhills communities by use of the Landsat imagery.

These maps were then compared with forest management and military training activities. The quality and availability of information on land use, forest management practices, and vegetation cover vary among the three installations. Recent maps and GIS files of land use at Fort Benning were obtained in April 2006. The land use information for Fort Gordon was somewhat older and possibly less accurate. At Fort Benning, sandhills and related communities are found mostly in heavy and light training areas and in dudded and non-dudded impact areas in the eastern and northern region of the installation (Figure 4, Appendix A.8.1). Many of these communities are also in areas that are under forest management for longleaf pine. At Fort Gordon, sandhills occur throughout various ranges and the dudded and non-dudded impact areas

(Appendix A.8.1), and are most abundant in sites classified as 'evergreen needleleaf trees, open to medium' on the vegetation map. Thus, these are pine sites that are predominantly loblolly. At the SRS, sandhills and related communities are most abundant in the eastern and northern regions of the site in areas that are managed as RCW habitat with a goal of promoting longleaf pine forests (Appendix A.8.1).

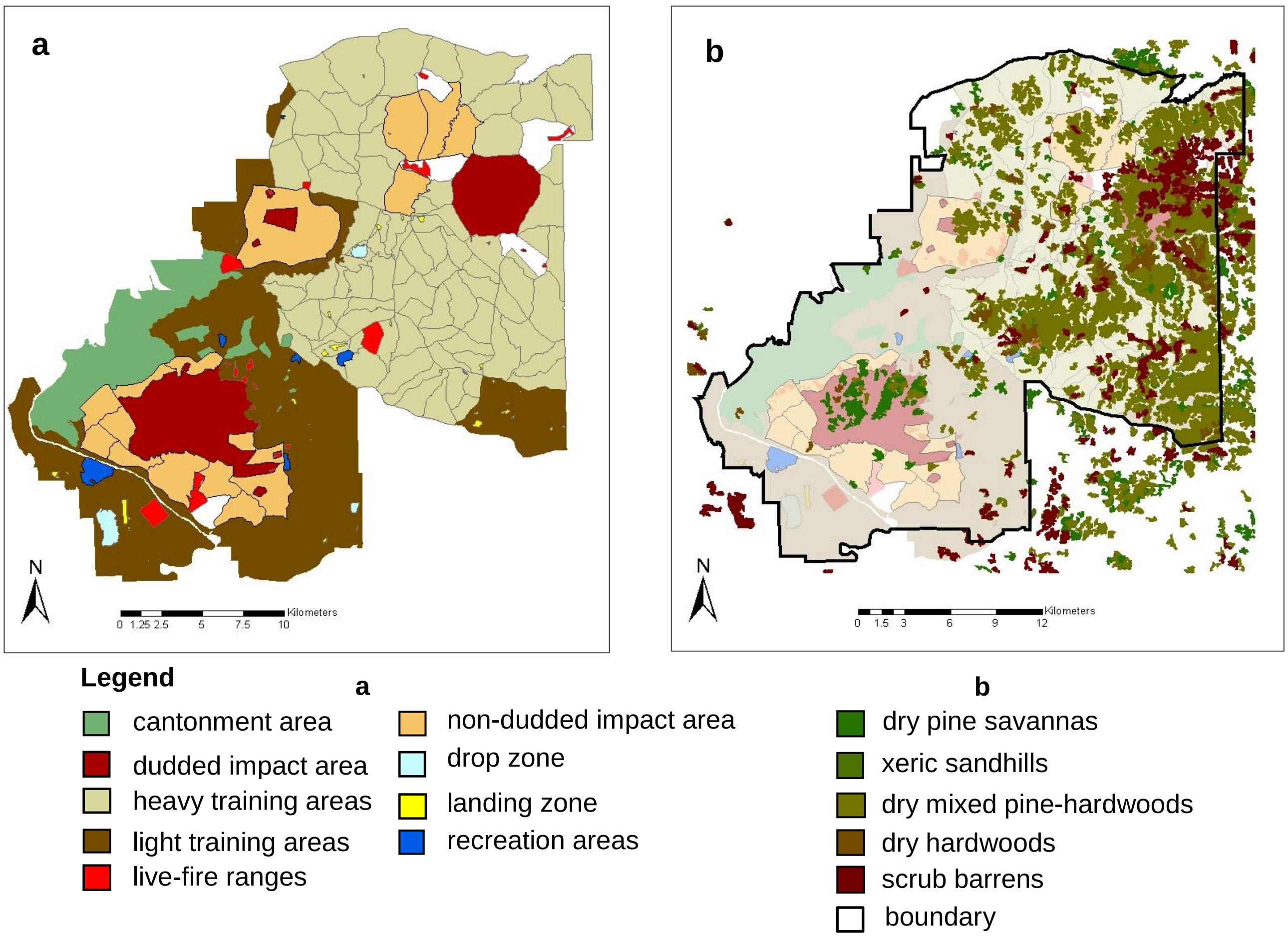


Figure 4. a) Map of the military training areas at Fort Benning. b) Sandhills and related xeric community types as determined from supervised classifications of Landsat imagery (Harper and Sharitz 2005) overlain over faded map of training areas. See .A.8-1 for additional maps of sandhills and land/forest management for Fort Benning, Fort Gordon and the SRS.

5.3. Effects of forest understory control practices used to maintain RCW habitat on sandhills plant communities

The hardwood understory control practices experimentally imposed on the sandhills community included: 1) burn only, 2) burn and mechanically shred, 3) burn and apply herbicide, and 4) burn, shred and apply herbicide (Table 4). The canopy and subcanopy layers before and after the disturbance treatments were composed primarily of longleaf pine, turkey oak, sand post oak, bluejack oak, persimmon (*Diospyros virginiana*), black gum (*Nyssa sylvatica*), hawthorn (*Crataegus flava*) and sparkleberry (*Vaccinium arboreum*). All canopy and subcanopy species decreased in basal area and density following disturbance; there were no significant differences among the burn only, burn and shred, and burn and herbicide treatments. Overall, longleaf pine decreased 18% in basal area and about 40% in density due to loss of small individuals. Similarly, turkey oak and sand post oak had a >50% decrease in basal area and >60% reduction in number of stems. Understory species, especially black cherry (*Prunus serotina*) and persimmon, and shrubs (sparkleberry and hawthorn) had the greatest loss with a decrease of up to 75% in both basal area and density. Basal area of all canopy and subcanopy species decreased significantly under the combined application of all three treatments (Table 4)

Species diversity during the first, second and third years post-disturbance remained relatively low overall for all treatments. There was relatively little effect of the burn only treatment on species composition or cover, although grasses (especially *Sorghastrum secunda*) increased slightly (Table 4). Both the shredding and the herbiciding treatments resulted in an initial decline of most ground cover species during year one and two, but most herbaceous groups were recovering by the third year. Bracken fern (*Pteridium aguilinum*) actually increased following the herbicide application, possibly due to increased light and reduced competition with other ground cover species that allowed regrowth from rhizomes. *Carphephorus bellidifolius* and *Liatris secunda* persisted in the burned and the shredded plots where they occurred, and *Liatris* was not significantly affected by the application of herbicide. Woody vegetation cover was reduced substantially by both the shredding and the herbicide application treatments, but by the third year there was extensive regrowth, primarily due to resprouting from surviving roots.

Table 4. Effects of forest understory treatments on groundcover in a sandhills forest. *Liatris secunda* and *Carphephorus bellidifolius* are TES plant species. Pre-treatment measurements were in 2004; year 1-3 post-treatment measurements were in the late summer of 2005, 2006 and 2007. Values are relative % cover scaled to a total of 100% for each treatment and year.

		Forbs	Grasses	Ferns	Mosses Lichens	Shrubs Trees	Vines	Woody Debris	Bare Ground	*Liatris*	*Carphephorus*
Burn Only	**Pre-Tmt.**	1.61	0.58	3.41	2.97	66.89	0.29	19.18	2.73	2.24	0.10
	Year 1	2.39	0.40	2.65	0.33	57.84	0.10	22.84	9.71	3.58	0.1
	Year 2	1.59	0.42	2.66	0.29	63.96	0.19	19.84	7.66	3.24	0.13
	Year 3	3.07	2.54	2.71	2.03	53.97	0.18	25.56	4.73	4.82	0.68
Burn + Shred	**Pre-Tmt.**	6.65	0.38	0.38	4.59	42.81	3.36	30.81	8.03	2.68	0.31
	Year 1	2.09	0.10	0.13	1.58	18.01	1.25	68.22	6.85	1.12	0.62
	Year 2	2.82	0.25	0.24	1.49	23.28	2.06	60.95	6.73	1.44	0.73
	Year 3	3.66	0.18	0.36	1.62	35.71	0.93	51.87	3.70	1.79	0.18
Burn + Herbicide	**Pre-Tmt.**	1.36	0.13	0.06	6.36	50.39	2.08	19.35	17.66	2.60	0
	Year 1	0.37	0.06	5.23	2.15	34.81	2.83	12.56	38.94	3.02	0
	Year 2	0.52	0.10	4.19	1.83	40.41	3.67	13.63	32.75	2.88	0
	Year 3	6.53	0.25	4.30	3.89	44.33	1.67	25.91	11.54	1.57	0
Burn + Shred + Herbicide	**Pre-Tmt.**	1.58	0.45	0	1.43	51.85	4.53	35.09	4.00	0.98	0.08
	Year 1	0	0	0	0.09	3.95	0.29	83.58	12.09	0	0
	Year 2	0.14	0	0	0.14	6.16	0.43	82.49	10.62	0	0
	Year 3	0.15	0.35	0	0	21.39	0.34	71.57	5.88	0.07	0.17

The combined burn, shred and herbicide application removed all herbaceous species, however, and there was little recovery of forbs by the third growing season although grasses were reappearing (Table 4). Both TES species were significantly reduced by the combined treatments; their reappearance in year three may have been through seed dispersal from plants outside the treatment areas. Woody vegetation cover also was much lower under this treatment combination, although by the end of the third growing season there was some recovery due to resprouting. Woody debris at this site remained very heavy.

In all treatments, the majority of the tree species recovering from the disturbance were sandhills oaks. Very few pine seedlings were found, although there was a notable increase of longleaf pine seedlings during the third growing season (Table 5). There was very low survival of hawthorn and persimmon in any of the treatments. Black gum seedlings, initially common in the understory at all sites, had high survival under the burn and the shredding treatments, but were killed by the herbicide applications and were not found by the third growing season. Many of the resprouting woody species were ericaceous sandhills shrubs, including dwarf huckleberry (*Gaylussacia dumosa*), sparkleberry and deerberry (*Vaccinium stamineum*).

Table 5. Effects of forest management treatments on seedlings of longleaf pine (*Pinus palustris*). Values are number of seedlings per $900m^2$ total area sampled for each treatment.

Treatment	Pre-tmt	Year 1	Year 2	Year 3
Burn Only	10	3	3	55
Burn + Shred	20	6	7	21
Burn + Herbicide	25	9	5	38
Burn +Shred +Herbicide	9	0	0	32

5.4 Habitat characterization of selected TES plant species

There was extensive overlap of environmental variables among TES species habitats and nearby sites without TES plants present (Table 6). All species grew in sandy soils with relatively low moisture and low organic matter content. Canopy openness differed among species and ranged from 17% (*Astragalus*) to 52% (*Chrysoma*). *Carphephorus* was often found in areas with greater slope than the other species.

TES plant populations occurred on several different soil series across the three installations. Collectively, Lakeland soils (Typic Quartzipsamments) were most prevalent, although Troup and Blanton soils (Grossarenic Kandiudults) were also common. These are all sand or fine loamy sand series. The TES species differed somewhat in their distribution relative to soil nutrients (Table 7). *Stylisma* typically occurred on more nutrient poor sites, as did *Chrysoma*. *Baptisia* was found in sites with higher levels of calcium, *Warea* occurred on sites with higher than average phosphorus levels, and *Nolina* was found in sites low in phosphorus.

Table 6. Environmental characteristics of sites with TES plants and nearby sites without TES plants. Values are means from all sites at the three installations combined. Values in parentheses are confidence intervals (p=0.05). Different superscripts represent significant differences among species based on Duncan's Multiple Range test (p=0.05)

TES Species	No. of Plots	% Canopy Openness	% Soil Moisture (0-10 cm)	% Organic Matter (0-10 cm)	% Sand (0-10 cm)	% Slope
Astragalus michauxii	10	17.2^{c} (0.6)	10.6^{a} (0.4)	2.0^{a} (0.1)	92.2^{b} (0.6)	2.5^{c} (0.3)
Baptisia lanceolata	236	38.7^{ab} (2.4)	8.0^{ab} (0.5)	0.8^{b} (0.1)	91.7^{b} (1.1)	6.1^{bc} (0.5)
Carphephorus bellidifolius	77	30.6^{b} (2.1)	4.8^{bc} (0.7)	1.4^{ab} (0.1)	91.1^{b} (1.7)	16.8^{a} (3.7)
Chrysoma pauciflosculosa	93	52.3^{a} (2.4)	3.3^{c} (0.4)	0.6^{b} (0.1)	95.4^{a} (3.6)	6.0^{bc} (0.5)
Liatris secunda	35	30.6^{b} (2.9)	7.0^{b} (0.7)	0.7^{b} (0.3)	91.4^{b} (3.6)	5.7^{bc} (1.2)
Nolina georgiana	189	23.2^{bc} (0.8)	9.1^{a} (0.5)	0.9^{b} (0.1)	91.1^{b} (0.9)	8.0^{b} (0.7)
Phaseolus polystachios	32	42.4^{ab} (5.1)	9.4^{a} (1.1)	0.8^{b} (0.4)	91.1^{b} (2.5)	7.8^{b} (1.1)
Stylisma pickeringii	88	45.1^{ab} (2.8)	3.7^{c} (0.4)	0.6^{b} (0.1)	94.3^{a} (0.8)	12.4^{ab} (1.5)
Warea cuneifolia	21	31.1^{b} (2.7)	5.6^{b} (1.0)	0.9^{b} (0.3)	94.4^{a} (1.1)	11.4^{ab} (3.9)
Plots without TES plants	878	32.0^{b} (0.9)	7.3^{b} (0.2)	0.8^{b} (0.1)	91.9^{b} (0.4)	8.4^{b} (0.4)

Table 7. Soil nutrient differences among sites with TES plant species on Lakeland soils. All values are for the upper 0-20 cm of soil depth. Values are from sites at the three installations combined. Bold numbers indicate significant differences (t-test, p=0.05) from other Lakeland soil samples where TES species did not occur.

TES Species	Calcium (mg/kg)	Magnesium (mg/kg)	Potassium (mg/kg)	Phosphorus (mg/kg)
Baptisia lanceolata	**27.11**	3.50	9.90	0.65
Carphephorus bellidifolius	11.03	2.49	8.73	0.96
Chrysoma pauciflosculosa	9.48	1.10	7.86	1.65
Liatris secunda	10.61	1.63	6.75	0.83
Nolina georgiana	16.53	3.08	9.63	**0.43**
Stylisma pickeringii	**5.11**	**0.80**	**6.05**	0.98
Warea cuneifolia	16.18	1.73	6.27	**1.75**
Sites without TES plants	19.74	2.98	9.12	1.18

Thirty-four canopy species and 230 understory species were found in the TES and non-TES sites. Longleaf pine accounted for more than 30% of the canopy coverage in the habitats of seven of the TES species; whereas, two species (*Stylisma* and *Warea*) were more commonly found under a canopy dominated by turkey oak (Figure 5). *Chrysoma* differed from the other species by occurring more frequently in association with shortleaf pine (*Pinus echinata*). In general, non-TES plant sites did not differ significantly in canopy composition from sites where the plants occurred.

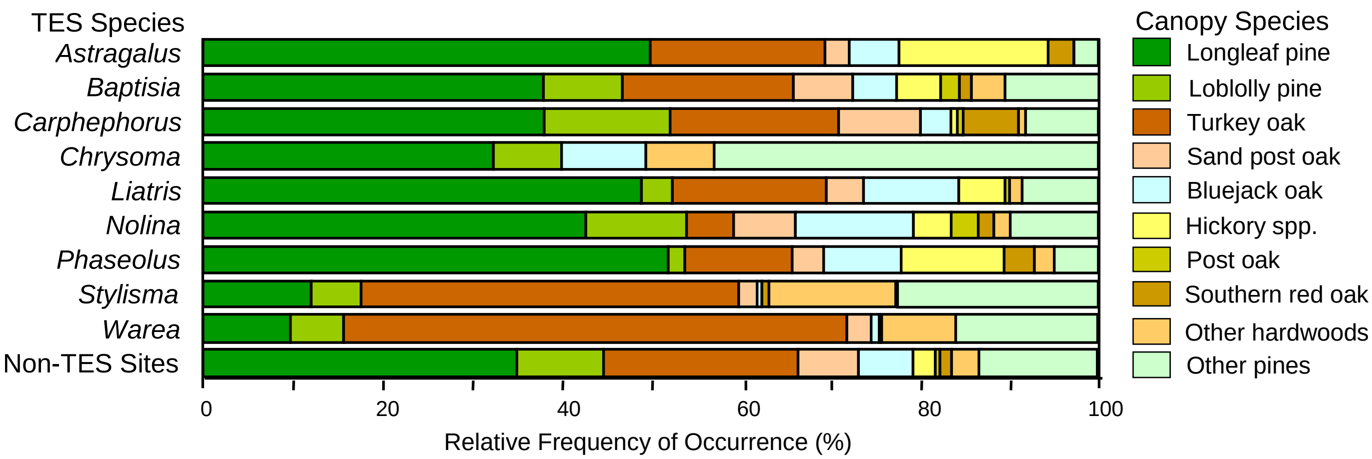


Figure 5. Relative frequency of occurrence of dominant canopy species at sites with TES plant populations and nearby sites without TES species. Data are from sites at Fort Benning, Fort Gordon and the Savannah River Site combined.

A non-metric multidimensional scaling (NMDS) ordination based on life form and species of herbaceous understory vegetation in the TES habitats revealed patterns in community composition and TES species distributions related to land management (Figure 6). Regression analyses of NMDS axis 1 and axis 2 scores with environmental variables resulted in R^2 values of 0.44 and 0.0.45, respectively. Axis 1 is significantly related to increases in woody debris that accumulates over time following burning. Axis 2 is significantly related to percent bare ground and to soil silt and moisture content (in opposite directions). Sites with minimal forest management and land use disturbance grouped together and the ground cover contained a more diverse mixture of asters, grasses, legumes and mosses. These sites also contained a greater number of characteristic sandhills understory species than did the other areas. *Chrysoma* and *Stylisma* were more abundant in these habitats than in any other locations. Sites burned three years before sampling and with a more frequent fire regime had a greater abundance of non-legume herbs, vines and grasses than did sites burned less frequently. *Nolina*, *Liatris*, *Carphephorus* and *Warea* were most commonly found in these sites. There was a trend of increasing soil moisture and silt content in sites burned five to six years before sampling, and legumes increased in dominance in these areas. *Baptisia*, *Phaseolus* and *Astragalus* were most abundant in these sites (Figure 6).

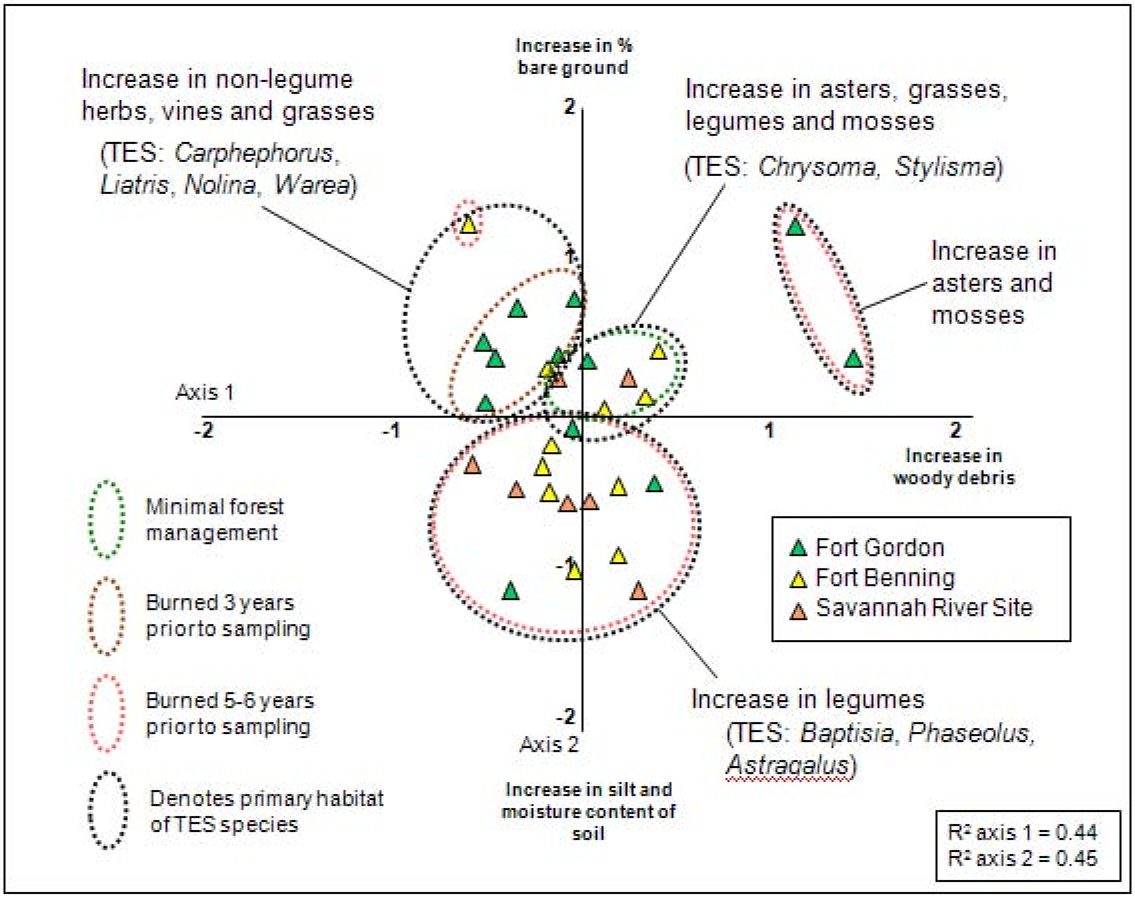


Figure 6. NMDS of cover values of understory species occurring in TES population sites grouped by life form or type (e.g., asters, legumes, other herbs, grasses, vines, mosses). Woody debris is significantly associated with axis 1 and percent moisture, silt content and bare ground are significantly associated with axis 2. The primary habitat conditions under which the different TES plant species are most abundant are indicated.

Vegetation data from gopher tortoise habitats show a strong similarity of canopy composition to the locations where the TES plant populations occur (Table 8). Canopy openness was greater in areas of tortoise burrows, but relative abundance of pines, oaks and other hardwood species was generally similar to that found in TES plant population sites Tuberville et al. 2007). Thus, efforts to conserve appropriate habitat for this TES animal species may have the potential for protecting TES plant species as well.

Table 8. Percent canopy openness and relative abundance of pines, oaks and other canopy species in gopher tortoise sites compared with TES plant habitats (NM = no management, GSB = growing season burns, DSB = dormant season burns).

		Relative Abundance		
Species (treatment)	**% Canopy Openness**	**Pines**	**Oaks**	**Other Hardwoods**
Gopherus polyphemus (NM)	64	25	68	7
Gopherus polyphemus (GSB)	67	53	47	0
Gopherus polyphemus (DSB)	56	84	13	3
Astragalus michauxii	17	53	30	17
Baptisia lanceolata	39	57	34	9
Carphephorus bellidifolius	31	60	38	2
Chrysoma pauciflosculosa	52	83	9	8
Liatris secunda	31	61	32	7
Nolina georgiana	23	64	30	6
Phaseolus polystachios	42	59	28	13
Stylisma pickeringii	45	39	46	15
Warea cuneifolia	31	31	61	8

5.5. Development of habitat models for TES plants and identification of potential additional suitable habitat

Populations of the TES plants were found across the full array of sandhills and xeric woodland community types described in objective 1.1. Probability-based habitat suitability models have been developed for the nine TES plant species, based upon the extensive data from their habitat characterization (Appendix A.8.2). These models are based upon species-specific affinities to habitat characteristics and their underlying factors. Often, these factors are strongly associated with general features related to soils, topography and climate, but locally regulated by the influence of disturbance and land-use histories.

Sampled TES plant species had differential actual and predicted environmental relationships that were associated with inherent site conditions such as soil moisture, nutrient storage, and topography (Figure 7). However, these species were also associated with biotic conditions which can be influenced by land management. Because of rarity, perfect alignment with site characteristics was not necessarily obvious at fine- and broad-scale dimensions. For most of these species, rarity is less likely to be due to the absence of suitable conditions and more likely to be due to either local extirpation or insufficient dispersal of seed from limited sources into locally suitable sites. Therefore, characterization of the frequency of suitable sites on the landscape is important for restoration and conservation as well as the implementation of successful survey and monitoring programs.

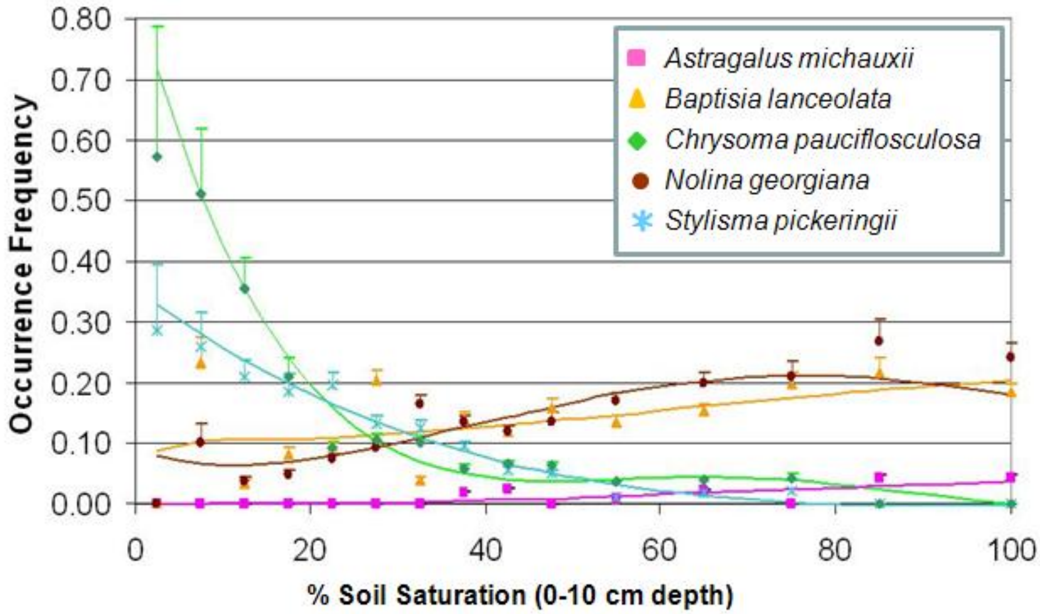


Figure 7. Actual and predicted occurrence of five sandhills TES plant species across a soil saturation gradient.

Chrysoma and *Stylisma* were associated with the harshest conditions characterized by deep, dry soil profiles with very high sand content, low nutrient content, and low organic matter. These were sites of low tree density and basal area that were dominated by xeric oaks (turkey oak, sand post oak, bluejack oak), and low shrub and herbaceous cover. Slightly less xeric sites harbored *Liatris* and *Astragalus*; these sites had greater tree basal area and canopy dominants that included longleaf pine mixed with xeric oaks and hickories. Still other TES species, such as *Carphephorus*, *Nolina*, and *Baptisia*, had broad distributions that ranged from xeric longleaf pine-scrub oak on coarse-textured soils into dry and finer-textured areas that had greater abundances of longleaf pine and other tree mixtures. Finally, *Phaseolus* and *Warea* occurred under unique site conditions such as transitional slopes with patchy mixed species compositions, and sandy open surface soils underlain by loamy sub-soils.

Performance of the models in predicting TES plant occurrence varied among the species. Light-seeded species (*Liatris, Carphephorus, Warea*) were less accurately predicted than the heavier-seeded legumes (*Astragalus*, *Baptisia*, *Phaseolus*) or the ultra-xeric site species (*Chrysoma*, *Stylisma*). Generally, predictions tended to somewhat overestimate species occurrences and habitat suitability, but only a very few sites actually contained TES plant populations without their predicted occurrence. Overestimation of suitable habitat was highest for the SRS and lowest for Fort Benning; these differences may be due to differences in both fire and military disturbances.

The patchy environment of the sandhills and related xeric woodlands cannot be easily quantified using data from large plots because of strong spatial patterning at fine scales. Unexpectedly, soil features changed rapidly over short distances. Typically, sandhills soils are thought to be deep sands that have little variance in depth of sandy textures as well as textural composition; however, conditions that impact estimated soil profile cation exchange capacity

(CEC) and moisture holding capacity change rapidly. The models suggest that a wide range of resource combinations and conditions that are capable of supporting a suite of sandhills TES species are likely to exist, and species presence is likely to be limited not only by tolerance of site conditions, but also by spatially patterned dispersal and biotic interactions in more suitable settings. Observations also suggest that large-scale management actions (e.g., broad-scale herbicide use) or land use (e.g., tracked vehicle training) may lessen local spatial patterning with unknown consequences on long-term site capacity to support certain species.

A more complete description of the details of the TES habitat modeling is provided in Appendix A.8.2). Overall, aboveground conditions poorly reflected TES species occurrence and density. When soil and topographic features were added, all measures of model solution quality greatly improved; therefore, models based only on aboveground features were discounted. Overall, this suggests that land management actions to improve habitat conditions are likely to be most effective when appropriate soil and topographic settings are in place.

In addition to developing predictive mathematical models of TES species habitats, maps of potential species occurrences were developed in a GIS framework based upon Landsat-7 ETM+ imagery and soils associated with known population locations (Figure 8, Appendix A.8.3). These GIS models and maps may be useful to resource managers at the installations in identifying additional habitat locations for the species or sites to which they might be transplanted if it becomes necessary to relocate a TES plant population.

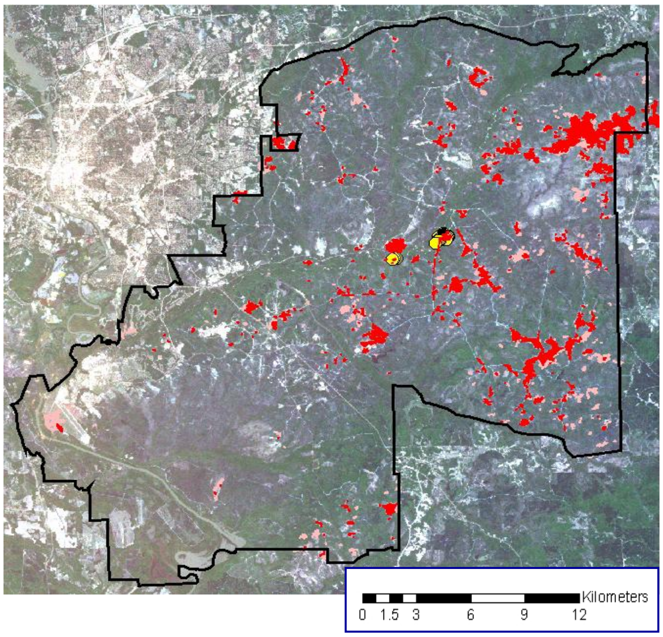


Figure 8. Map of potential suitable habitat for *Stylisma pickeringii* on Fort Benning as defined from Landsat-7 ETM+ imagery for two time periods (December 2002—leaf off, and April 2003—leaf on) and soils (Troup and Lakeland) associated with known population locations. See .A.8-3 for additional maps of TES species habitat at each of the three installations.

The maps were validated by surveys of 64 locations across the installations. Populations of TES species were found at more than 50% of the predicted sites, and more than 78% of the sites had soil and vegetation characteristics similar to known TES plant species habitats (Table 9).

Table 9. Validation of TES plant species potential habitat maps produced from Landsat imagery and soils data.

Installation	No. Sites Visited	% with TES Species Present	% Suitable TES Habitat
Fort Benning	27	33.3	70.4
Fort Gordon	22	72.7	90.9
Savannah River Site	15	60.0	73.3
All Sites Combined	64	55.3	78.2

These potential TES species habitat maps have been compared with forest inventory maps and military training/land management maps of each of the installations to determine the management conditions at the predicted TES sites (Appendix A.8.4). From these maps, it is possible to determine the potential area of occurrence of each TES species in each land cover class. At Fort Benning, four of the TES plants (*Baptisia, Chrysoma, Phaseolus* and *Stylisma*)

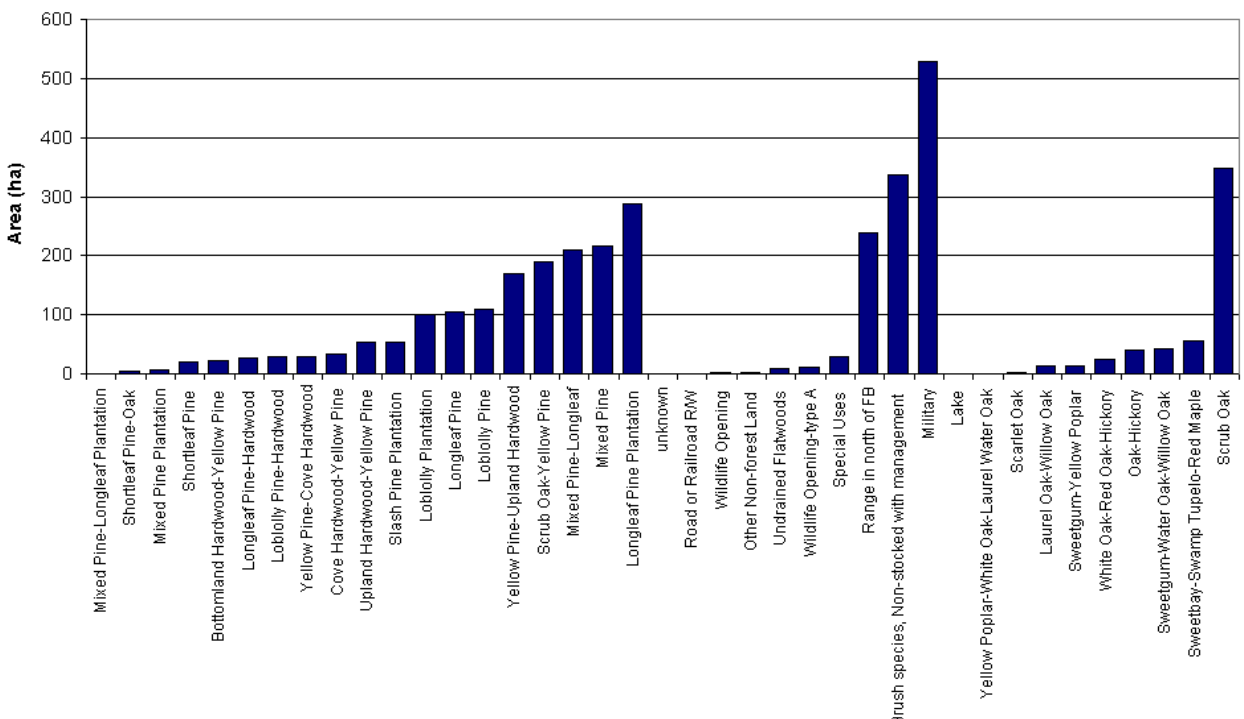


Figure 9. Potential occurrence of *Stylisma pickeringii* at Fort Benning associated with different forest communities and land coverage. See Appendix A.8.4 for information on other TES species.

were likely to be abundant in scrub oak, pine, and military training sites (see Figure 9, Appendix A.8.4), whereas *Warea* was more likely to be found in mixed pine and mixed hardwood forested areas. At Fort Gordon, *Baptisia*, *Carphephorus*, *Liatris*, *Nolina* and *Warea* were predicted to be most abundant in areas managed for natural or planted longleaf or loblolly pine or planted slash pine; these pine sites were the predominant forest type (Appendix A.8.4); however, *Stylisma* was also likely to occur in longleaf pine-scrub oak sites. On the SRS, the sandhills areas were included in pine-hardwood sites in the forest inventory, and the TES species were largely restricted to these areas (Appendix A.8.4).

Once these potential habitat maps were developed and validated, the maps for all TES species were combined in composite maps showing potential habitat for multiple species. As expected based upon the environmental characterization of the species habitats (objective 2.4), there was extensive overlap of probable locations where multiple TES species might occur (Figure 10, Appendix A.8.5). Such maps may be useful to resource managers in identifying priority sites for conservation of multiple TES species.

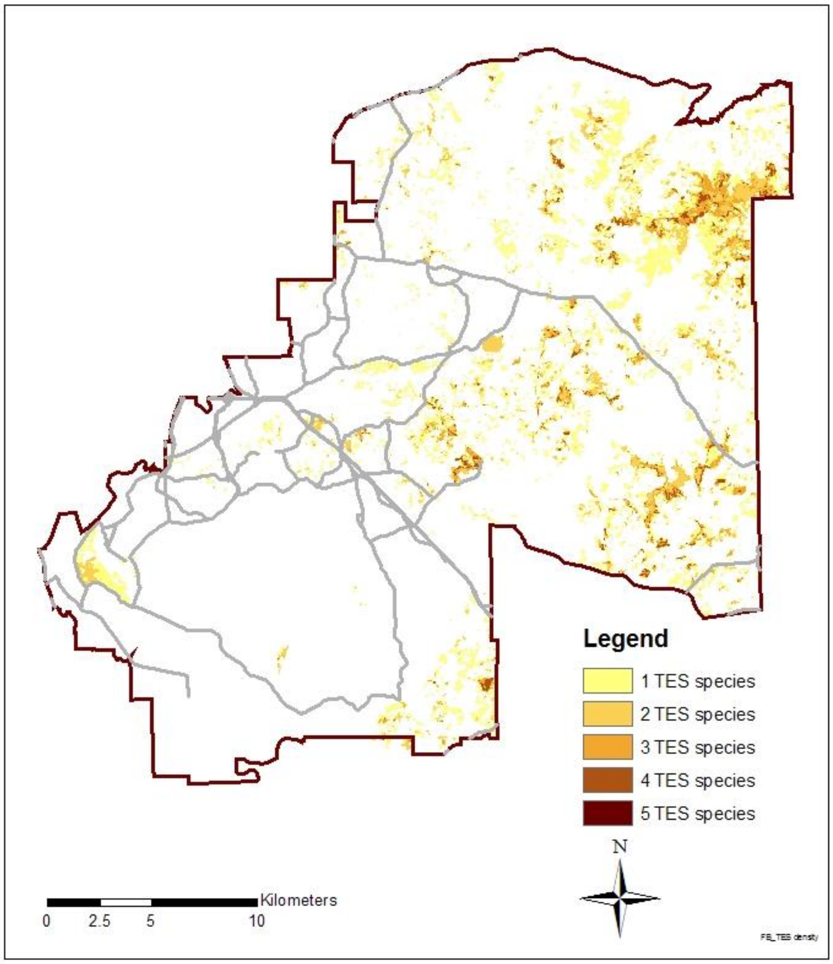


Figure 10. Potential species richness of multiple sandhills TES plants on Fort Benning, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils associated with known TES plant population locations. See Appendix A.8.5 for additional maps of all three installations.

Most of the TES plant populations occurred in areas of moderately open sandy pine-dominated forest similar to sites known to be preferred gopher tortoise habitat (Tuberville et al. 2007). In particular, gopher tortoise sites managed by burning (during either growing or dormant seasons) were comparable to TES plant habitats (Balbach et al. 2007). Potential TES plant habitat maps were combined with information on known locations of gopher tortoise burrows on Fort Benning, and there was substantial overlap among habitats of this sandhills animal and the plants (Figure 11). Of 8395 mapped gopher tortoise burrows, 4854 (or 58%) were within areas mapped as probable habitat for one to five TES plant species. Furthermore, the areas of highest occurrence of both plant and animal TES are within the most xeric sandhills areas with open pine canopy.

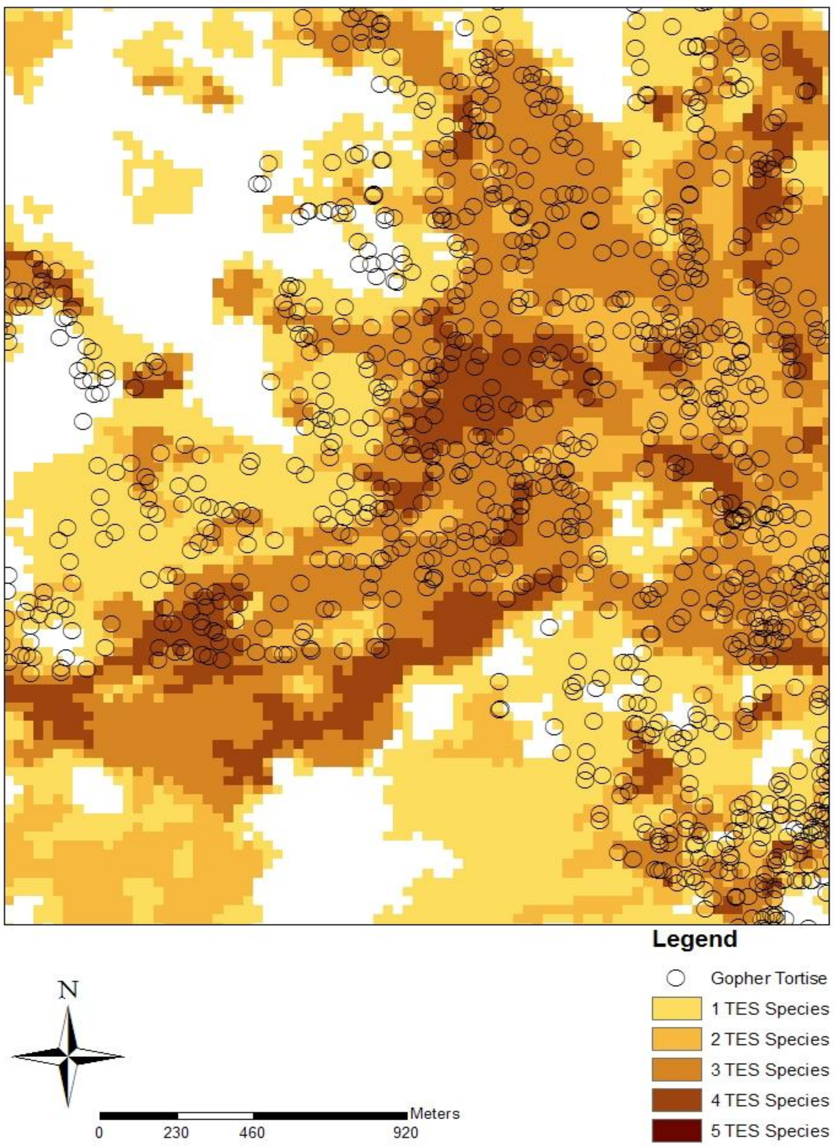


Figure 11. Overlap of mapped locations of gopher tortoise burrows with map of potential suitable habitat for multiple TES plant species for a region of Fort Benning.

In 2006, the gopher tortoise was proposed for federal protection as a threatened species, due largely to declining numbers following fragmentation of its habitat. A large group of federal and state agencies, combined with private conservation groups and private landowners developed a memorandum of understanding, with the intent of maintaining an environment in which the gopher tortoise will thrive. The hope is that this effort will preclude the necessity to list the gopher tortoise as a federally protected species. These efforts to protect habitat for a TES animal species that is widely recognized to be of conservation concern may have the additional benefit of protecting habitat for poorly studied TES plant species in the sandhills.

5.6. Experimental garden study of selected TES plant responses to disturbances related to military training and forest management

Soils in all the experimental gardens had relatively high sand content and low soil nutrients (Table 10). The high disturbance gardens at Fort Gordon that mimicked tank and motorized vehicle training were highest in calcium (Ca), potassium (K) and magnesium (Mg) and had the most open canopies. By the end of the first summer, these high disturbance gardens were densely packed with asters and grasses in addition to the TES plants, and by the end of the third growing season percent cover of herbs and woody sprouts was 90-95% (Figure 12). Percent cover of other species remained relatively low in the no disturbance (control) and low disturbance gardens throughout the course of the study. The highly disturbed gardens on the SRS had much less herbaceous cover and more bare ground or pine needle cover. Several of the gardens on both of the installations showed extensive evidence of deer grazing, and each of the TES species was affected by grazing in either undisturbed or low disturbance gardens. In one of the control gardens on Fort Gordon, *Nolina* and *Stylisma* were heavily grazed and there was little evidence of their recovery by the end of the study (Figure 13).

Table 10. Environmental characteristics (canopy openness, soil sand and organic matter content, and soil nutrients) of experimental TES plant gardens. SRS = Savannah River Site, FG = Fort Gordon.

Treatment	% Canopy Openness	% Sand	% Organic Matter	Ca*	K*	Mg*	Mn*	P*	Zn*
No Disturbance									
SRS 1	29.53	88.0	1.48	32.25	10.97	6.86	0.45	3.31	2.08
SRS 2	30.47	92.0	1.90	9.76	8.18	2.97	9.02	10.69	2.81
FG 1	25.04	98.0	1.56	10.27	8.32	2.92	3.51	2.17	1.28
FG 2	23.94	92.0	1.90	11.05	10.36	3.28	0.56	1.88	3.25
Low Disturbance									
SRS 1	36.47	90.0	1.24	13.26	8.69	2.88	0.60	2.91	2.86
SRS 2	34.79	90.0	1.88	8.18	8.37	2.72	7.70	11.26	2.75
FG 1	35.79	92.0	1.34	7.54	8.41	2.50	0.01	1.86	3.29
FG 2	30.27	92.0	1.58	8.95	7.62	2.08	0.07	1.88	2.45
High Disturbance									
SRS 1	37.95	90.0	1.22	27.42	11.94	5.52	3.33	4.05	3.94
SRS 2	36.99	88.0	1.80	25.30	14.49	7.18	0.41	3.05	3.70
FG 1	78.05	90.0	1.84	58.70	16.56	10.31	8.65	3.26	0.73
FG 2	64.17	88.0	3.43	67.70	16.65	12.02	8.47	3.13	0.60

* Data are from the top 10 cm of soil, reported in parts per million

Figure 12. Three experimental TES plant gardens at Fort Gordon during the summer 2007. From left to right, gardens are no disturbance (control), low disturbance, and high disturbance sites.

All four TES species became established and survived in the disturbed and control gardens (Figure 13), although there was considerable variation in species response within treatments and across treatments. Survival in the most disturbed gardens at Fort Gordon was generally >40%, although a decline in survival of each species was observed in the fourth growing season. In particular, *Carphephorus* and *Stylisma* had greatly reduced survival in the most disturbed sites. These low-growing plants (with herbaceous rosettes or ground-spreading

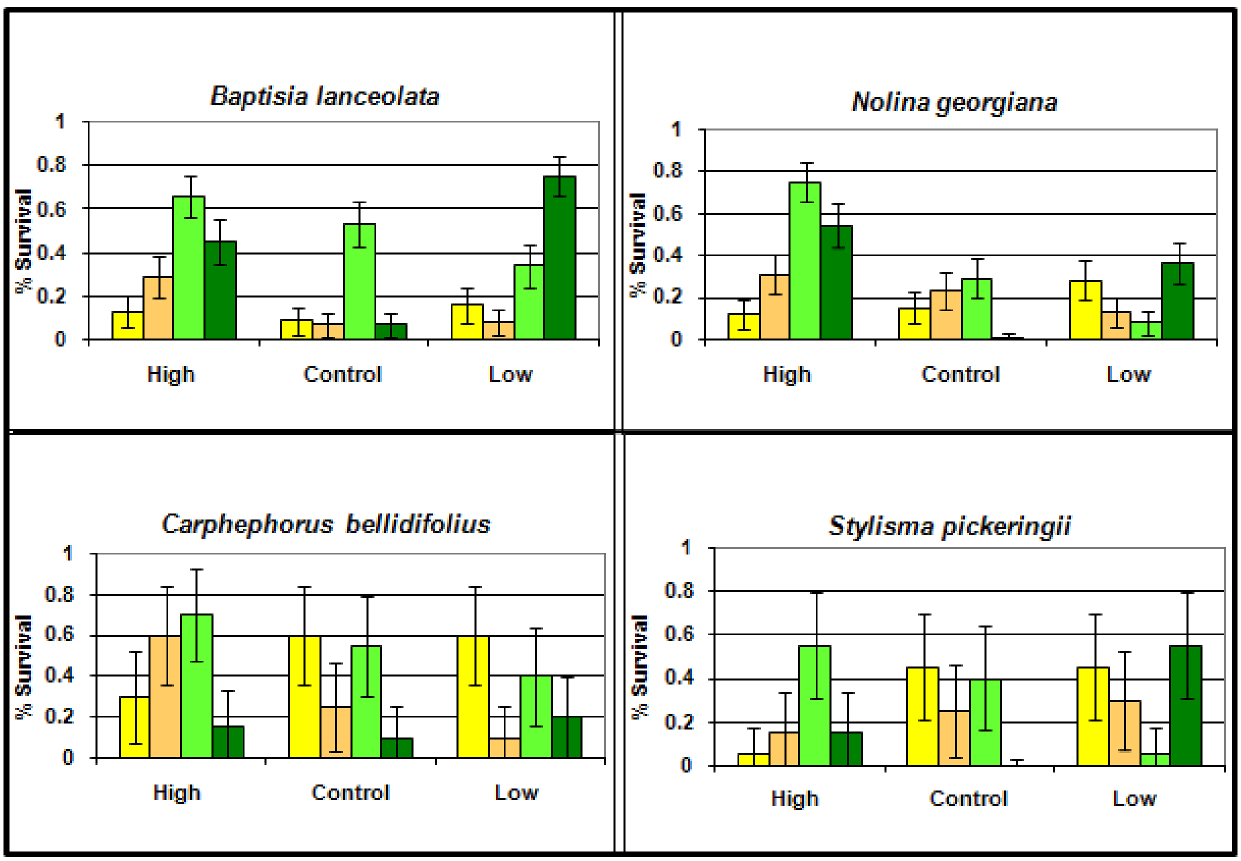


Figure 13. Total percent survival of four planted TES species in each disturbance treatment (high, low, control) at the end of the fourth growing season. The first two columns in each graph are the Savannah River Site gardens; the second two columns are the Fort Gordon gardens. Lines are 95% confidence intervals.

vines) were likely more sensitive to shading by other herbaceous and woody species at the Fort Gordon gardens than were the more robust *Baptisia* and *Nolina*. Survival of *Baptisia* and *Nolina* was generally lower in the control gardens than in the disturbed sites; whereas, survival of *Carphephorus* and *Stylisma* was similar in control and low disturbance gardens.

Growth responses of the four species also differed among treatments. *Baptisia* grew taller in the more disturbed sites (Figure 14) than in the low disturbance or control gardens, with plants averaging 20 cm in height in the SRS gardens and up to 35 cm in the Fort Gordon gardens. Likewise, *Nolina* grew larger under more highly disturbed conditions, even though its survival was lower at these sites. This plant forms a large basal rosette with linear leaves, thus leaf length was used as the measure of size increase in this species. Since most of the *Nolina* plants were not reproducing by the fourth growing season, no distinction in size could be made between male and female plants.

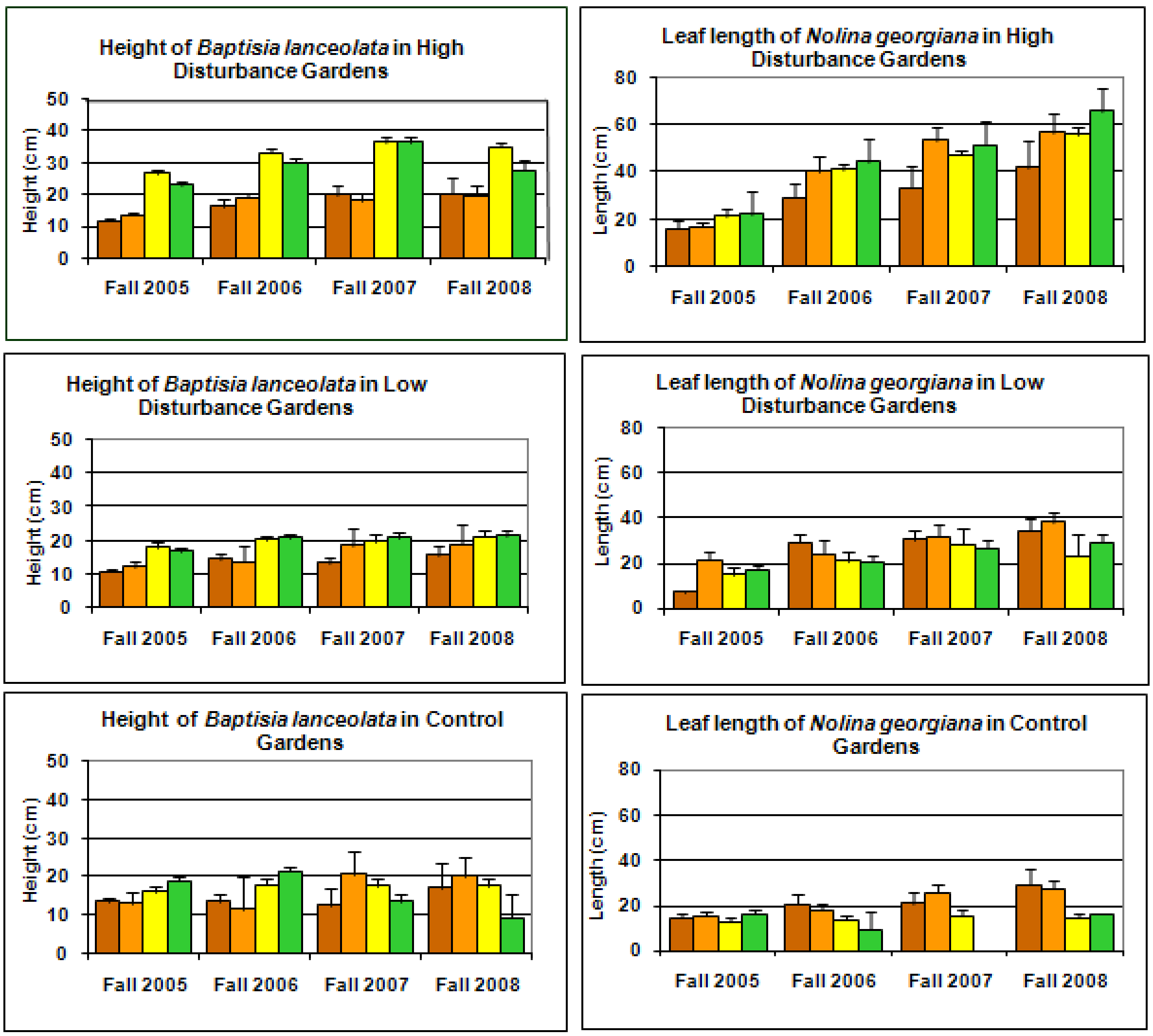


Figure 14. Plant height growth of *Baptisia lanceolata* and leaf length growth of *Nolina georgiana* over four years following transplantation to experimental gardens under different levels of disturbance (high, low, control). The first columns in each graph are the Savannah River Site gardens; the second two columns are the Fort Gordon gardens. Lines are 95% confidence intervals.

There was much variation in size in both *Carphephorus* and *Stylisma* (Figure 15). In the low disturbance gardens, several of the *Carphephorus* rosettes were >40 cm in diameter at the end of the fourth growing season, although most plants in each of the treatments ranged between 5-15 cm. *Stylisma* vines grew to greater lengths (>50cm) in both highly disturbed gardens at Fort Gordon, even though their survival in one of the gardens was somewhat lower. Most *Stylisma* vines ranged between 10-30 cm in the other disturbed and control sites.

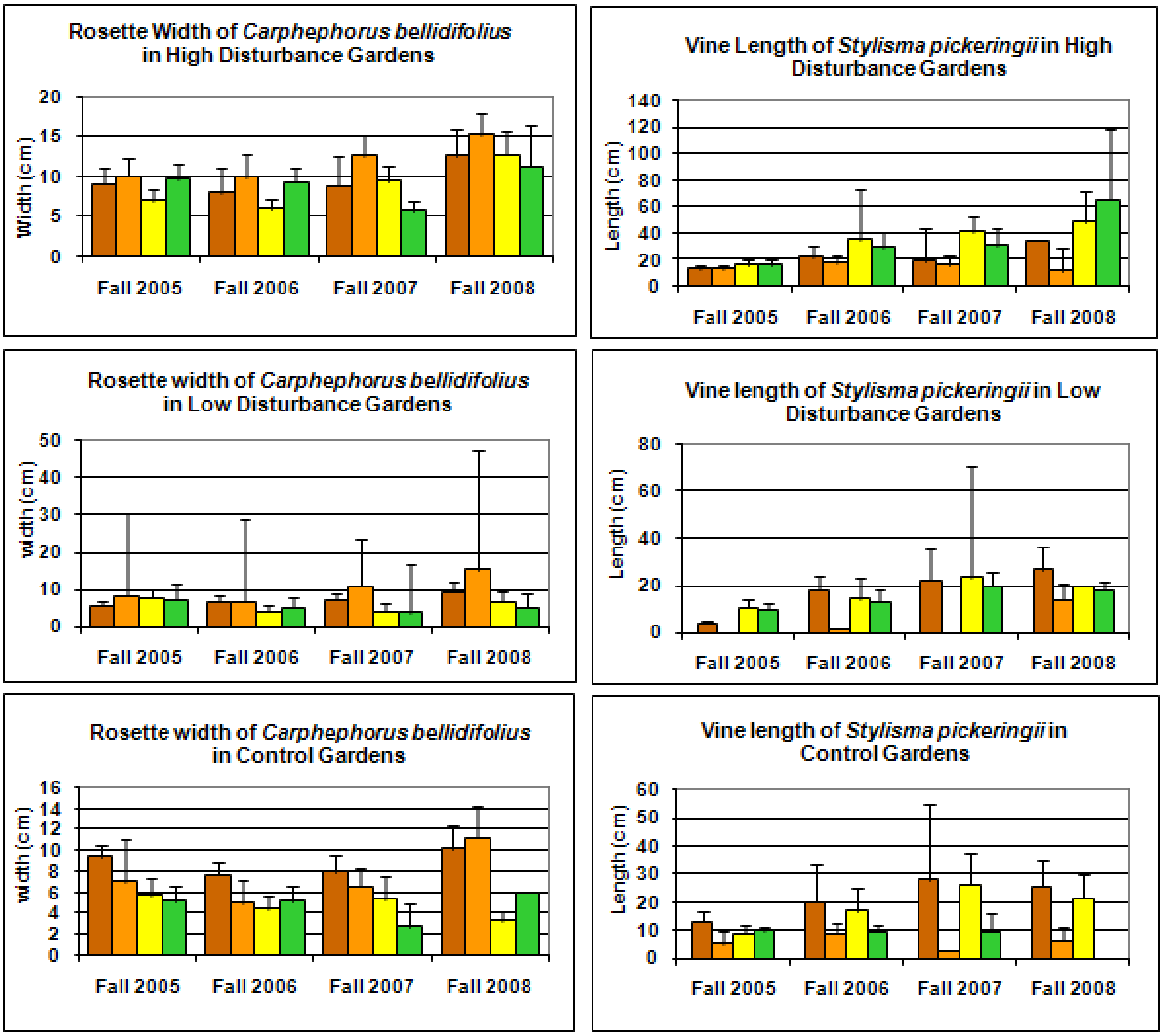


Figure 15. Rosette width of *Carphephorus bellidifolius* and vine length growth of *Stylisma pickeringii* over four years following transplantation to experimental gardens under different levels of disturbance (high, low, control). The first columns in each graph are the Savannah River Site gardens; the second two columns are the Fort Gordon gardens. Lines are 95% confidence intervals. Note that the scales on the Y-axis differ among treatments within a species.

As expected, *Carphephorus* was the only species that flowered the first year, and this species continued to reproduce under disturbed and control conditions throughout the study (Figure 16). *Baptisia* flowered in a highly disturbed site the second season, and under both disturbance conditions the third and fourth season although the number of flowering plants was low in the low disturbance sites. This species did not flower in the more shaded control gardens. A few *Stylisma* vines flowered in the second season, and several more flowered in the high disturbance gardens in years three and four. Five *Nolina* plants flowered in the most disturbed site by year four; both male and female plants flowered.

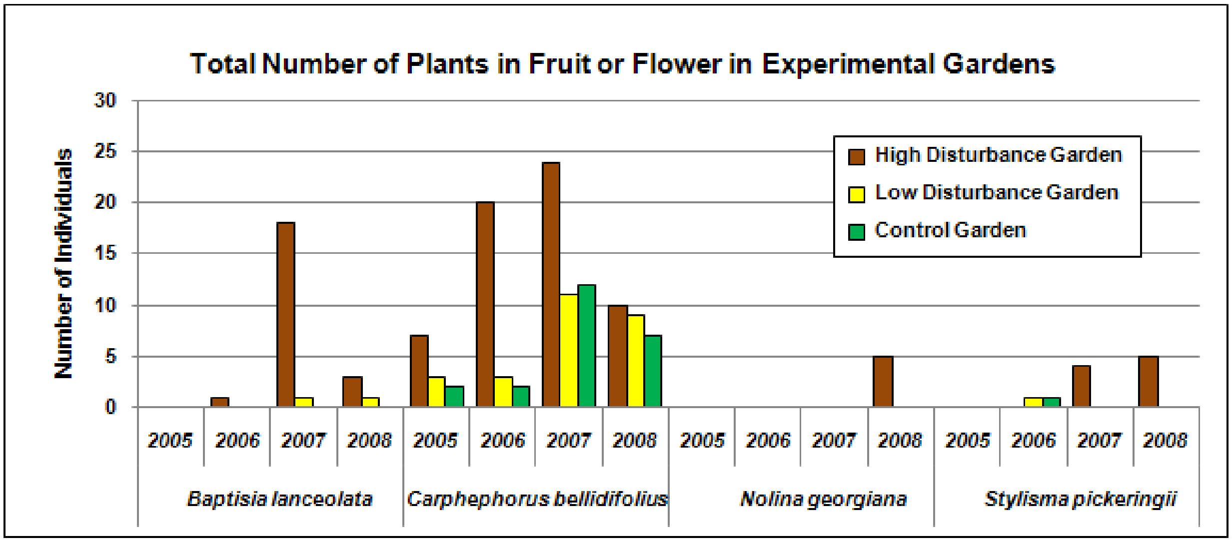


Figure 16. Reproduction of TES plants in experimental gardens under different levels of disturbance (high, low, control) over four years following transplantation.

Transplantation of these sandhills TES plants into new habitats was successful across a range of disturbance conditions. Most sandhills TES plant species, including these four, are long-lived perennials, but each differs in life form and reproductive strategy (Duke 1961, Radford et al. 1964). *Baptisia* is a legume that sprouts from a rhizome and will develop a shrub-like appearance as the plants grow and mature (Figure 17). *Nolina* is a dioecious plant related to the lily family that typically has separate male and female plants. *Carphephorus* is in the aster family and, based on the TES population surveys (objective 2.4), is likely to maintain the highest survival and reproductive success of the transplanted TES species. *Stylisma* is a small herbaceous vine that is a member of the morning glory family.

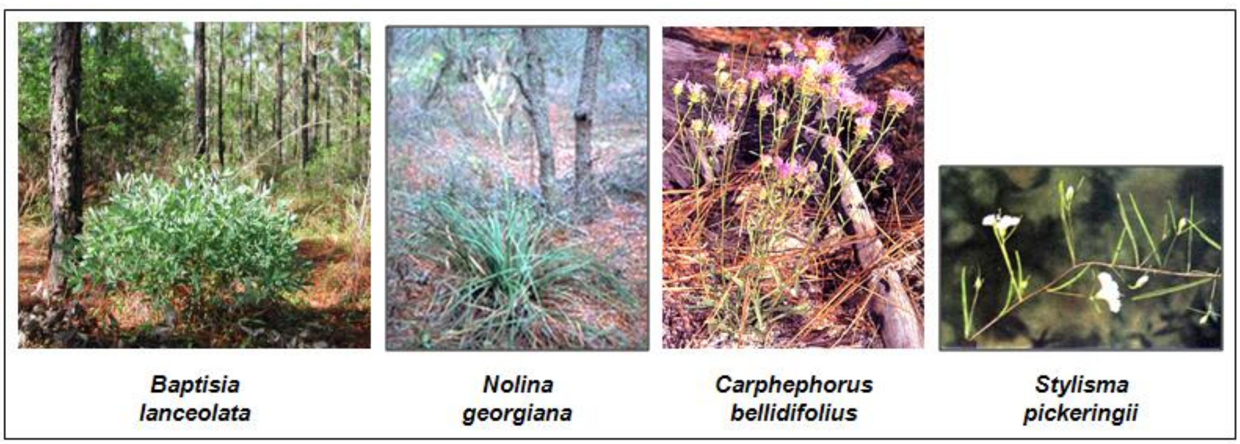


Figure 17. Sandhills TES plant species planted into experimental gardens.

6. Conclusions

This research has evaluated the effects of forest management for RCW habitat and military training activities on the sustainability of Fall Line sandhills communities and associated TES plant species on military installations and other federal lands. Field studies of woody plant species composition and abundance, and of environmental characteristics including soil texture and nutrient levels, have allowed discrimination of sandhills and related xeric woodland communities along the Fall Line from surrounding pine and hardwood forests. These sandhills and related dry woodlands also can be generally discriminated from surrounding forests in a spatial context, using Landsat ETM+ imagery (leaf-on and leaf-off) and soils information. Development of such maps enables comparison of these fragile xeric communities with forest management and other land uses in a GIS framework, for the assessment of management practices that may be compatible, or incompatible, with sustaining the integrity of the sandhills and related xeric woodlands on federal installations along the Fall Line.

Management of forests to provide open pine woodland habitats to support populations of the federally endangered RCW requires burning or other activities to limit development of woody understory species. This research has shown that burning at intervals of several years is compatible with maintenance of the sandhill community, including at least some of the TES plant species. Other hardwood understory control methods such as application of herbicide or mechanical shredding, especially when combined, have more detrimental effects on the maintenance of sandhills species. Thus, burning during the growing season or dormant season, at intervals of several years, is the preferred management method for sandhills communities associated with RCW habitat.

Rare plant species of the Fall Line sandhills have received relatively little conservation attention, and their habitat requirements are poorly understood. Populations of nine species listed as Species of Conservation Concern in Georgia and South Carolina were studied, and their habitat conditions characterized. Probability-based habitat suitability models for these species provide an understanding of site conditions related to their population distributions, and a prediction of species occurrences and habitat suitability. Though the resulting models somewhat overestimated species actual occurrences, they are well-suited for surveys because only a very few sites actually contained TES plant populations without their predicted occurrence. The models are also useful in identifying sites for restoration of TES species populations if such becomes necessary under current management protocols.

In addition, potential suitable TES species habitat can be identified in a GIS framework with input data such as Landsat ETM+ imagery and soils maps. Such potential habitat maps for individual TES species may be combined to identify potential habitat of multiple species. These maps are useful to resource managers in visually identifying sites where new populations of TES species may be found, and in prioritizing locations for the conservation of multiple species. A comparison of potential habitat for multiple sandhills plant TES species at Fort Benning with known locations of gopher tortoise burrows revealed substantial overlap. More than half of the mapped gopher tortoise burrows were within areas mapped as probable habitat for one to five TES plants species. None of the plants examined in this research are federally listed as endangered or threatened, and plants typically receive less conservation attention than animals. Thus, conservation efforts directed at sandhills TES animal species may have the additional benefit of providing habitat protection to some TES plants.

It is inevitable that land uses on federal installations will at times conflict with the habitat needs of the sandhills TES plants. When such conflicts arise, it may become necessary to transplant TES species to other locations. Potential suitable habitat maps are useful in identifying sites appropriate for transplantation, and this research has shown that at least some of the TES plants, with different growth forms and life histories, can be successfully transplanted to new sites. Thus, population relocation should be a considered as a conservation tool in the management of rare plants on federal lands along the Fall Line sandhills. Furthermore, the protection of habitat afforded by federal lands has resulted in the protection of populations of numerous TES plant species on these sites (Jordan et al 1997, Martin et al. 2001).

The need for an ecosystem-based approach to TES species management on military has been discussed in previous reports (e.g., Trame and Tazik 1995, Martin et al. 2001). An understanding of the habitat requirements of the multiple TES species that occupy the Fall Line sandhills and related xeric woodland communities should aid in the application of such an approach. This research suggests that management practices such as burning at intervals of several years to promote habitat for TES animal species, including the RCW and the gopher tortoise, may be a suitable management approach for certain TES sandhills plants. Furthermore, it appears that conservation practices for these at-risk animals may aid in conservation of TES plants. The following recommendations for future management and research should aid in TES plant species conservation efforts:

1) Use the potential habitat maps for multiple TES plant species to identify and prioritize sites for conservation efforts on Fort Benning, Fort Gordon and the SRS.
2) Compare locations of TES plant populations with locations of RCW colonies at the three installations to determine overlap and potential for plant conservation associated with management of this federally endangered animal species.
3) Using the approach described in this research, develop similar potential habitat maps for multiple TES species on other federal lands along the Fall Line sandhills region.
4) Conduct studies of the potential for transplantation of additional TES plant species as a means of protecting them when land use conflicts arise.

In addition, further studies regarding the causes of rarity of these TES plants would be useful in developing management recommendations. For example, it is known that seedling establishment may be limited by predispersal seed predation in *Baptisia* (Horn and Hanula 2004), and it appears that this may be likely in other TES plants as well. Furthermore, the ability for seeds of these species to withstand heat shock during burns may be an important component of their survival (Young et al. 2007). Virtually no seedlings of any of the TES plants were observed during this study of natural populations, and further research on their reproductive biology and conditions needed for population recruitment are warranted.

7. Literature Cited

Balbach, H., R. Sharitz, D. Imm, T. Tuberville and G. Wein. 2007. Strategy for *in situ* conservation of at-risk and declining sandhills species. Proceedings 3rd Global Botanic Gardens Congress, Botanic Gardens Conservation International, Surrey, UK.

Christensen, N. L. 1988. Vegetation of the southeastern Coastal Plain. pages 318-363. *In* M. G. Barbour and W. D. Billings (eds.) North American Terrestrial Vegetation. Cambridge University Press, Cambridge, UK.

Duke, J. A. 1961. The Psammophytes of the Carolina Fall-line sandhills. Journal of the Elisha Mitchell Scientific Society. 77:3-25

Environmental Systems Research Institute (ESRI). 2004. ArcGis Desktop. Ver. 8.3. Redlands, CA.

Harper, M. G., A.-M. Trame, R. A. Fischer and C. O. Martin. 1998. Management of longleaf pine woodlands for threatened and endangered Species. USACERL Technical Report 98/211, U.S. Army Construction Engineering Research Laboratories, Champaign, IL.

Harper, S. J. and R. R. Sharitz. 2005. Delineating sandhill communities: the use of advanced techniques to extract features from satellite imagery. pages 123-136. *In* Proceedings of the 4th Southern Forestry and Natural Resources GIS Conference. P. Bettinger, et al. (eds.). University of Georgia Warnell School of Forest Resources. Athens, GA.

Horn, S. and J. L. Hanula. 2004. Impact of seed predators on the herb *Baptisia lanceolata* (Fabales: Fabaceae). Florida Entomologist 87:398-400.

Husch, B., C. I. Miller and T. W. Beers. 1982. Forest Mensuration. John Wiley and Sons, New York.

Jordan, R. A., K. S. Wheaton, W. M. Weiher and T. J. Hayden. 1997. Integrated endangered species management recommendations for army installations in the southeastern United States. USACERL Special Report 97/94, U.S. Army Construction Engineering Research Laboratories, Champaign, IL.

Laessle, A. M. 1958. The origin and successional relationship of sandhill vegetation and sand-pine scrub. Ecological Monographs. 28: 361-389.

Leslie, M., G. K. Meffe, J. L. Hardesty and D. L. Adams. 1996. Conserving biodiversity on military lands: a handbook for natural resource managers. The Nature Conservancy, Arlington, VA.

Martin, C. O., R. A. Fischer, D. J. Tazik, M. Harper and A. Trame. 1996. Regional strategies for managing threatened and endangered species habitats: a concept plan and status report. SERDP-96-1, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Martin, C. O., M. G. Harper, A-M. T. Shapiro and R. A. Fischer. 2001. A community-based regional plan for managing threatened and endangered species on military installations in the southeastern United States. USACOE, ERDC-TR-01-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

McCune, B. and M. J. Medford. 1999. PC-ORD: Multivariate analysis of ecological data. Ver. 4.33. Glenden Beach, OR, MjM Software.

Monk, C. D. 1960. A preliminary study on the relationships between vegetation of a mesic hammock community and a sandhill community. Quarterly Journal of the Florida Academy of Science. 23: 1-12.

Radford, A. E., H. E. Ahles and C. R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press, Chapel Hill, NC.

SAS Institute. 1999. SAS systems for windows, Ver. 8.02. SAS Institute, Cary, NC.

Thompson, I. D., D. A. Ortiz, C. Jastrebski and D. Corbett. 2006. A comparison of prism plots and modified point-distance sampling to calculate tree stem density and basal area. Northern Journal of Applied Forestry 23:218-221.

Trame, A. and M. G. Harper. 1997. Potential military effects on selected plant communities in the southeastern United States. USA CERL Tech. Rept. 97/115. U.S. Army Construction Engineering Research Laboratories, Champaign, IL.

Trame, A., and D. J. Tazik. 1995. The implications of ecosystem management for threatened and endangered species conservation by the U.S. Army. USA CERL Tech. Rept. 95/27. U.S. Army Construction Engineering Research Laboratories, Champaign, IL.

Tuberville, T. D., K. A. Buhlmann, H. E. Balbach, S. H. Bennett, J. P. Nestor, J. W. Gibbons and R. R. Sharitz. 2007. Habitat selection by the gopher tortoise (*Gopherus polyphemus*). ERDC/CERL TR-07-01. U.S. Army Construction Engineering Research Laboratory, Champaign, IL.

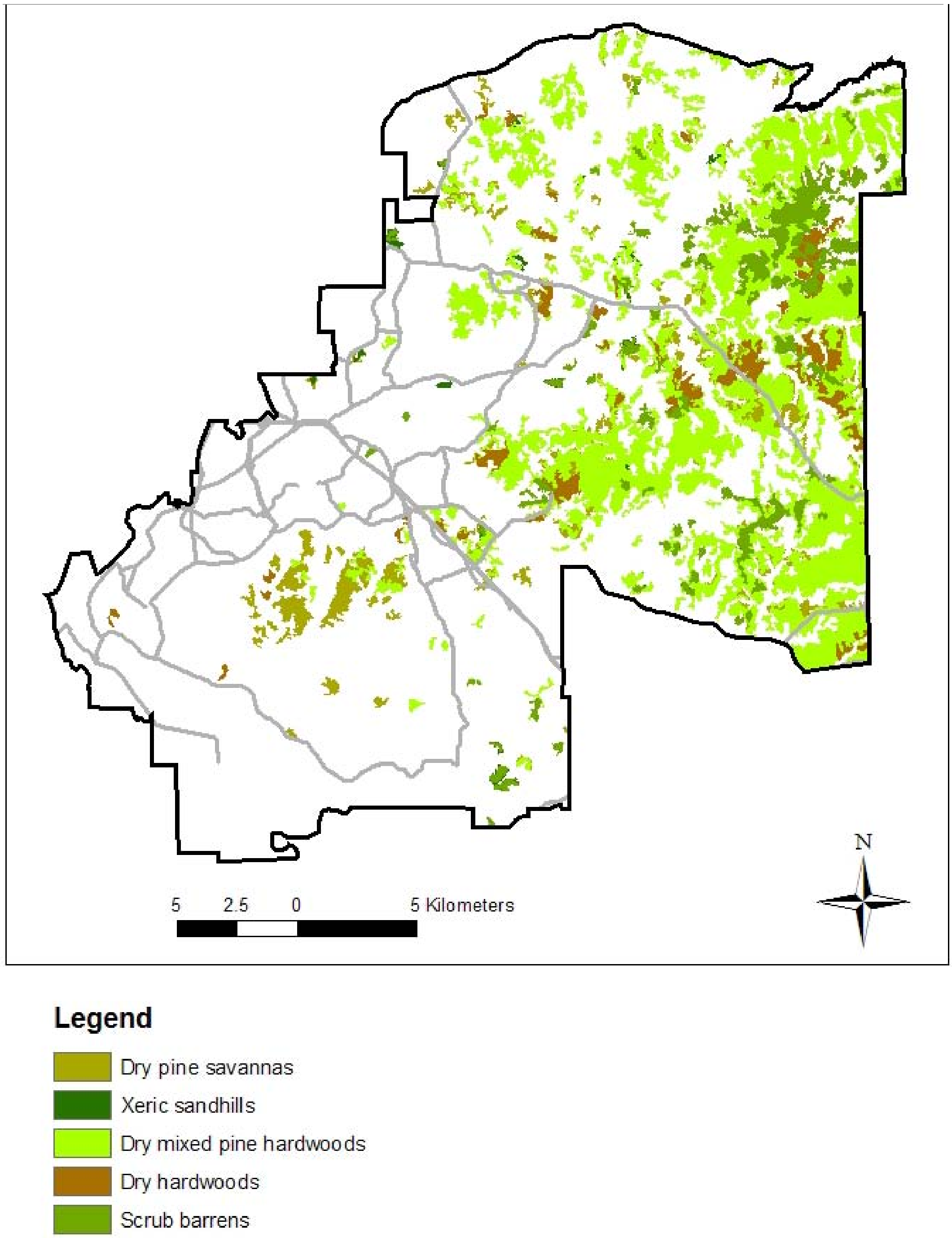
Visual Learning Systems, Inc. 2004. Feature analyst professional. Ver. 3.4. Missoula, Mt.

Wells, B. W. and I. V. Shunk. 1931. The vegetation and habitat factors of coarser sands of the North Carolina Coastal Plain: an ecological study. Ecological Monographs. 1: 465-520.

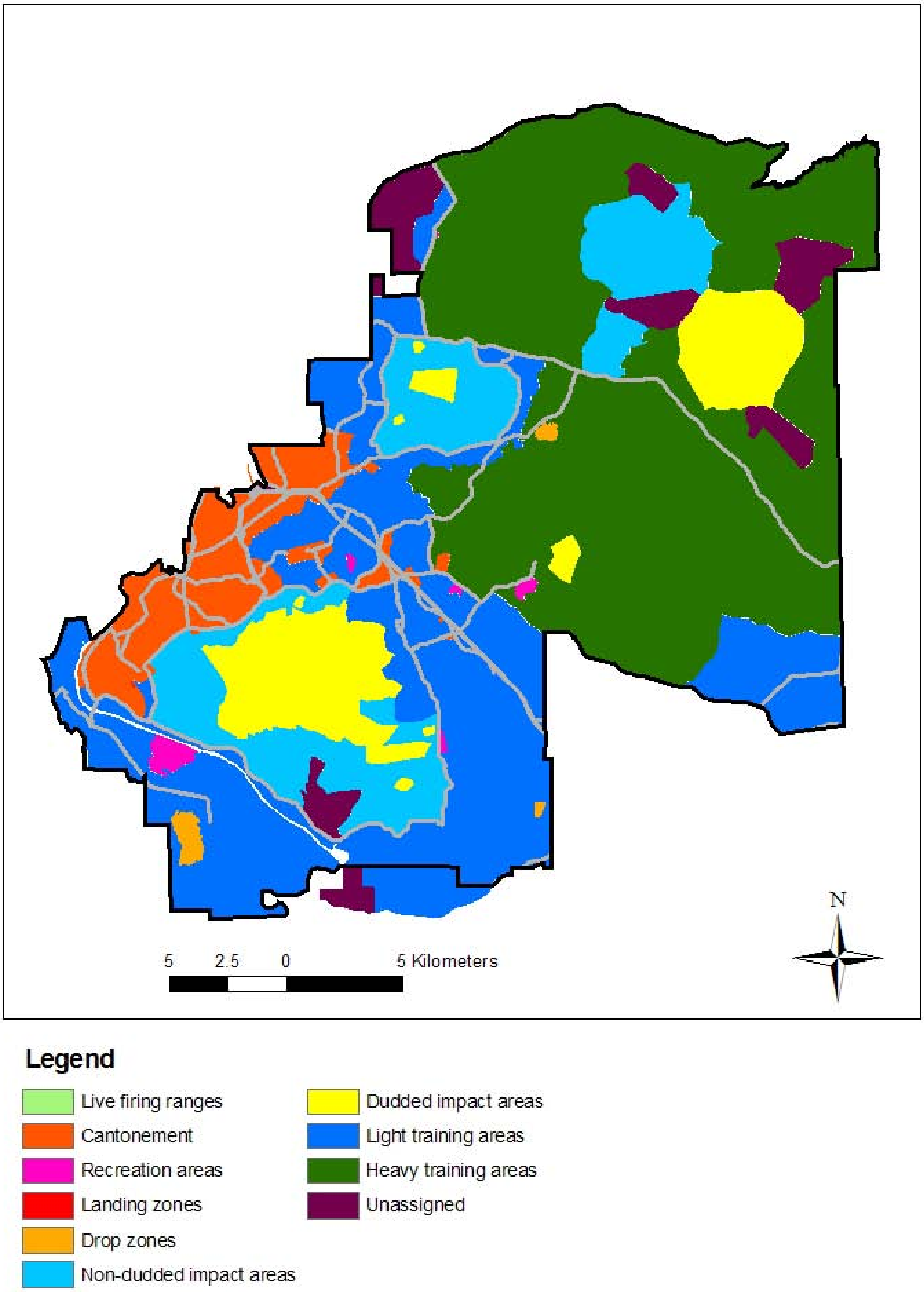
Young, A. S., S.-M. Chang and R. R. Sharitz. 2007. Reproductive ecology of a federally endangered legume, *Baptisia arachnifera*, and its more widespread congener, *B. lanceolata* (Fabaceae). American Journal of Botany 94:228-236.

8. Appendix A

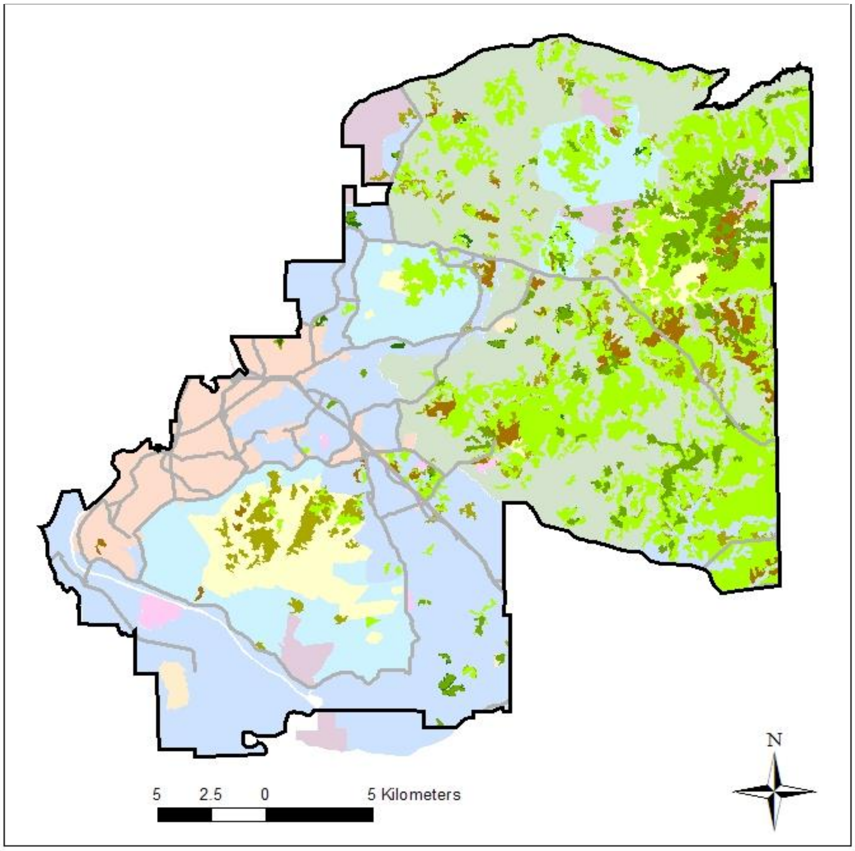
Appendix A.8.1. Maps of sandhills and related xeric woodland communities on Fort Benning, Fort Gordon and the Savannah River Site, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery, compared with military training and land management activities.



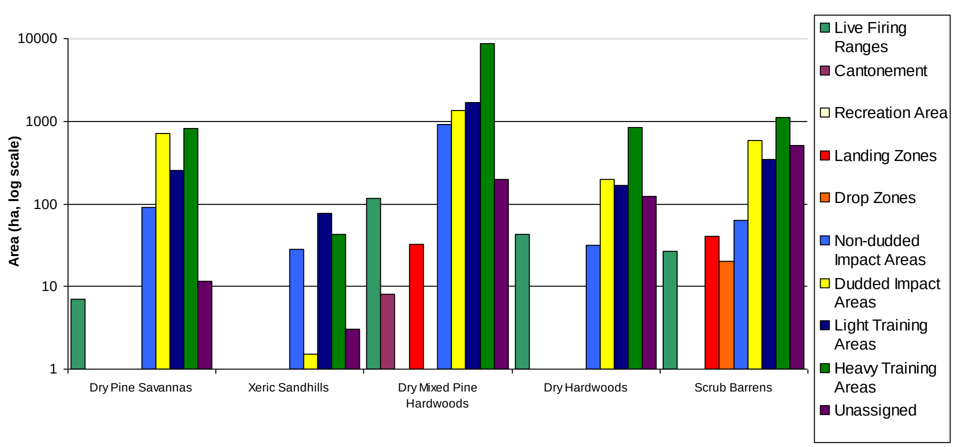
Sandhills and related xeric woodland communities on Fort Benning as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on). Methods are described in Harper and Sharitz 2005.



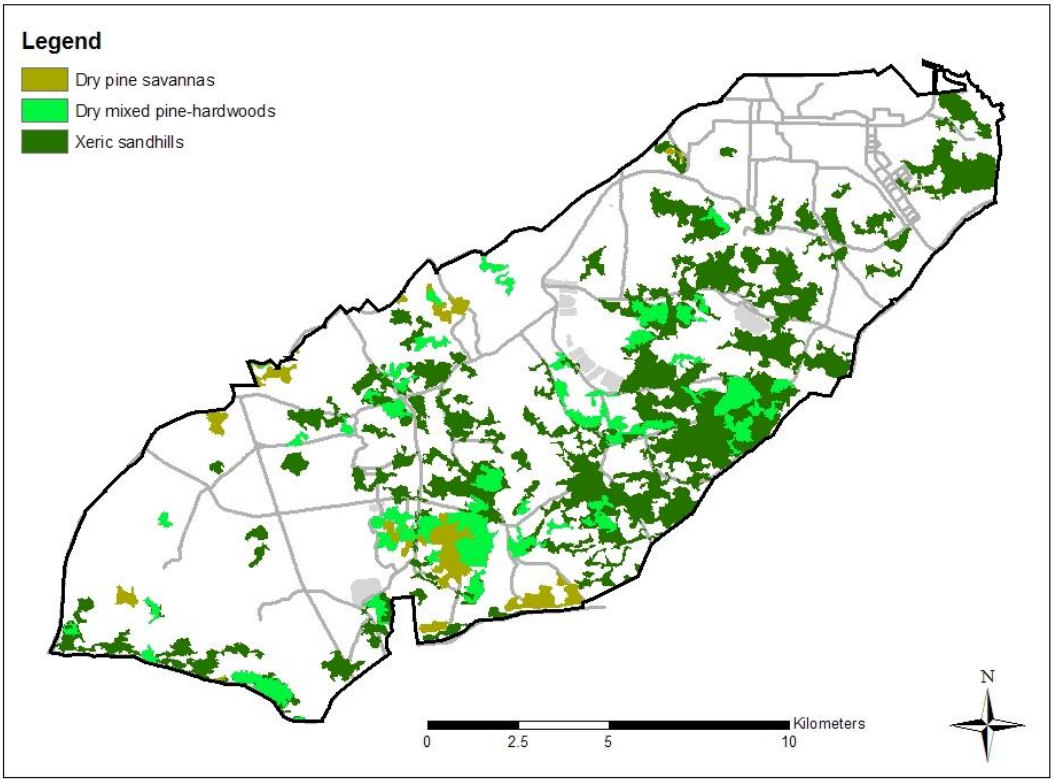
Military training and land management on Fort Benning based upon data provided in April 2006.



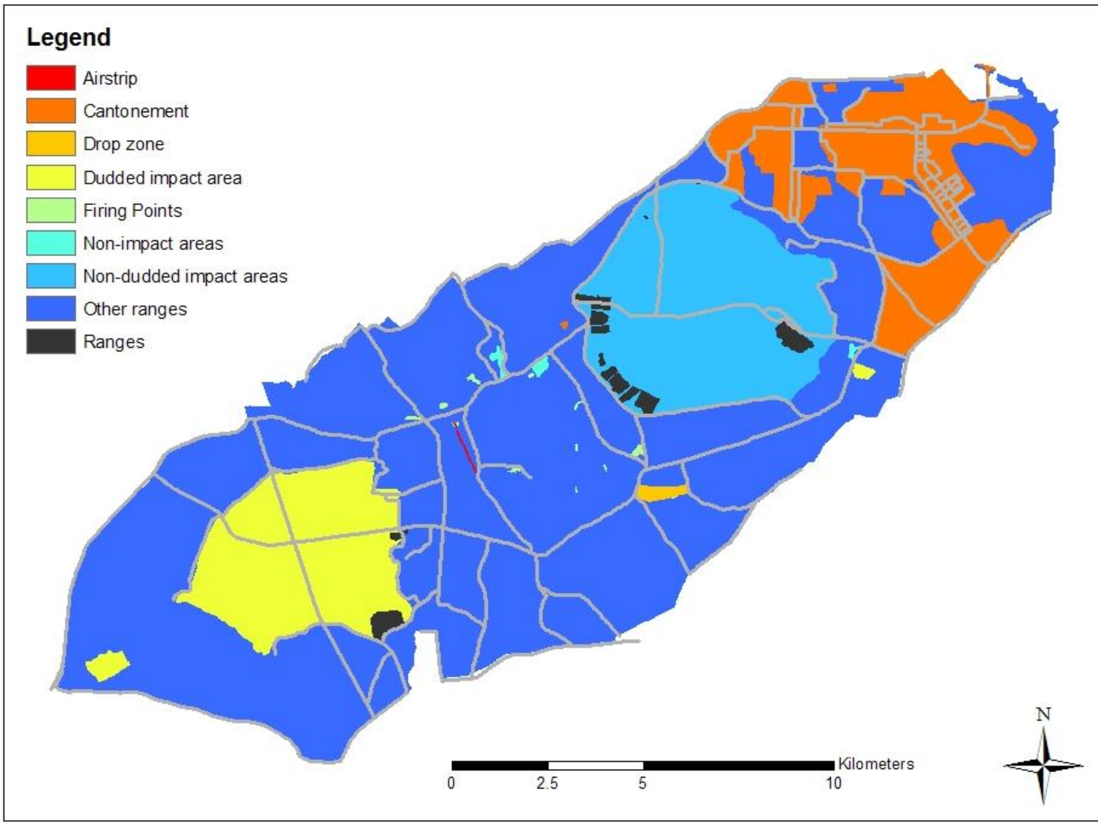
Map of sandhills and related xeric woodlands overlain across previous map of military training and land management areas on Fort Benning (colors faded for visibility).



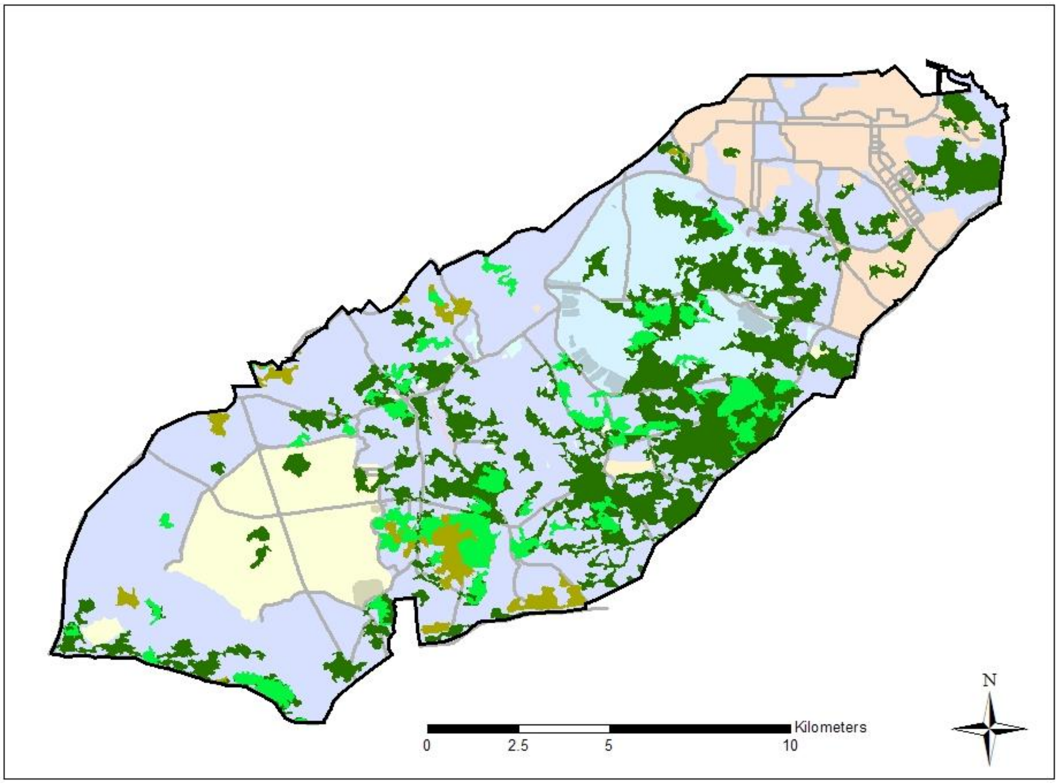
Distribution of sandhills and related xeric forests across military training and land management areas on Fort Benning.



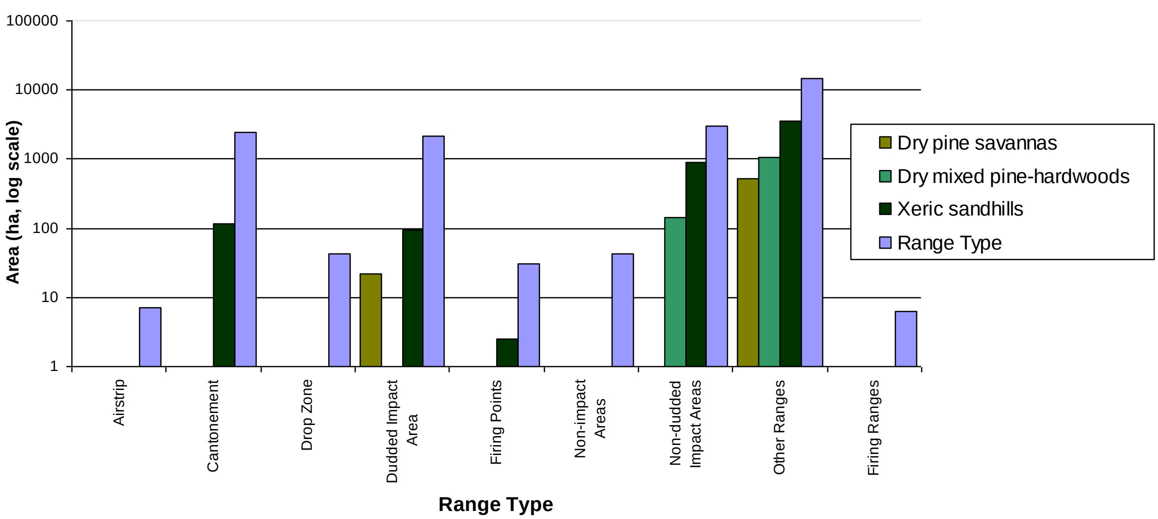
Sandhills and related xeric woodland communities on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on). Methods are described in Harper and Sharitz 2005.



Military training and land management areas on Fort Gordon.



Map of sandhills and related xeric woodlands overlain across previous map of military training and land management areas on Fort Gordon (colors faded for visibility).



Distribution of sandhills and related xeric forests across military training and land management areas on Fort Gordon.

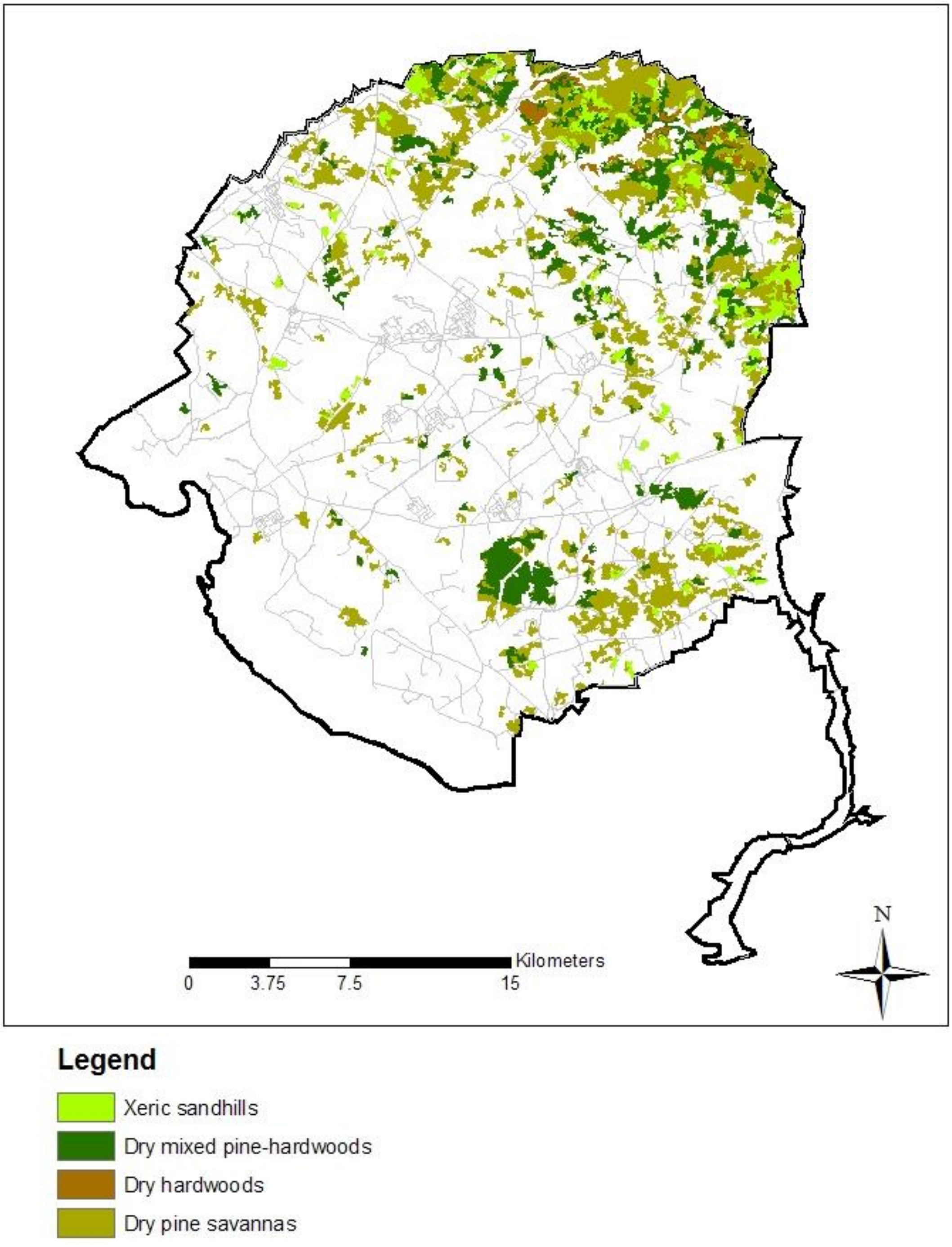
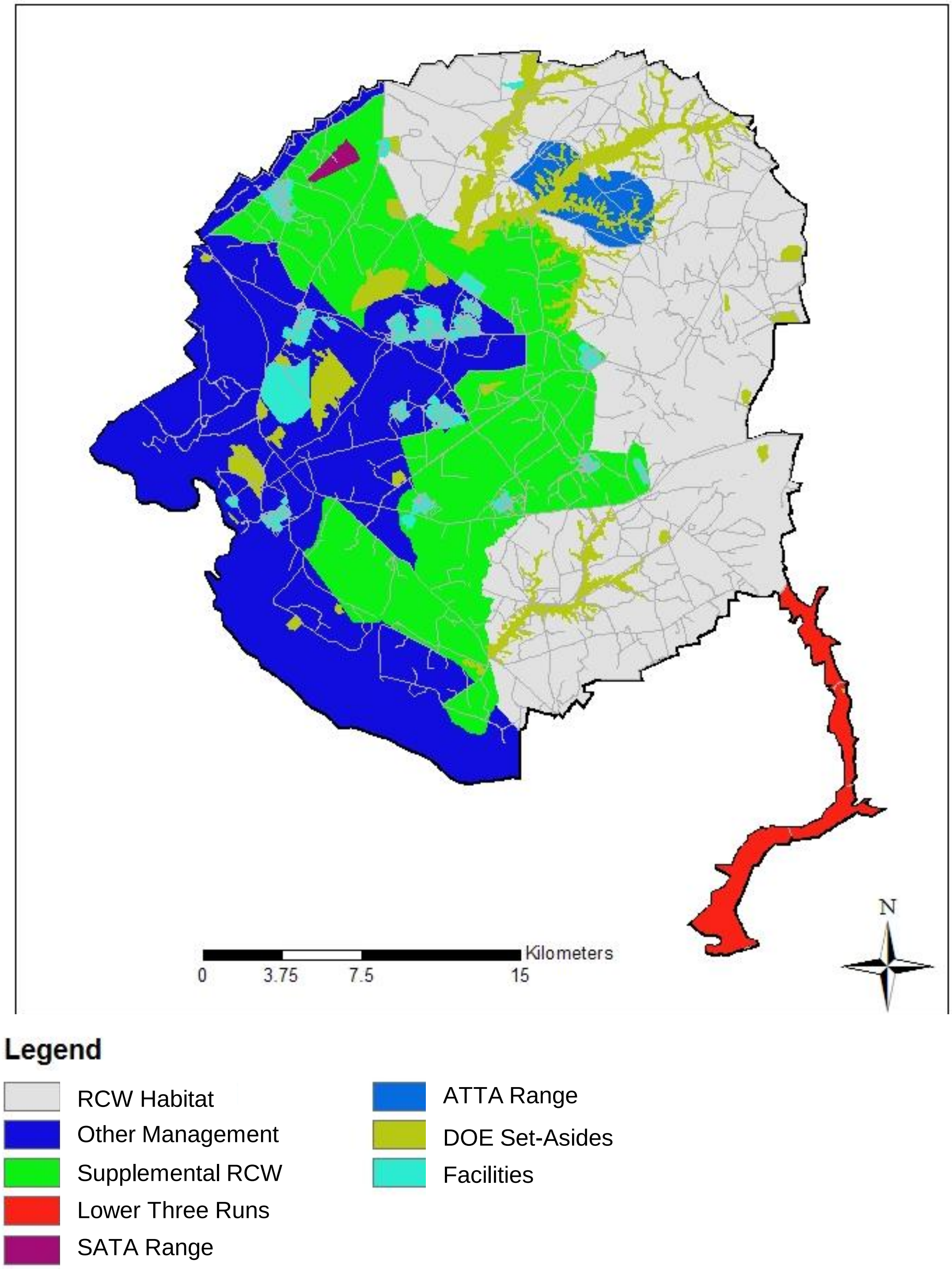
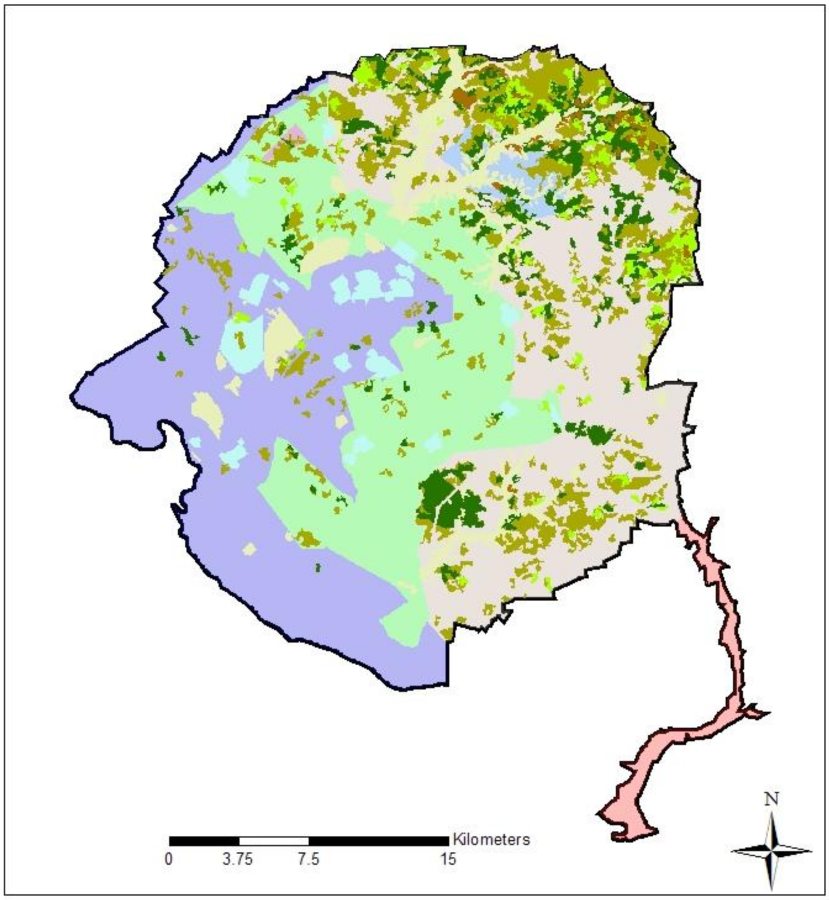


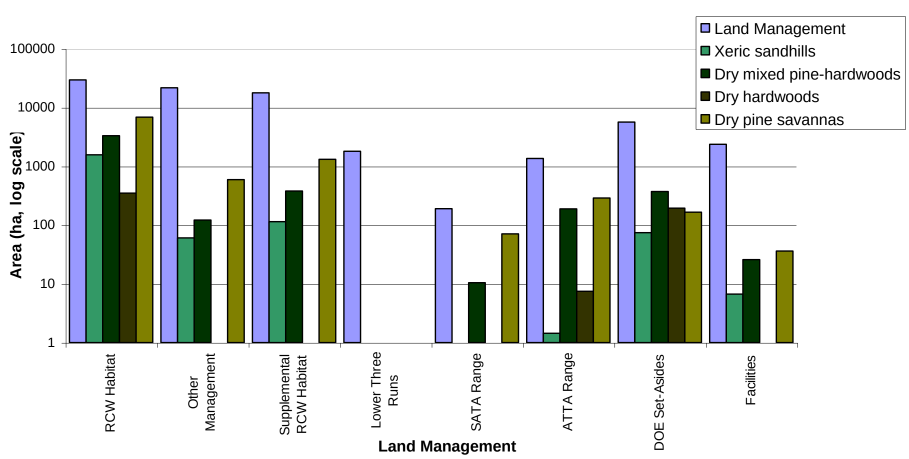
Figure A.1.9. Sandhills and related xeric woodland communities on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on). Methods are described in Harper and Sharitz 2005.



Land management areas on the Savannah River Site (SATA = small arms training area, ATTA = advanced tactical training area; DOE Set-Asides protect specific habitat types).



Map of sandhills and related xeric woodlands overlain across previous map of land management areas on the Savannah River Site (colors faded for visibility).



Distribution of sandhills and related xeric forests across land management areas on the Savannah River Site.

Appendix A.8.2: TES Species' Habitat Relationships (by Co-PI Donald W. Imm)

A goal of this research has been to conduct extensive sampling of selected sandhills TES plant populations, to characterize the conditions under which they occur, and to develop models predicting suitable habitats where additional populations might occur or where plants might be relocated in the event of habitat use conflicts. Sixty-three populations of nine plant species listed as Species of Conservation Concern for Georgia and South Carolina were sampled in the summers of 2003 and 2004, and their habitat conditions were characterized. Probability-based habitat suitability models were developed and refined as described here.

Sampled TES plant species had differential environmental relationships that were associated with inherent site conditions such as soil moisture, nutrient storage, and topography (Figure 8.2.1). However, these species were also associated with biotic conditions which can be influenced by land management. Because of rarity, perfect alignment with site characteristics was not necessarily obvious at fine- and broad-scale dimensions. For most of these species, rarity is less likely to be due to the absence of suitable conditions and more likely to be due to either local extirpation or insufficient availability of seed dispersed from limited sources into locally suitable sites. Therefore, characterization of the frequency of suitable sites on the landscape is important for restoration and conservation as well as the implementation of successful survey and monitoring programs.

Of the sandhills TES plants, *Chrysoma pauciflosculosa* and *Stylisma pickeringii* were associated with the harshest conditions characterized by deep, dry soil profiles with very high sand content, low nutrient content, and low organic matter. These sites also had low tree density and basal areas that were dominated by xeric oaks (*Quercus laevis, Q. margaretta, Q. incana*), and low shrub and herbaceous cover. Slightly less xeric sites harbored *Liatris secunda* and *Astragalus michauxii*; these sites had greater tree basal areas and canopy dominants that included longleaf pine (*Pinus palustris*) mixed with xeric oaks and hickories (*Carya* spp.). Still other TES species, such as *Carphephorus bellidifolius, Nolina georgiana*, and *Baptisia lanceolata*, had broad distributions that ranged from xeric longleaf pine-scrub oak on coarse-textured soils into dry and finer-textured areas that had greater abundances of longleaf pine and other tree mixtures. Finally, *Phaseolus polystachios* and *Warea cuneifolia* occurred under unique site conditions such as transitional slopes with patchy mixed species compositions, and sandy open surface soils underlain by loamy sub-soils.

Resource Patterning

Comparisons of spatial patterning associated with individual rare plants and unoccupied locales indicate that no significant difference exists in spatial autocorrelations of soil and light resources. As expected, canopy openness above the sampled TES plots is strongly dependent on tree density, basal area, and shrub coverage. Within 5 m of a TES plant, however, the relationship of canopy openness becomes highly variable as the

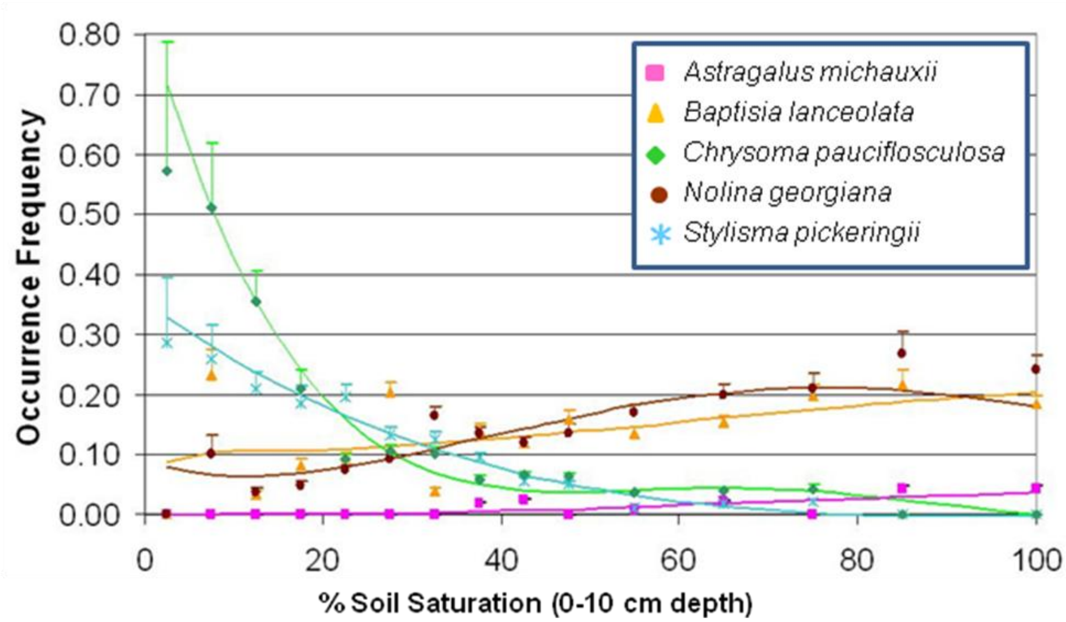


Figure 8.2.1. Actual and predicted occurrence of five sandhills TES plant species across a predicted soil saturation gradient.

influence of canopy content declines. For example, Pearson product moment correlations developed using multiple linear regressions to compare canopy openness (based on hemispherical photographs) to distance-based measures of tree biomass and composition as well as to shrub/vine/sprout plot coverage yielded an R^2 value of 0.58. When these same comparisons were made using information from adjacent TES plots, the R^2 value dropped to 0.23. When semi-variogram comparisons were used, spatially based correlations declined at a distance of 4.7 m. This pattern suggests that the patchy environment of sandhills systems cannot easily be quantified using data from large plots because of strong spatial patterning at fine scales. The influence of these patches is also likely to affect belowground resource patterns and fire behavior because of fine-scale differences of canopy litter as well as differential patterning of belowground resource competition.

Unexpectedly, soil features also changed rapidly over short distances. Typically, sandhills soils are thought to be deep sands that have little variance in depth of sandy textures as well as textural composition; however, conditions that impact estimated soil profile cation exchange capacity (CEC) and moisture holding capacity change rapidly. Similar to canopy openness relationships with tree composition, moderate correlative relationships (R^2 = 0.38) change to weak relationships at distances beyond 5.8 m (R^2 = 0.13). Similar patterns were exhibited when soil moisture content was used for comparisons. Though strongly spatially autocorrelated, a wide range of resource combinations and conditions that are capable of supporting a suite of sandhills species are likely to exist, and biodiversity patterning is likely to be limited by spatially patterned dispersion, tolerance of site conditions, and biotic interactions in more suitable settings.

Observations also suggest that large-scale management actions (e.g., broad-scale herbicide use) or land use (e.g., tracked vehicle training) may lessen local spatial patterning with unknown consequences on long-term site capacity to support species richness.

For both aboveground and belowground conditions, ultra-xeric sites exhibited the highest levels of spatial patterning, and differences among the installations were also apparent. Fort Gordon had the lowest levels of fine-scale variation and Fort Benning had the highest levels of variation. The rate of change of soil features is greatest at Fort Benning and least at the SRS. This observation may reflect historic land use. The greatest rate of change of soil features is associated with plots having little or no tree coverage; again, this may reflect training activities because military use would be expected to be greatest away from forest vegetation.

Plot-level soil variation was great enough that 26% of the collected soil samples did not meet appropriate NRCS-defined soil classification criteria for the soil association that they represented. For example, 43% of the soils collected from Lakeland sand (Thermic, Typic, QuartziPsamment) at Fort Benning did not match the texture profile criteria associated with Lakeland soils. These soils were most commonly misclassified because of finer textures near the surface or shallow soil profiles. Spatially, misclassification tended to occur more frequently near vegetation transitions (e.g., sandhills to slope vegetation); thus, vegetation pattern is a much better indicator of site character than maps depicting soil associations. Though equally variable in within-site soil characteristics, Blanton and Troup soils were less frequently misclassified relative to Lakeland soils. However, three sites at Fort Benning had misclassification frequencies greater than 50%. This suggests that classification of sandhills soils at Fort Benning is less reliable than at Fort Gordon and the SRS, and this can likely be attributed to training.

Model Development

Because the analysis is based on density of species within $1m^2$ plots and presence-absence data within an area having a variable plot radius (max = 7.5m); two analyses were used: criteria associated with the $1m^2$ plots and criteria associated with the variable plots at known distances. Using the various spatially auto-correlated relationships, predictive relationships and projected conditions were generated to mimic overall site conditions. Projected conditions were then compared by applying boot-strapping techniques to local plot information, and then associated with TES species occurrence patterns. These relationships were not developed for smaller sampled TES population sites because of limited local site information as well as an increased likelihood of gradient-dependent transitions.

Data were log-transformed prior to developing forward-selected logistic regressions. Models were developed for each species using three approaches: 1) all plots at all sample sites, independent of location (except where geographically excluded); 2) all plots at all sample sites with installation separation, which was the most conservative approach; and 3) all plots, but only in areas with local species representation. In all cases, installation-specific models were developed and compared, and then combined in the absence of significant difference. With the exception of *Baptisia*, limited differences existed between model results, so the first approach was used for all further analyses. The multivariate solution for *Baptisia* at Fort Benning was significantly different from that representing Fort Gordon and the SRS. In general terms, *Baptisia* was better associated with more open, drier site characteristics at Fort Benning.

Using the identified approach, three independent models were initially developed to address aboveground conditions, belowground conditions, and competition. Distinguishing between suitable soil and vegetation settings is important to land managers because vegetation settings can be manipulated through management actions. A fourth model considering all factors was also developed and allows for consideration of interacting factors associated with vegetation and soil settings.

Most measured variables contributed to at least one model solution. When data were pooled, nutrient information was also valuable in model development. To accommodate correlative relationships between environmental parameters and create independence between model components, structured equations were used. For example, canopy openness was measured using tree distance, tree volume, and species identification as well as shrub, sprout, and vine coverage. Tree volume estimates were generated from diameter-based allometric equations developed by Clark (1992, 1994). Once these equations were developed and compared to other similar estimates (average tree size, basal area, density, % composition), residual error estimates for measured variables (e.g., density, basal area) were used as independent variables during canopy openness model development.

Similarly, soil moisture holding capacity and CEC were estimated using equations developed by Saxton et al. 1986. These exponential equations consider soil texture, soil organic matter, and bulk density. Bulk density estimates were taken from other local studies; measurements of soil texture and organic matter, from various depths, were based on collected samples. These estimates were then used to calculate potential water and nutrient holding capacity and, with direct field measurements of soil moisture and soil chemistry, used to evaluate TES species' responsiveness to existing conditions (e.g., soil water volume estimates from measured percent soil moisture) and potential conditions (e.g., potential soil water volume at various water potential estimates such as 3500 KPa). Similar comparisons could be made between CEC estimates and actual nutrient and cation measurements. The estimates of soil holding capacities are reflective of site potential, while actual measurements reflect current conditions. Again, forecast models should consider both inherent conditions and those that can be modified.

Aboveground and Floristic Conditions. Aboveground conditions focused on factors that impact light availability. Hemispherical photographs were used to estimate canopy openness above each plot and plant occurrence. Canopy openness was strongly associated with distance, tree size, and species type. Percent shrub, sprout, and vine cover within each plot also significantly contributed to the solution. As expected, each

TES species had different relationships with canopy openness and significantly different solutions, and these relationships are consistently reflected by regression coefficients in all models.

Independent of distance, the influence of trees on TES species' patterns and canopy openness was best reflected by diameter-based, species-specific, live-weight biomass estimates developed from various allometric equations. These were used in model development rather than basal area because of improved model performance. Model performance was also greatly improved using an inversely-weighted distance function, where nearby trees contributed more to the solution than those more distant.

Other factors that significantly contributed to the model relationship include percent bare ground, and percent herbaceous cover. Two approaches were used to evaluate composition; life form and floristic groupings (e.g., % grass) and scores from non-metric multidimensional scaling (NMDS) ordination. The strongest solution relationship differed by TES species; for example, ultra-xeric species had stronger relationships with NMDS ordination scores that reflect compositional uniqueness, while longleaf pine-transition species were better associated with floristic groupings, which likely reflect competitive settings. Because NMDS ordination scores more strongly reflect cumulative effects of environmental factors (e.g., light, soil) on compositional patterning, life form and floristic groupings were used to develop final model settings.

Overall, aboveground conditions poorly reflected TES species occurrence and density. When soil and topographic features were added, all measures of solution quality greatly improved; therefore, models based on only aboveground features were discounted. Overall, this suggests that land management actions to improve habitat conditions are likely to be most effective when appropriate soil and topographic settings are in place.

Soil and Topographic Features. Belowground conditions were focused on water content, water holding capacity, and nutrient holding capacity. Interestingly, each species was associated with soil features at different depths (0-10, 11-20, 21-40, >40 cm). This suggests that individual species may have unique adaptations (e.g., rooting depth) to adjust to competition and harsh resource settings. The influence of clay and silt content on model solutions was improved when these measurements were combined and referred to as "fines"; individual measures were used to develop estimates of soil moisture holding capacity and CEC.

Measurements of soil moisture were converted to soil moisture volume to allow for comparisons with estimates of soil moisture holding capacity. These comparisons included estimates of differences at varying depths as well as collective content. Both soil moisture volume and soil moisture holding capacity estimates were associated with different TES species occurrence patterns. For most TES species, moisture and nutrient-regulating features (e.g., CEC, soil pH, base saturation) had similar regressional relationships. Similar to soil texture measurements at different depths, moisture and chemical relationships were consistent with all models evaluated.

Preliminary analysis revealed that nutrient measurements contributed significantly to explaining the distributions of species. These measurements were from locally pooled samples, so for analysis other parameters including TES occurrence frequency and densities were also pooled. These analyses resulted in significantly improved solutions, though they represented a smaller grouping of pooled sample locations. Overall, phosphorus and a variety of cations were associated with TES species occurrence and density (Table 8.1). Few studies have found direct compositional relationships to total or available cation concentrations. More frequently, cation concentrations loosely reflect other indirect influences associated with other soil quality parameters (e.g., CEC, base saturation, disturbance history) and compositional patterning (Monk 1966, Monk et al. 1990). In this study, cations were also well correlated with our textural estimates of CEC, base saturation, and soil pH.

Overall Model

The combination of aboveground and belowground features improved all model estimates. A variety of features contributed to species-dependent regressional model solutions. Most species were influenced by estimates of canopy openness, herb cover, vine cover, 0-10 cm sand content, overall water holding capacity, CEC (0-10 cm), and calcium content (11-20 cm). Interestingly, only loose species-specific trends associated with these variables could be developed. For example, *Chrysoma* and *Stylisma* have similar relationships with the environment (xeric, sandy, nutrient-poor conditions with open canopies and low cover), but *Stylisma* is significantly associated with herb cover and slope, while *Chrysoma* is negatively associated with herb cover. The remaining species tend to be associated with herbaceous cover, increased surface soil water volume and overall water holding capacity, as well as increased sub-soil cation content. Again, each species has unique environmental relationships, including occasionally co-occurring species such as *Nolina*, *Baptisia*, and *Carphephorus*. Less frequently occurring species such as *Liatris, Astragalus, Warea,* and *Phaseolus* have environmental relationships consistent with the other TES species, but unique soil profile characteristics (e.g., very sandy surfaces above finer textured soils) and sub-soil nutrient concentrations.

As a caveat, it should be noted that the habitat forecast models neglected to consider factors such as seed dispersal, patterns of plant establishment, or the role of fire. Certainly, seed dispersal is spatially autocorrelated at some scale for all of these species, particularly for infrequently occurring species that would have limited dispersal capacity at the landscape scale. It should be noted, however, that most of the study sites are fairly stable and intact, and based upon available information (Dale 2006, Frost SRFS internal report), do not have agricultural land-use histories. Thus, dispersal and occurrence histories may not be strongly spatially autocorrelated, and some expectation of potential occurrence could be assumed throughout the sandhill study sites. Patterns of offspring survivorship are also likely to be spatially autocorrelated due to dispersal likelihoods as well as fine-scale, spatially-autocorrelated vegetation patterns, processes, and resource settings. Furthermore, since there are limited occurrences of juveniles of the TES species in the study areas, site characteristics associated with germinant survival cannot be ascertained and may differ from those site characteristics associated with persistent adults. Finally, all study sites have been subject to burning for at least the past 20 years;

Table 8.2.1. Multiple regression coefficients for TES species for all installations, using all parameters

Species	***Liatris secunda***	***Carphephorus bellidifolius***	***Astragalus michauxii***	***Warea cuneifolia***	***Nolina georgiana***	***Stylisma pickeringii***	***Baptisia lanceolata***	***Chrysoma pauciflosculosa***	***Phaseolus polystachios***
R-value	0.213	0.381	0.402	0.431	0.472	0.497	0.526	0.573	0.608
SE of Estimate	0.148	0.274	0.0678	0.102	0.271	0.183	0.32	0.177	0.141
F-value	6.90	12.21	28.00	27.37	18.72	15.66	19.56	19.30	29.92
Probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Coefficients									
Intercept	-0.642	1.023	-0.0476	0.011	0.293	-0.0528	-1.863	-0.00675	-1.675
Contour Slope	-	-	-	0.00093	-0.00057	0.00403	-	-	0.0034
Canopy Cover									
Ave.tree.size.(cm)	-	-0.00415	0.006347	-	-	-	-0.00886	-	-
Density/ha	-	-	-	-	-	-0.000018	-	-0.000024	-
%canopy openness	-0.112	-0.159	-	-	-0.307	0.1186	-	0.192	-
Ground Cover									
Bareground cover	-	-0.00117	-	-	-	0.00191	-	0.00093	-
Herb cover (%)	0.00045	-	-	-	0.00247	0.000877	0.0032	-0.000453	-
Shrub cover (%)	-	-	-	-	-	-	-	-0.00114	-
Sprout cover(%)	-	-0.00235		-0.00079	-	-	-	-	-
Vine cover(%)	-	-0.00149	0.000664	-	-	0.00124	-	-	-0.00087
Soil Texture									
0-10 % organic	-	-	-	-	-	-0.00038	-	-0.00062	0.00921
0-10 cm % sand	-	-0.00018	-	0.00079	-	0.000452	-	0.001691	-0.00037
10-20 cm % sand	-	-	0.000729	-	-	-	-	-	-
10-20 cm % fines	-	-	-	-	-	-	0.00408	-	-
>40 cm % fines	-	-	-	0.00045	-	-	-	-	-
Moisture									
0-10 water volume	-	-	-	-	0.132	-0.155	-	-	-0.0843
10-20 water volume	-	0.0846	-	-	-	-	-	-	-
20-40 water volume	-	-	-	-	-0.0293	-	-	-	-
0-100 water volume	-	-	-	-	-	-	-	-0.00019	-
0-10 water hold cap	-	-	-	-0.183	-	-	-	-	-
Overall wtr hold cap	0.00019	0.00038	-	-	-	-0.00022	0.000389	-	-
Nutrients 0-10 cm									
CEC	0.00676	-	-	-	-0.00045	-0.00096	-	-0.00057	0.00189
pH	0.146	-0.154	-	-	-	-	0.177	-	0.278
Buffering capacity	-	-	-0.0922	-	-	-	-	-	-
P (mg/kg)	-	-0.103	-	-	-	-	-	-	-
K (mg/kg)	-	-	-	-	-	-0.128	-0.259	-	0.314
Ca (mg/kg)	-	-	-	-	-	-	-	-	-0.606
Mg (mg/kg)	-0.182	-0.185	-	-0.0994	-	-	-	-	0.748
Mn (mg/kg)	-	-	-	-	-0.0919	-	0.206	-	0.115
Nutrients 11-20 cm									
pH	-	-	-	-	-	0.0463	-	-	-
Buffering capacity	-	-0.000335	-	-	0.00066	-	-	0.00023	-
P (mg/kg)	-	-	-0.00504	-	-	-	-	0.0341	-
K (mg/kg)	-	-	-	-	-0.029	-0.0152	0.0263	-	-
Ca (mg/kg)	-	-	-	0.0134	-0.0272	-0.0037	-	-0.00334	0.00353
Mg (mg/kg)	-	-	-	-	-	0.00753	0.0225	-0.018	-0.0157
Mn (mg/kg)	-	-	-	-	-	0.0461	0.0819	-0.0257	-
Living Biomass									
Pinus palustris	-	-	-	-	-	-	0.000043	-	0.0000367
Pinus echinata	-	-	-	-	-	-	-	-0.00076	-
Pinus taeda	-	-	-	-	-	-0.00043	-	-	0.000298
Quercus laevis	-	-	-	-	-	0.000349	-	0.000279	-
Q. incana	-	-	-	-	-	-	-0.00048	-	-
Q. margaretta	0.00391	0.00192	-	-	-	-	-	-	-
Q. marilandica	-	-	-	-	-	-	0.00116	-	-
Q. hemisphaerica	-	-	-	-	-	-	-	0.000138	-
Carya sp.	-	-	-	0.000087	-	-	-	-	-0.000066
Sassafras albidum	-	-	-	0.00238	-	-	-	0.00423	-
Other hardwood	-	-	-	0.0412	-	0.00552	-	-0.00446	-0.000798
Dead Biomass									

Pinus palustris	0.000116	-	-	-	-	-	-	-	-
Pinus taeda	-	-	-	-	0.00323	-	-	-	-
Quercus laevis	-	-	-	-	-	-	-	-	-
Q. margaretta	-	-	-	-	0.00244	-	-	-	-
Quercus sp.	-	-	0.00275	-	-	-	0.00561	-	-
Carya sp.	-	-	-	-	0.00685	-	-	-	-

therefore, fire-associated influences are likely to be minimized due to existing conditions that have allowed the sampled species to persist. Lastly, differences in local fire histories across all sites would have made evaluations of the impact of fire difficult to ascertain. Therefore, the predictive model makes the assumption that local establishment and occurrence is not limited by dispersal, differences in individual survival that may or may not be associated with site quality, differential influences of recent fire history, or military training.

Model parameters used for a multiple-regression approach and can be used to forecast are listed in Table 8.2.1. Other models were developed (e.g., SEM and path analysis based solutions) that considered hierarchical arrangements of specific parameters within a general overall grouping (e.g., soil moisture, soil nutrients, canopy, shrub/midstory, ground cover, etc.). These groupings were used to assess direct and indirect relationships with TES plant density and presence-absence data. However, these more complex models did not yield significant improvement in model performance; therefore, the multiple regression approach was selected. Estimated habitat conditions between sample points were obtained by splining (inverse distance weighting). These methods were evaluated by comparing measurement differences between grid-plot locations and near-neighbor TES plots (varied distance from grid-plot). Estimates of suitability for TES species were then made using estimated environmental conditions; these results were then spatially compared within individual sampling sites. Additional methodology or results information will be provided in forthcoming publications or can be obtained by contacting Donald W. Imm (donimm@uga.edu).

Model Performance

Estimates of within-site species relationships with individual parameters produced consistent estimates of TES plant occurrence. Using sensitivity coefficients, thresholds within these areas can identify areas of non-linear change in abundance. The combination of these threshold estimates, relative to estimated spatially-explicit, autocorrelated patterns, can then be used to identify areas of greatest potential occurrence on the landscape (Figure 8.2.2). Some of the areas within Figure 8.2.2 indicate that particular parameter thresholds are indicative of species' occurrence patterns. After consideration of independency, cumulative threshold estimates can then be combined for those variables that contribute to regressional model solutions. The resulting patterns can then be used to estimate areas with the greatest likelihood of occurrence or potential re-establishment of individual species. Model improvement is gained by using forward selection regressional forecasting that depicts environmental combinations that represent sufficient suitability.

Overall model performance is contingent upon model and data representation as well as the predictability of spatially-explicit patterning. Some TES species were also found to be less capable of being modeled accurately. For example, light-seeded species such as *Liatris, Carphephorus*, and *Warea* were less accurately predicted than ultra-xeric site species (*Chrysoma, Stylisma*) and legumes (*Astragalus, Baptisia, Phaseolus*). Further, within an installation, the occurrence of some species was poorly predicted relative to others. Generally, predictions tended to over-estimate occurrence and suitability at fine-scales (plots) as well as at site-scales. This suggests that suitable conditions exist within many occupied sites as well as at other sites that are unoccupied. Previously unsampled areas have since been sampled to evaluate site conditions using a sub-set of conditions. These comparisons yielded similar results, with one exception being a broadened definition of suitability for *Phaseolus*. In this case, soil characteristics remained similar, but a broader definition of suitability for canopy composition and openness was identified.

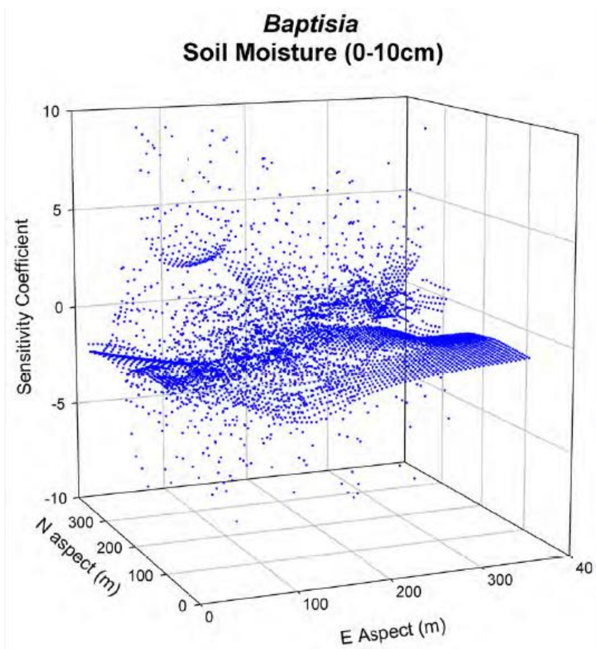


Figure 8.2.2. *Baptisia lanceolata* sensitivity coefficient estimates for a sampled site at Fort Benning (K-11).

The accuracy of prediction within a site and between sites (p=0.10) is illustrated in Table 8.2.2 at the end of this section. Again, site and plot suitability predictions tend to more frequently over-estimate occurrence and the potential suitability of site characteristics for some species. To make these comparisons, Fisher's exact test was used to evaluate errors of commission (absent, but predicted to be present) and omission (present, but predicted to be absent) relative to accurate predictions of occurrence and absence. Overall, errors of commission were much higher than omission for all species. Depicted in Table 8.2.2 are combinations of actual observed occurrence (+) and absence with predicted site occurrence. Predicted presence (+) and absence (none) is based on the expected occurrence within at least one plot within the study site. Fort Benning had the highest errors of omission and lowest errors of commission. The SRS sites had the lowest error of omission for all species. These findings may reflect installation differences in fire frequency and ground disturbance.

Patterns of prediction were species-specific. Site suitability was most accurate in predicting occurrence of *Chrysoma, Stylisma,* and *Nolina*, and least effective at predicting the occurrence of heavy-seeded species such as *Astragalus* and *Baptisia*. Interestingly, these patterns do not directly reflect regression model performance and accuracy (F-values, R-values, SE of estimation) for all species. In fact, light-seeded species (*Liatris, Carphephorus*) were intermediate in accuracy of prediction.

Predictability within specific plots of the sampled sites also tended to slightly over-estimate occurrence, but less so than site-predictability. This may suggest that local seed dispersal to suitable sites is less limited than dispersal into isolated sites with suitable conditions. For the most part, type I and type II errors of predictability were less than 10%. Overall predictive performance was greatest at Fort Gordon and least at the SRS. The SRS sample areas also had the highest frequency of predicted occurrence without actual occurrence. This may reflect past histories of less frequent burning and within-site disturbance.

Again, plot predictability was species-dependent. *Astragalus* and *Phaseolus* were most accurately predicted. *Carphephorus, Liatris, Nolina*, and *Baptisia* had the highest frequencies of over-prediction (predicted occurrence in a plot without presence in the plot). These patterns were particularly evident within the SRS sample areas. *Stylisma* was also poorly predicted at the plot scale, including the lack of predicted occurrence when there was actual plant presence.

Interestingly, suitable sites for *Stylisma* can be accurately predicted (open, xeric sands); but specific locations within the site can not be accurately predicted. In contrast, suitable sites for *Astragalus* and *Phaseolus* are poorly predicted; but in areas with the species present, plot predictability is very accurate. These differences have important implications for restoration and outplanting. Effective restoration for *Stylisma* may be to identify suitable areas and then broadly plant individuals throughout. For *Astragalus*, restoration may require outplanting individuals in specific microsites (plot) in known population areas. In retrospect, *Stylisma* may have poor microsite (plot) associations because of a sprawling growth habit, and the limited occurrences of heavy-seeded *Astragalus* may complicate accurate site prediction within broadened combinations of factors associated with its more mesic settings.

Overall, the accuracy and pattern of predictability would likely be improved through the inclusion of site information from other study areas. Though the resulting models over-predict site occurrence, they are well suited for surveys because only a limited number of sites had actual species, occurrence without predicted occurrence. Conservatively, the result is that greater acreage should be surveyed for sandhills TES species, but there is a limited likelihood that a species will occur in an unexpected area. Application of these models toward restoration may result in TES species over-planting; however, using adjusted model confidence, these problems could be avoided.

Table 8.2.2. Overall model performance using plot-level and site-level conditions for each TES sandhills species.

Species	Fort Benning = 404 plots				Fort Benning = 12 sites				Fort Gordon = 528 plots				Fort Gordon = 13 sites				Savannah River Site = 730 plots				Savannah River Site = 7 sites			
	Plot		predicted		site		predicted		plot		predicted		site		predicted		plot		predicted		site		predicted	
Baptisia lanceolata			none	+			none	+			none	+			none	+			none	+			none	+
	Obs	none	74.4	3.6	obs	None	4	5	obs	none	79.3	1.4	obs	none	6	6	obs	none	71.6	9.9	obs	none	2	1
		+	1.9	20.1		+	0	3		+	0.5	18.8		+	0	1		+	0.0	18.5		+	0	4
Carphephorus bellifolius											none	+			none	+			none	+			none	+
									obs	none	87.8	2.2	obs	none	2	3	obs	none	70.5	12.4	obs	none	1	2
										+	0.8	9.2		+	1	7		+	0.0	17.1		+	0	4
Nolina Georgiana											none	+			none	+			none	+			none	+
									obs	none	80.7	2.4	obs	none	4	1	obs	none	77.0	9.4	obs	none	2	2
										+	0.2	16.6		+	0	8		+	0.0	13.6		+	0	3
Stylisma pickeringii			None	+			none	+			none	+			none	+								
	Obs	none	52.6	13.5	obs	None	5	2	obs	none	80.3	3.4	obs	none	7	2								
		+	4.1	29.8		+	0	5		+	1.1	15.2		+	0	4								
Chrysoma pauciflora			none	+			none	+																
	obs	none	72.6	4.4	obs	None	5	3																
		+	1.3	21.7		+	0	4																
Warea cuneifolia			none	+			none	+			none	+			none	+								
	obs	none	96.6	2.4	obs	None	8	2	obs	none	93.6	2.4	obs	none	8	2								
		+	0.5	0.5		+	0	2		+	0.3	3.6		+	0	3								
Liatris secunda											none	+			none	+			none	+			none	+
									obs.	none	91.9	3.7	obs	none	4	3	obs.	none	86.0	12.4	obs	none	2	3
										+	0.1	4.2		+	1	5		+	0.0	1.6		+	0	2
Astragalus michauxii																			none	+			none	+
																	obs.	none	97.9	0.7	obs	none	3	3
																		+	0.1	1.2		+	0	1
Phaseolus polystachos			none	+			none	+											none	+			none	+
	obs.	none	91.5	2.1	obs	None	5	2									obs.	none	96.8	2.4	obs	none	5	1
		+	0.7	5.7		+	0	5										+	0.3	0.5		+	0	1

Literature Cited

Clark, A. III and R. A. Souter. 1994. Stem cubic-foot volume tables for tree species in the south. Research Paper SE-290. USDA Forest Service, Southern Research Station, Asheville, NC.

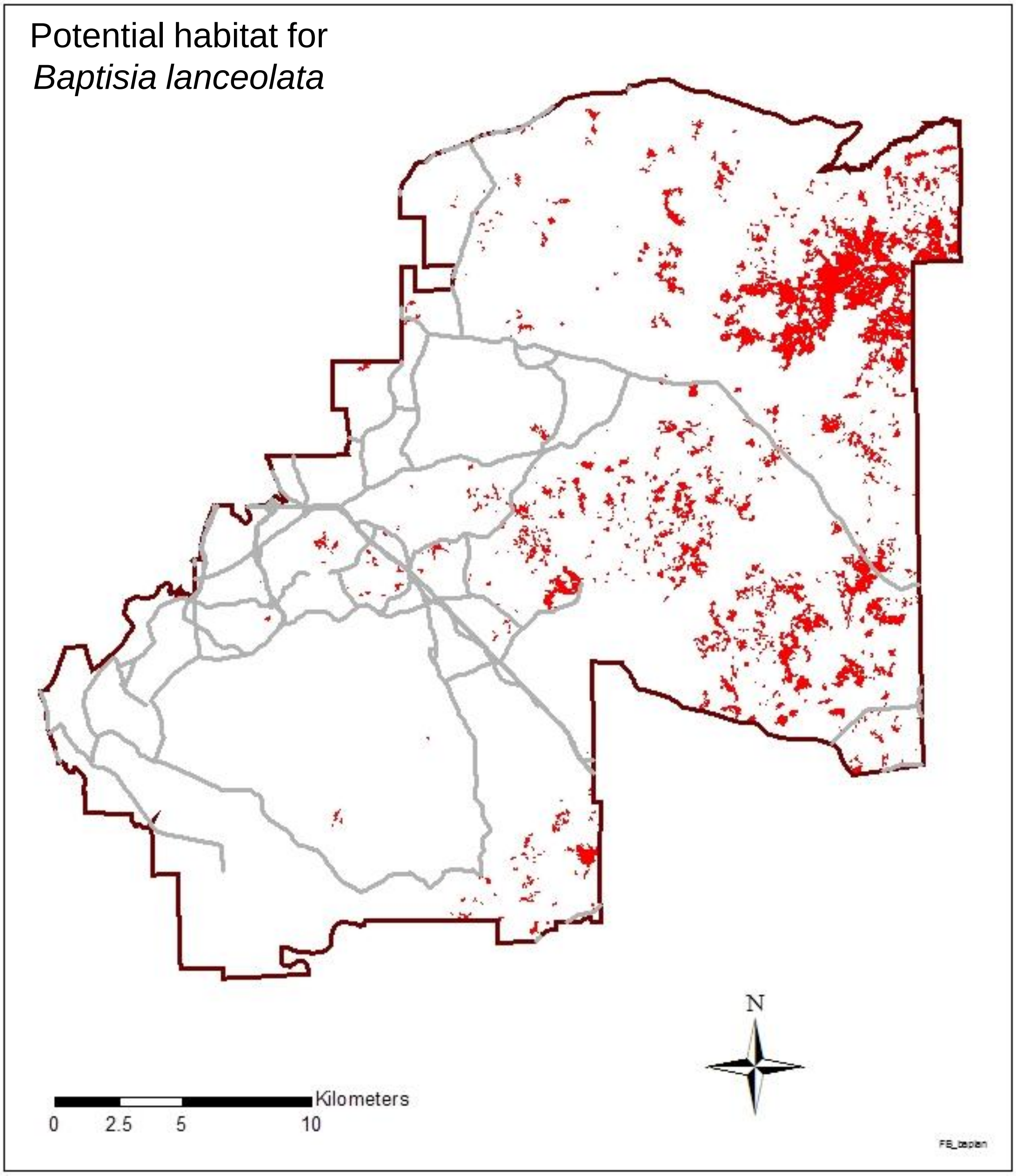
Clark, A. III and R. A. Souter. 1996. Stem cubic-foot volume tables for trees in the upper Coastal Plain. Research Paper SE-296. USDA Forest Service, Southern Research Station, Asheville, NC.

Dale, V. H. 2006. SEMP integration project: final report (CS-1114). SERDP Office Washington, DC.

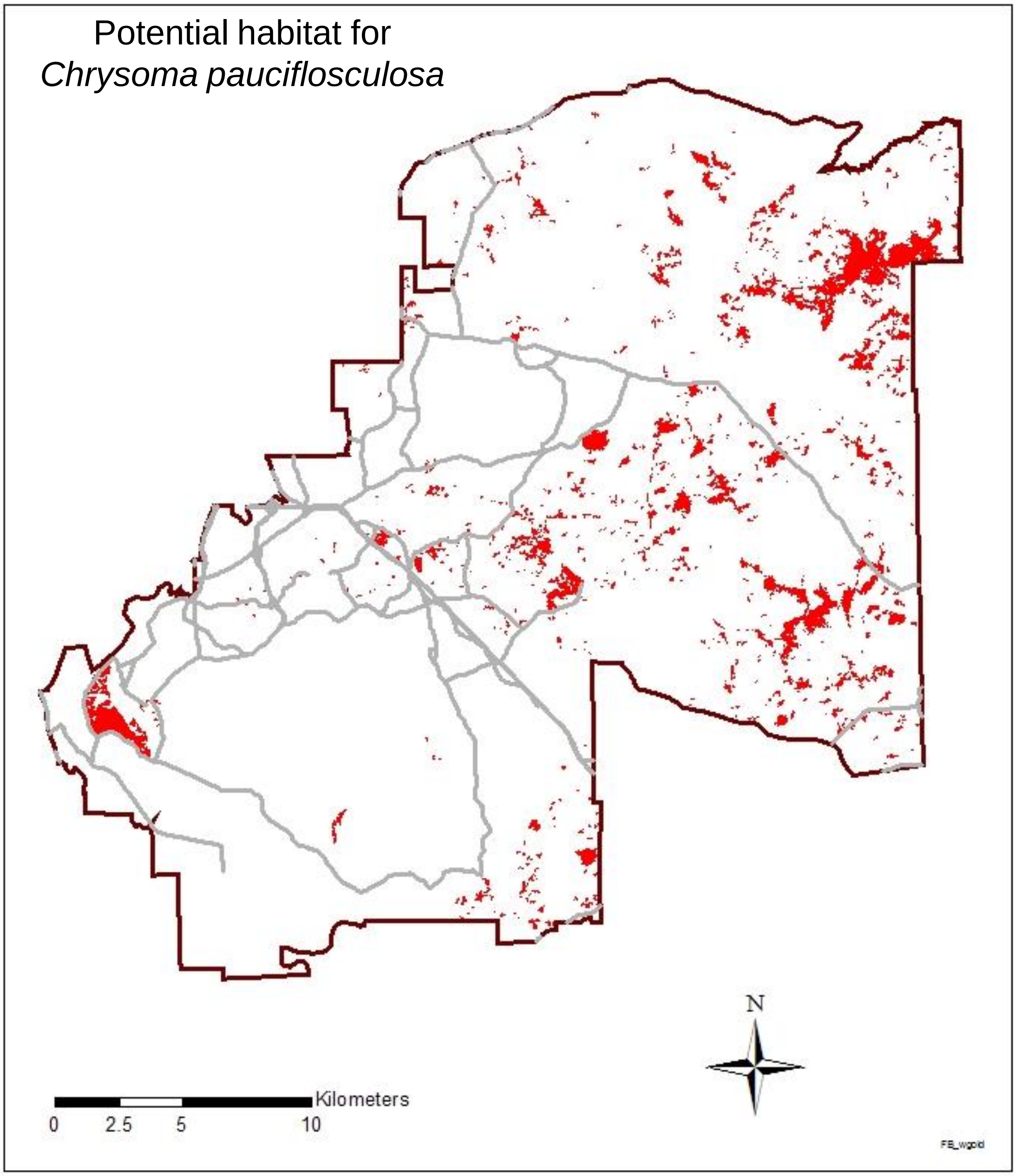
Monk, C. D. 1966. Tree species diversity in six forest types in north-central Florida. Journal of Ecology 54:341-344.

Saxton, K. E., W. J. Rawls, J. S. Romberger and R. I. Papendick. 1986. Estimating generalized soil-water characteristics from texture. Soil Science Society of America Journal 50:1031-1036.

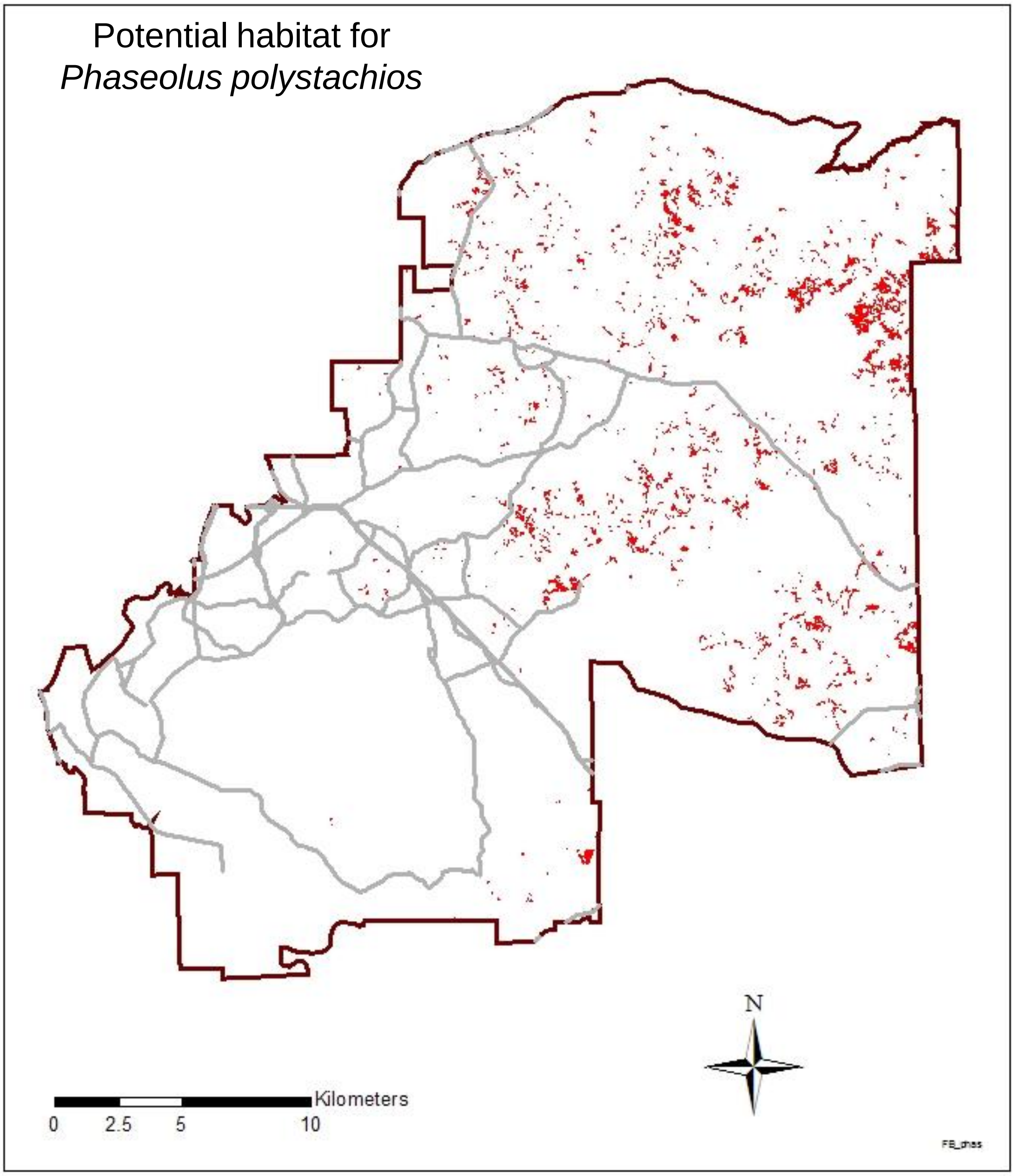
Appendix A.8.3. Maps of potential habitat for individual sandhills plant TES species on Fort Benning, Fort Gordon, and the Savannah River Site, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 - leaf off and April 2003 – leaf on) and soils associated with known TES population locations.



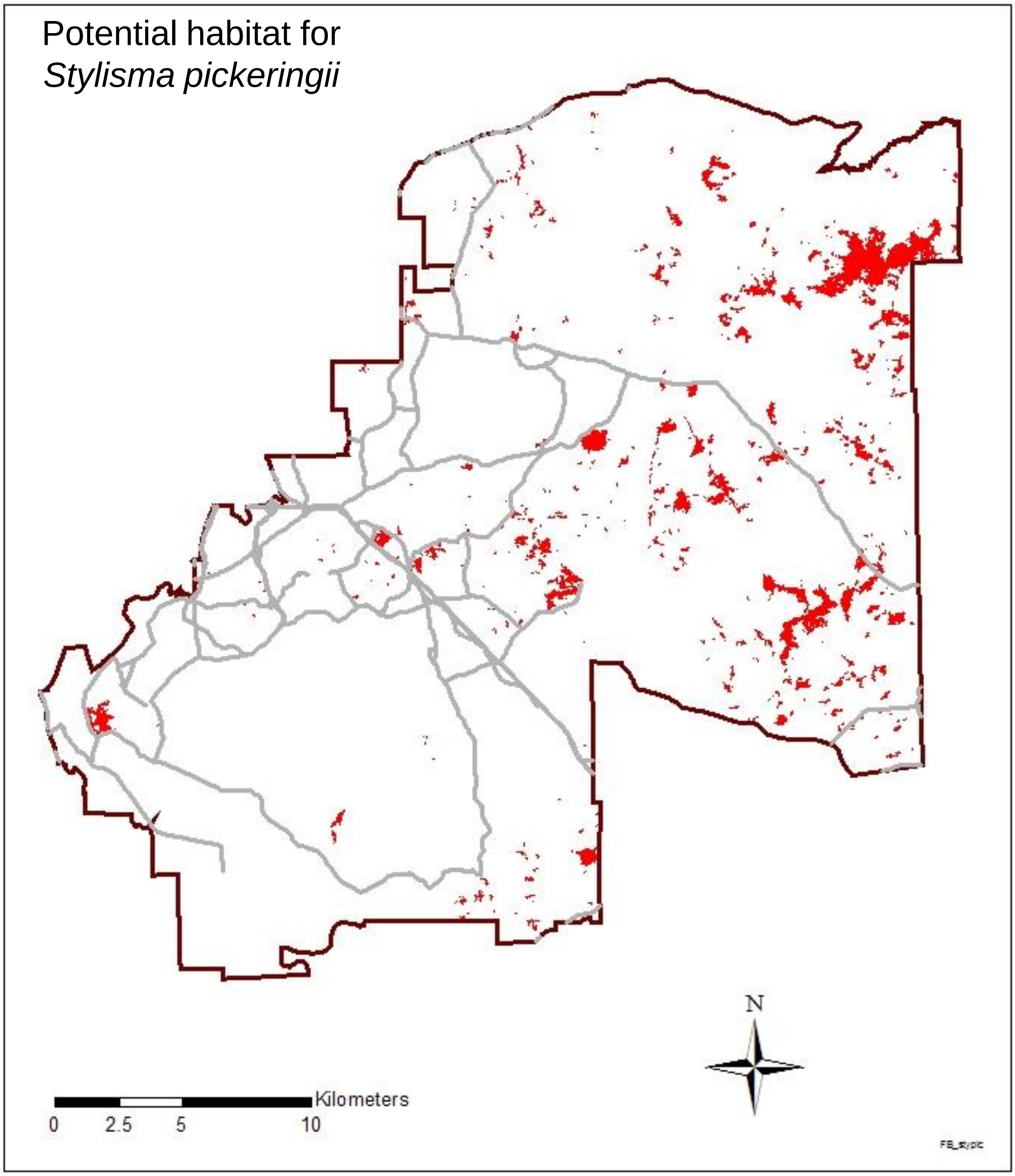
Map of potential habitat for *Baptisia lanceolata* on Fort Benning as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



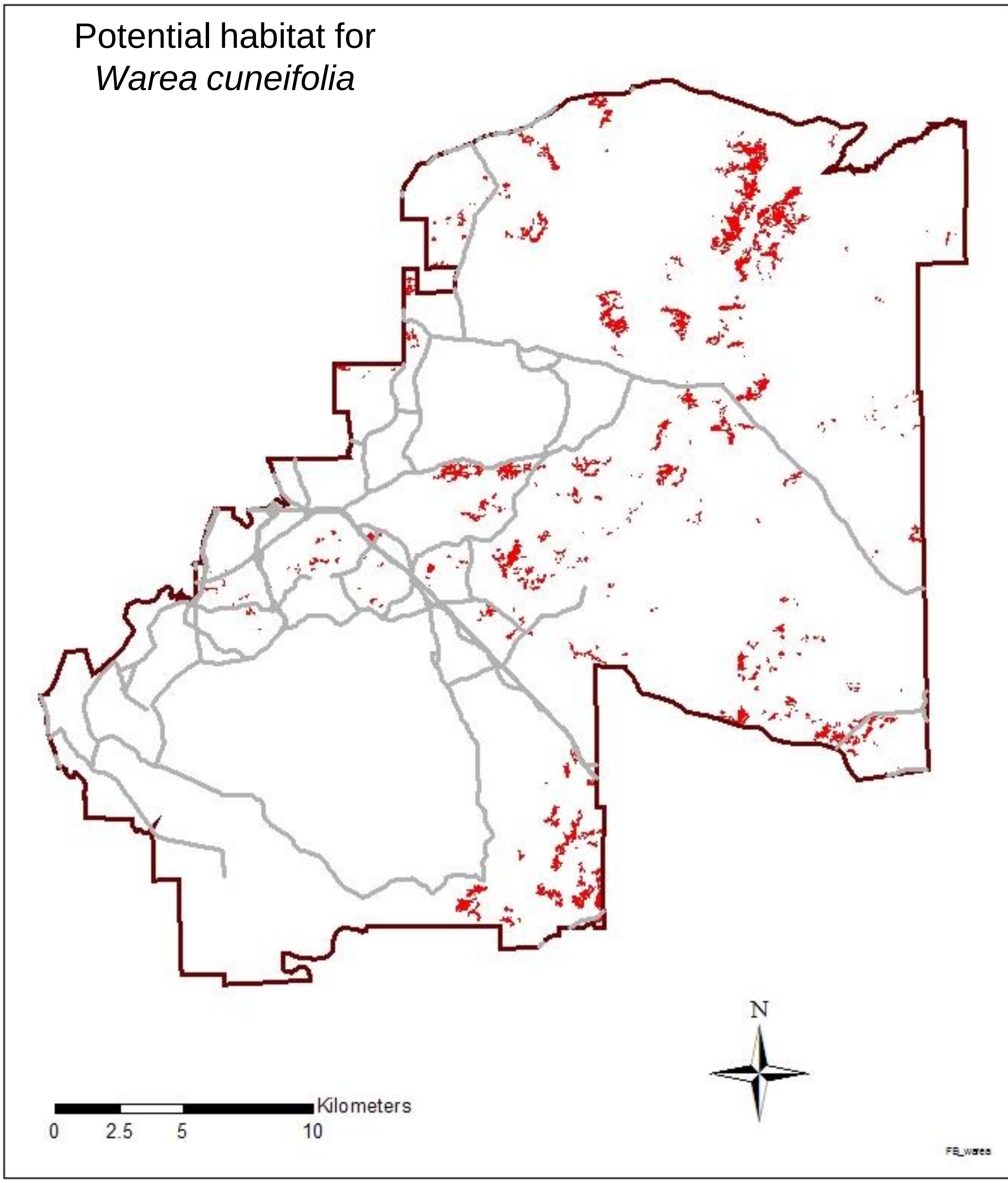
Map of potential habitat for *Chrysoma pauciflosculosa* on Fort Benning as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



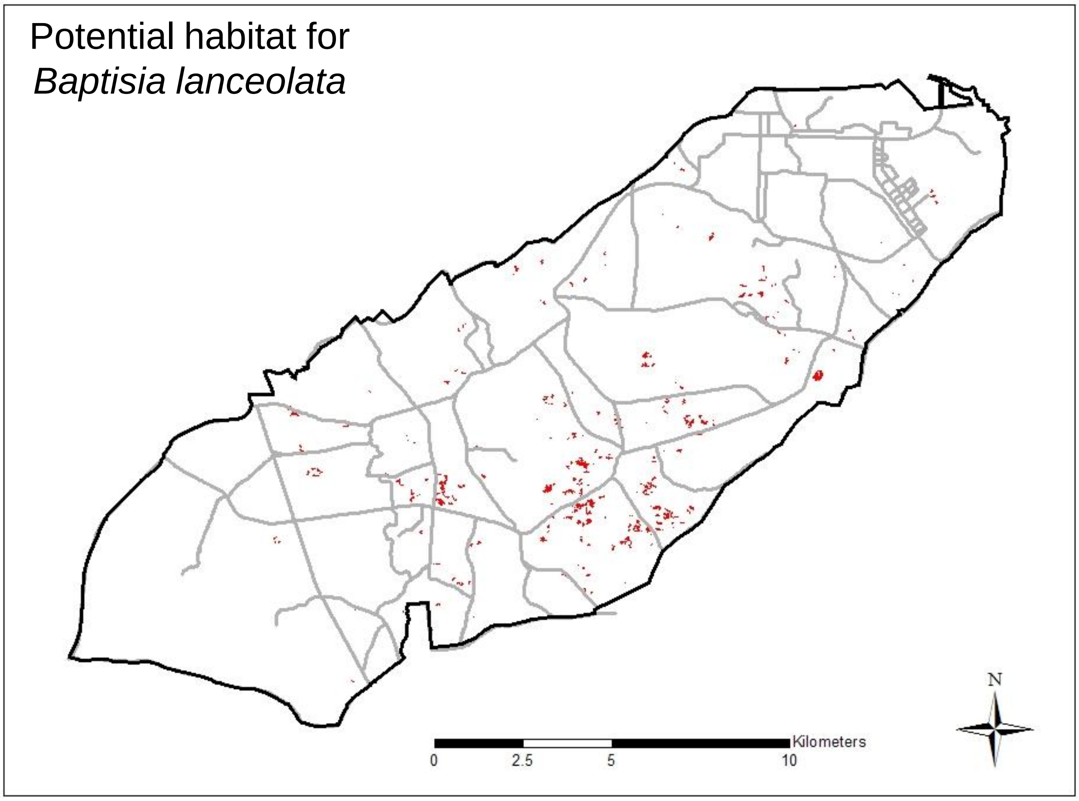
Map of potential habitat for *Phaseolus polystachios* on Fort Benning as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



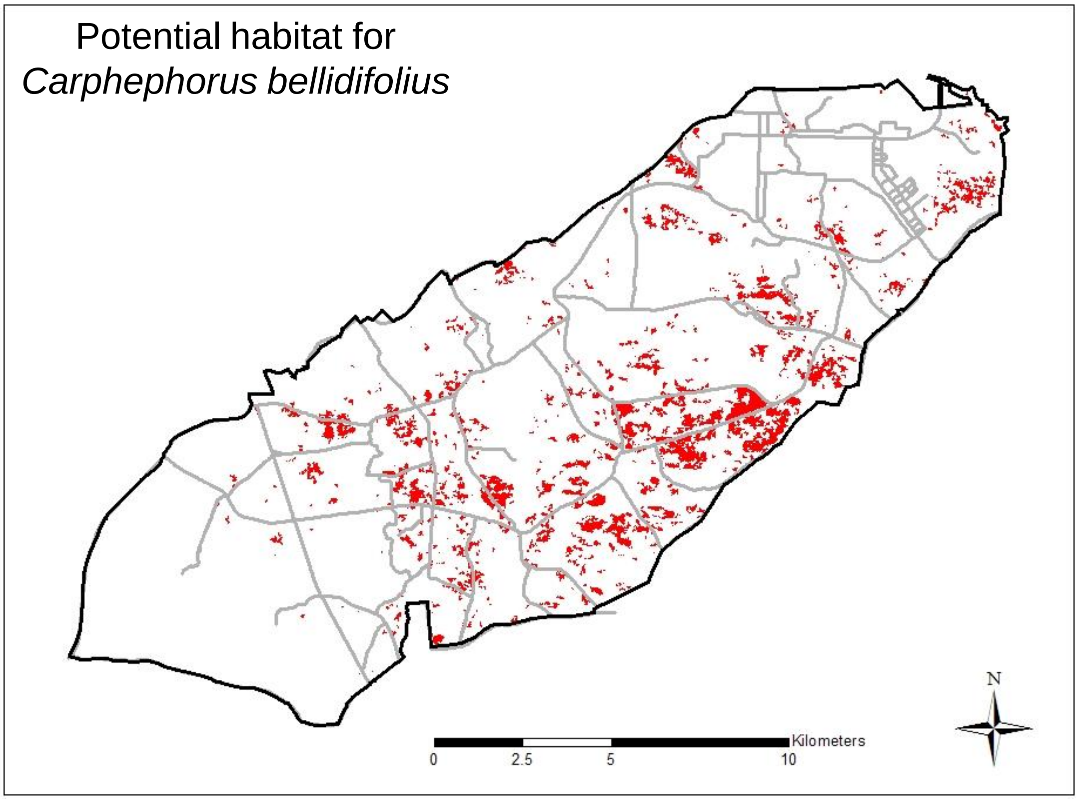
Map of potential habitat for *Stylisma pickeringii* on Fort Benning as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



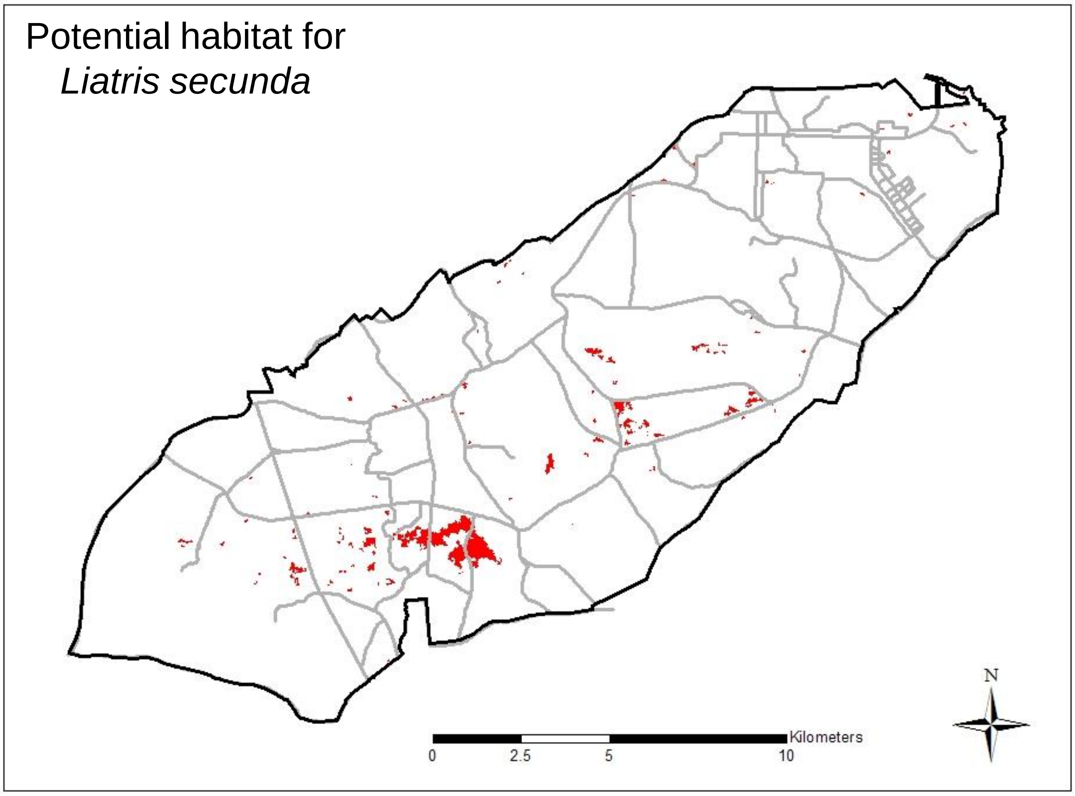
Map of potential habitat for *Warea cuneifolia* on Fort Benning as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



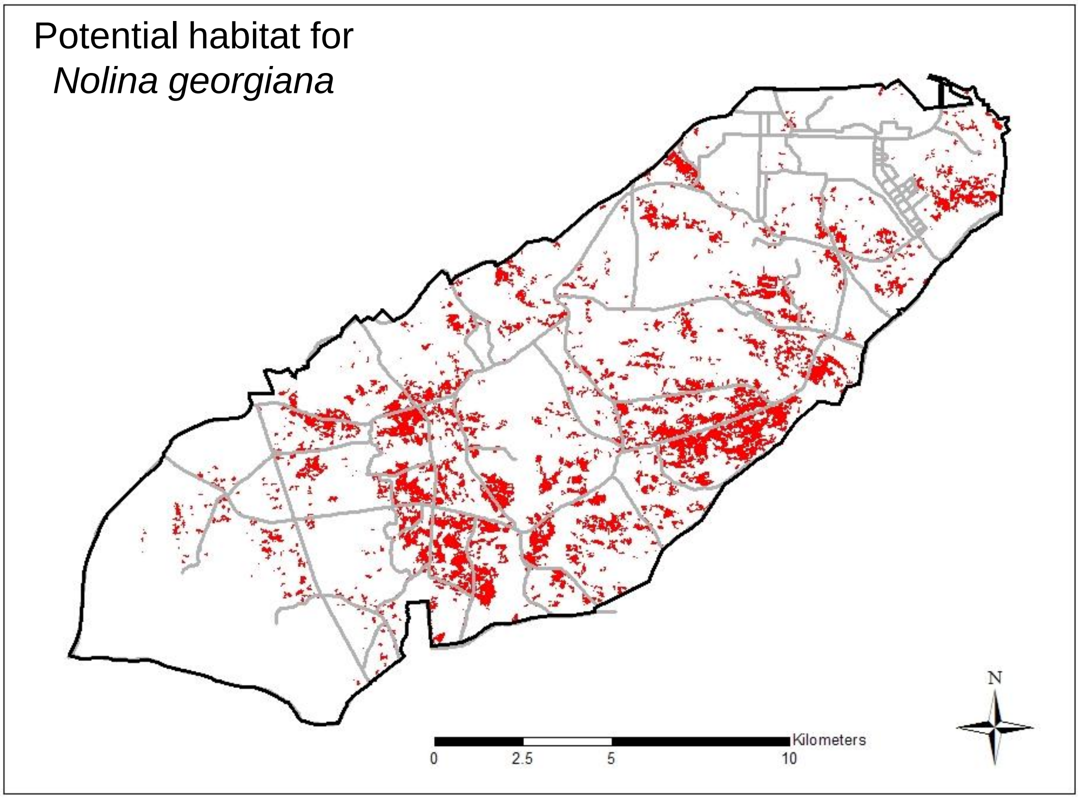
Map of potential habitat for *Baptisia lanceolata* on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



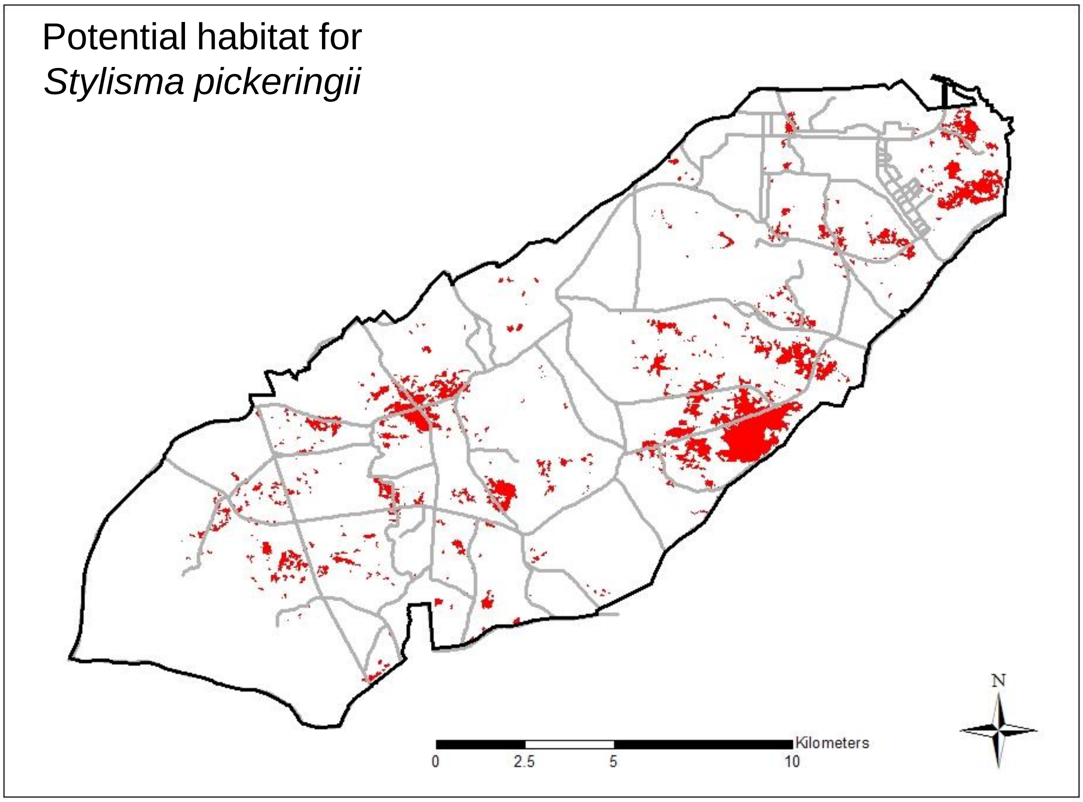
Map of potential habitat for *Carphephorus bellidifolius* on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



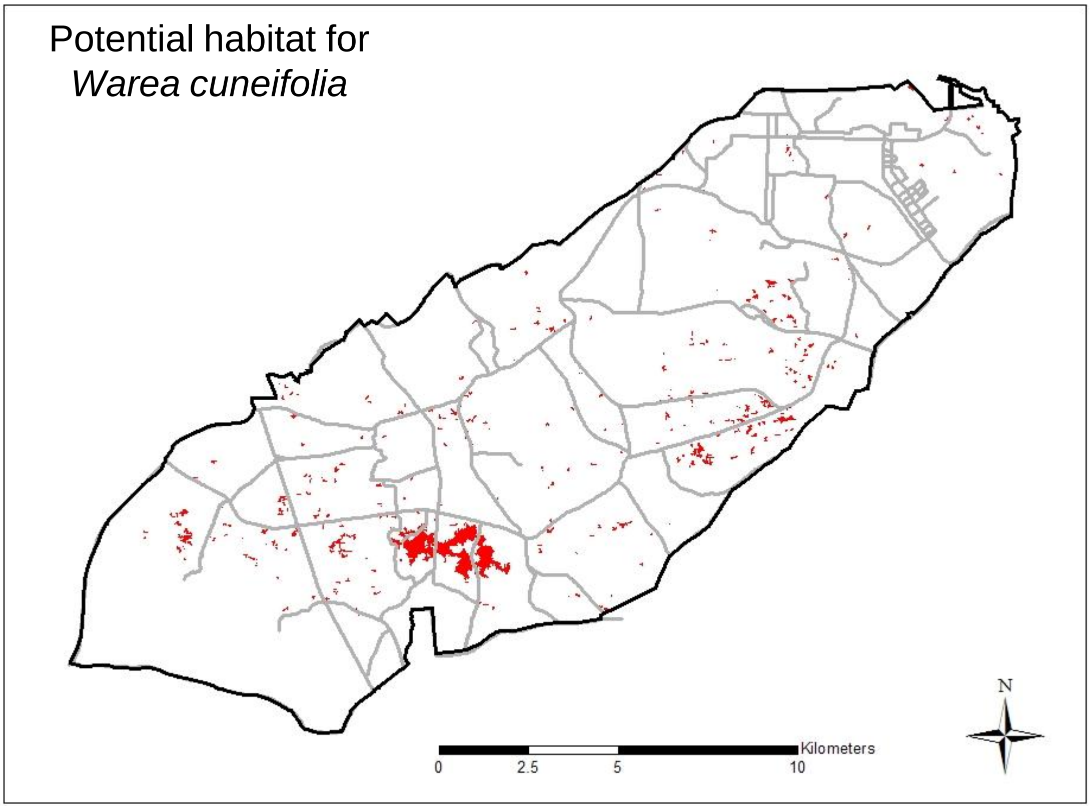
Map of potential habitat for *Liatris secunda* on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



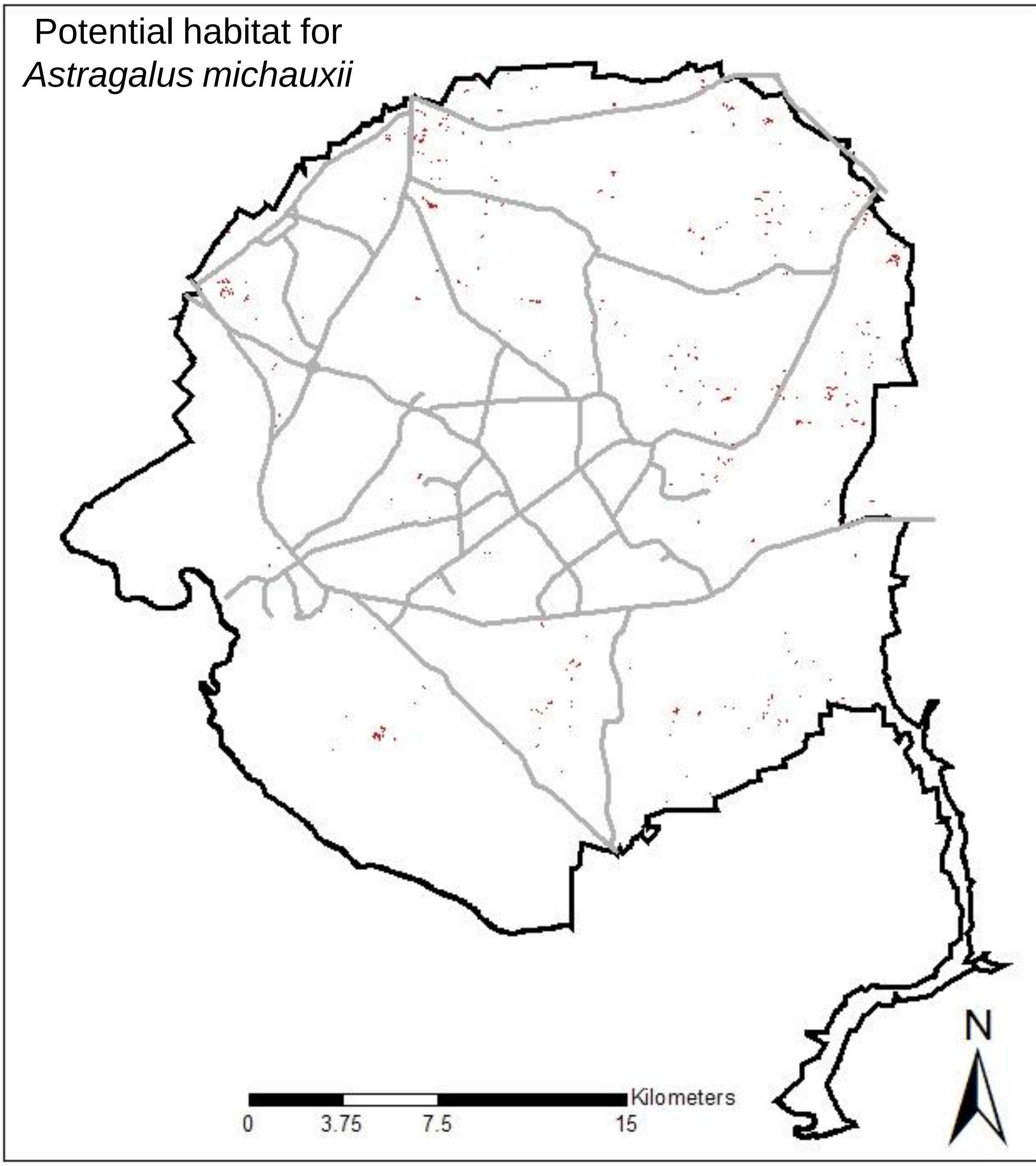
Map of potential habitat for *Nolina georgiana* on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



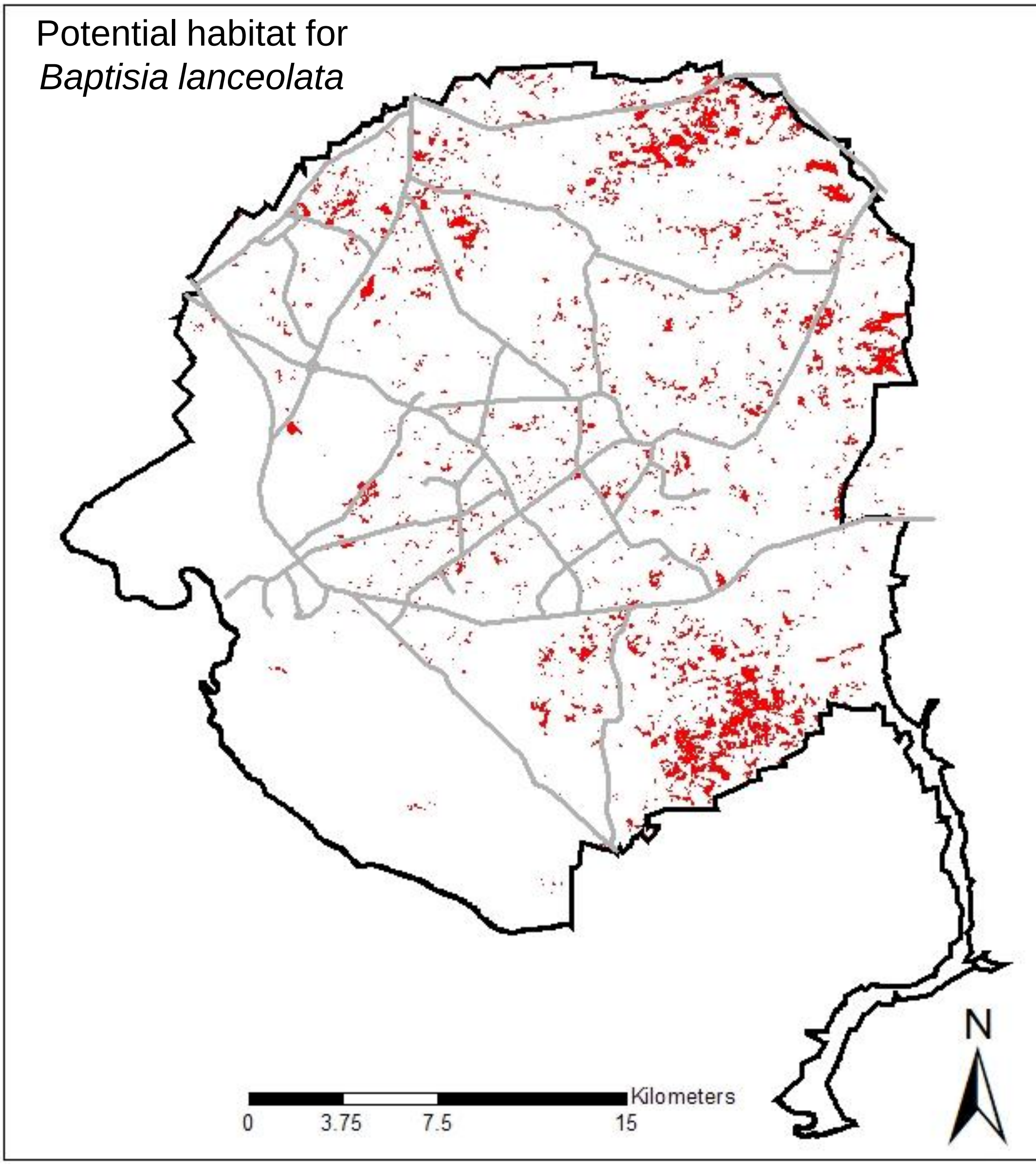
Map of potential habitat for *Stylisma pickeringii* on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



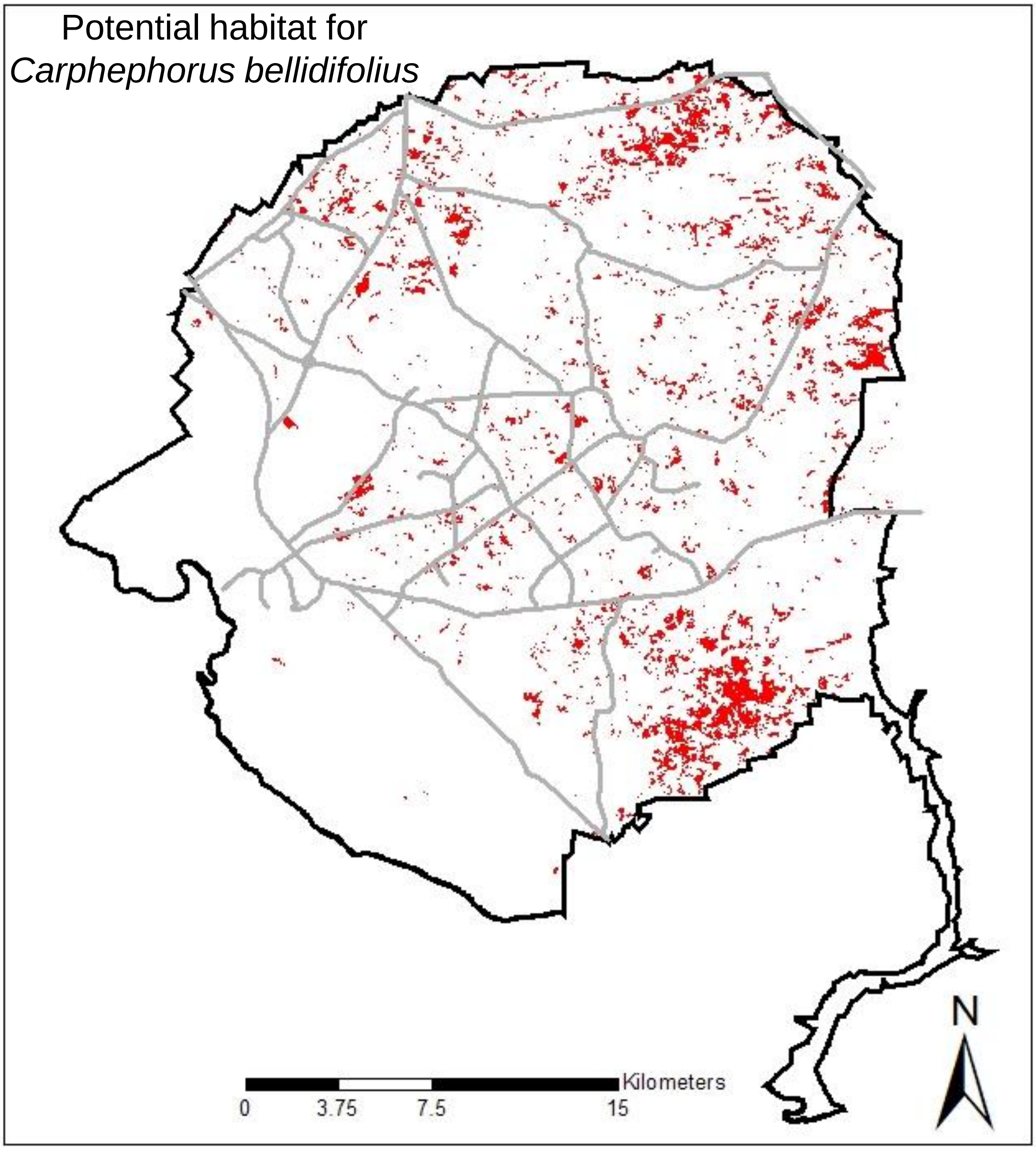
Map of potential habitat for *Warea cuneifolia* on Fort Gordon as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.



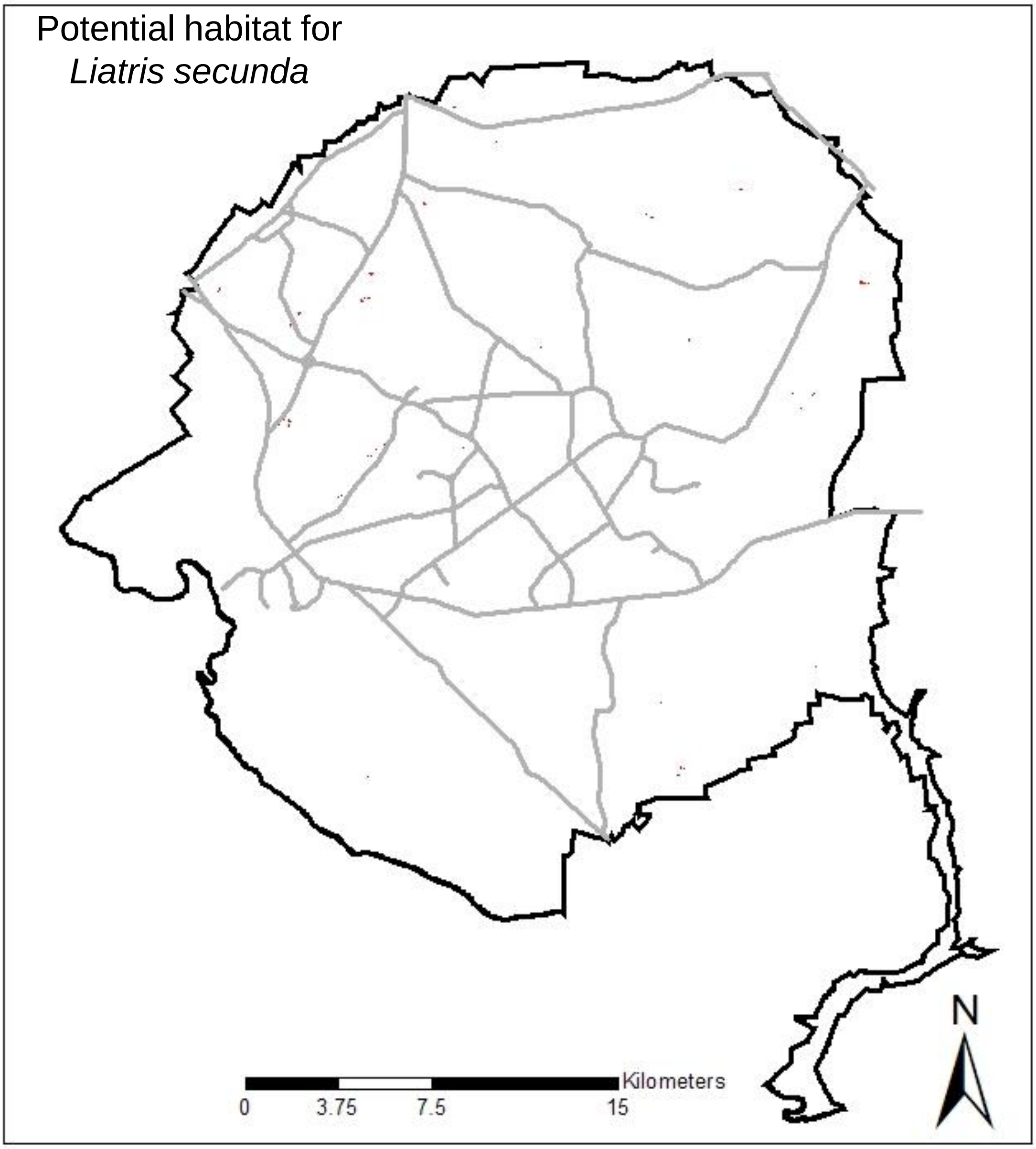
Map of potential habitat for *Astragalus michauxii* on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.



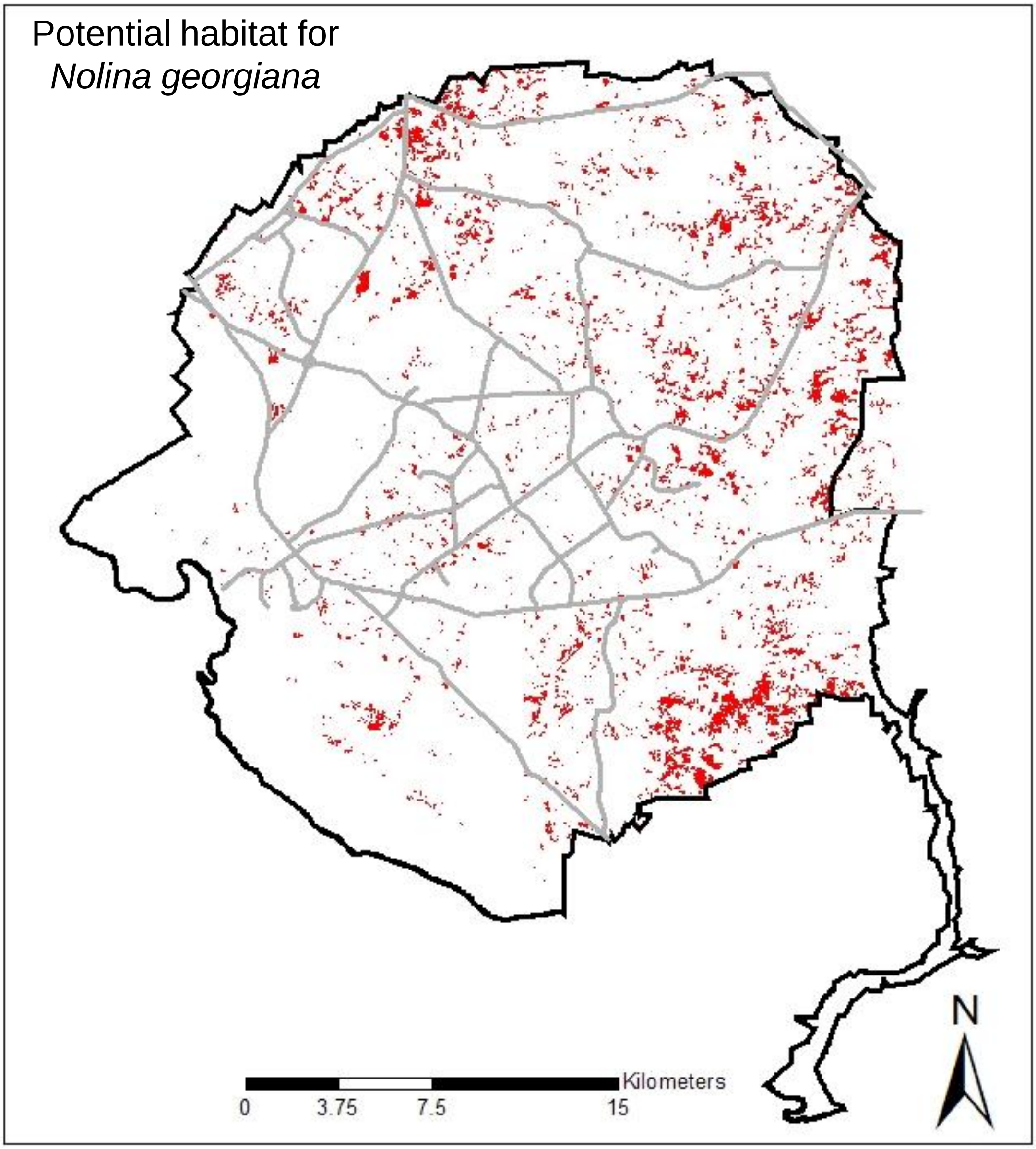
Map of potential habitat for *Baptisia lanceolata* on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.



Map of potential habitat for *Carphephorus bellidifolius* on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.



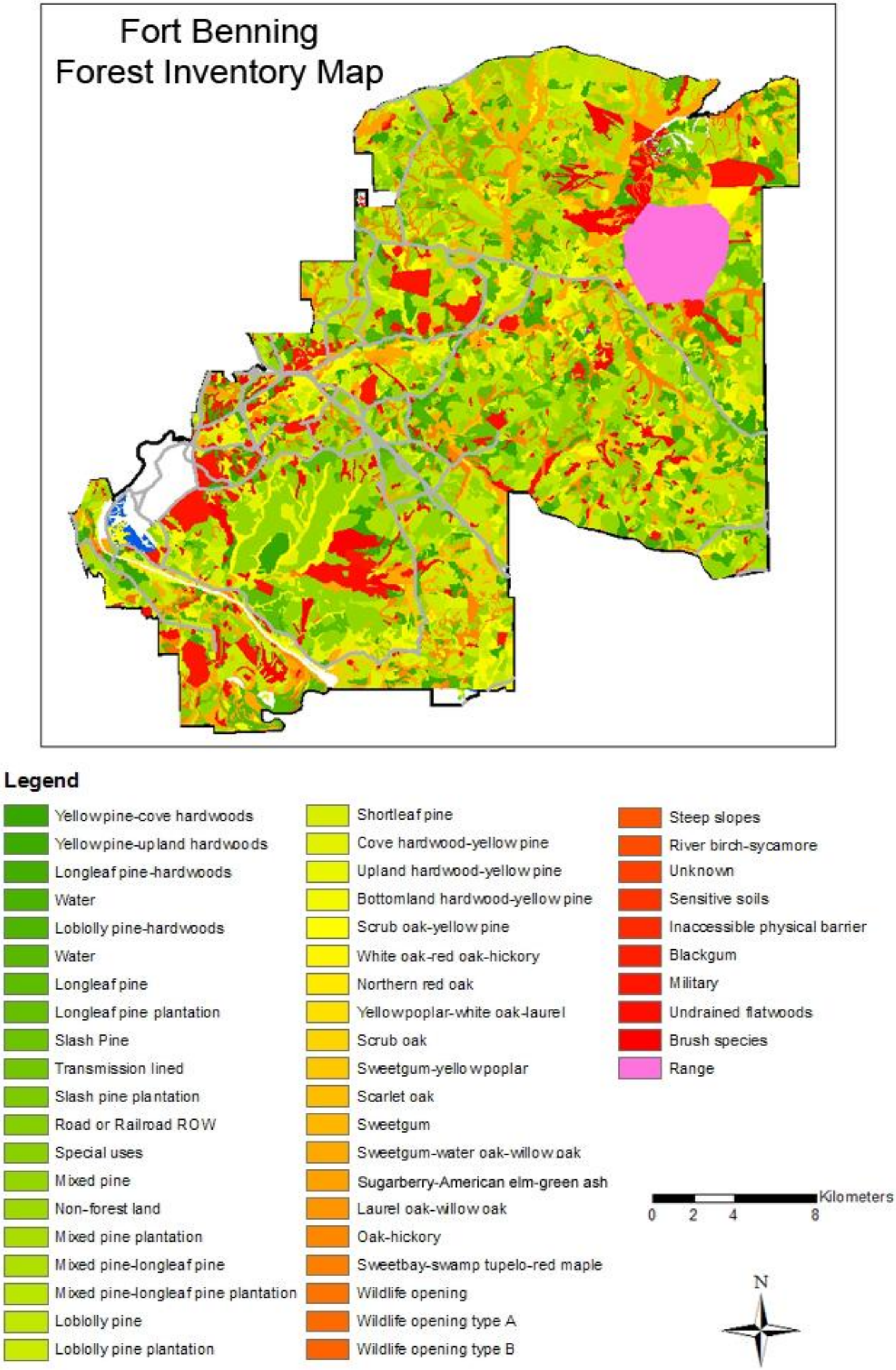
Map of potential habitat for *Liatris secunda* on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.



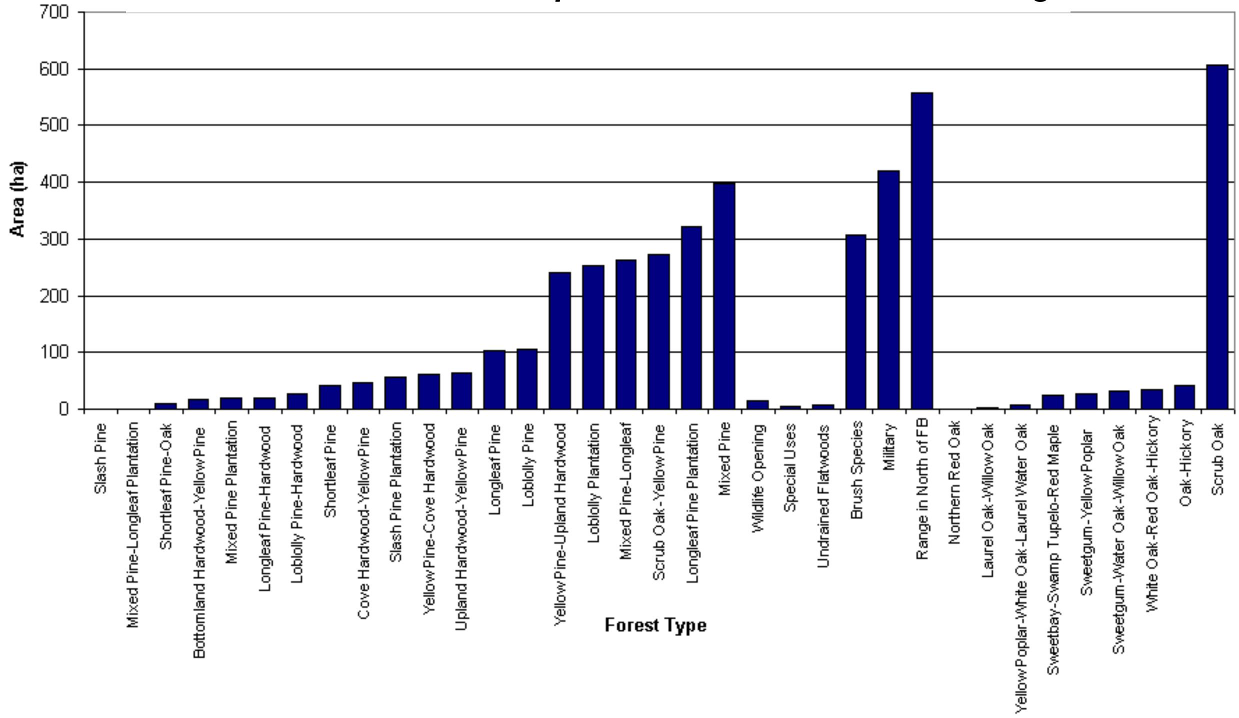
Map of potential habitat for *Nolina georgiana* on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.

Map of potential habitat for *Phaseolus polystachios* on the Savannah River Site as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.

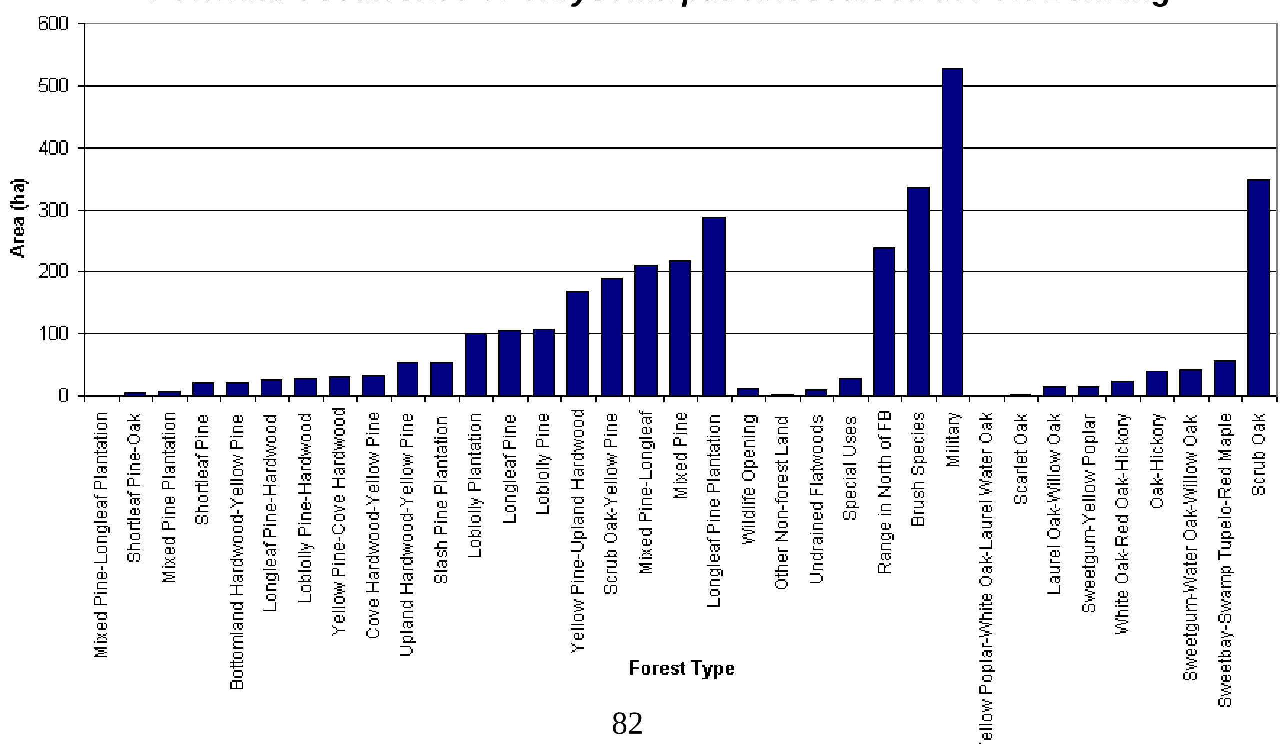
Appendix A.8.4. Forest inventory and training/land management maps for Fort Benning, Fort Gordon, and the Savannah River Site, and the potential occurrence of individual plant TES species within forest types and training/land management categories.


Fort Benning
Forest Inventory Map
Legend
Yellowpine-cove hardwoods
Yellowpine-upland hardwoods
Longleaf pine-hardwoods
Water
Loblolly pine-hardwoods
Water
Longleaf pine
Longleaf pine plantation
Slash Pine
Transmission lined
Slash pine plantation
Road or Railroad ROW
Special uses
Mixed pine
Non-forest land
Mixed pine plantation
Mixed pine-longleaf pine
Mixed pine-longleaf pine plantation
Loblolly pine
Loblolly pine plantation
Shortleaf pine
Cove hardwood-yellow pine
Upland hardwood-yellow pine
Bottomland hardwood-yellow pine
Scrub oak-yellow pine
White oak-red oak-hickory
Northern red oak
Yellowpoplar-white oak-laurel
Scrub oak
Sweetgum-yellowpoplar
Scarlet oak
Sweetgum
Sweetgum-water oak-willow oak
Sugarberry-American elm-green ash
Laurel oak-willow oak
Oak-hickory
Sweetbay-swamp tupelo-red maple
Wildlife opening
Wildlife opening type A
Wildlife opening type B
Steep slopes
River birch-sycamore
Unknown
Sensitive soils
Inaccessible physical barrier
Blackgum
Military
Undrained flatwoods
Brush species
Range
Kilometers
0 2 4 8
N

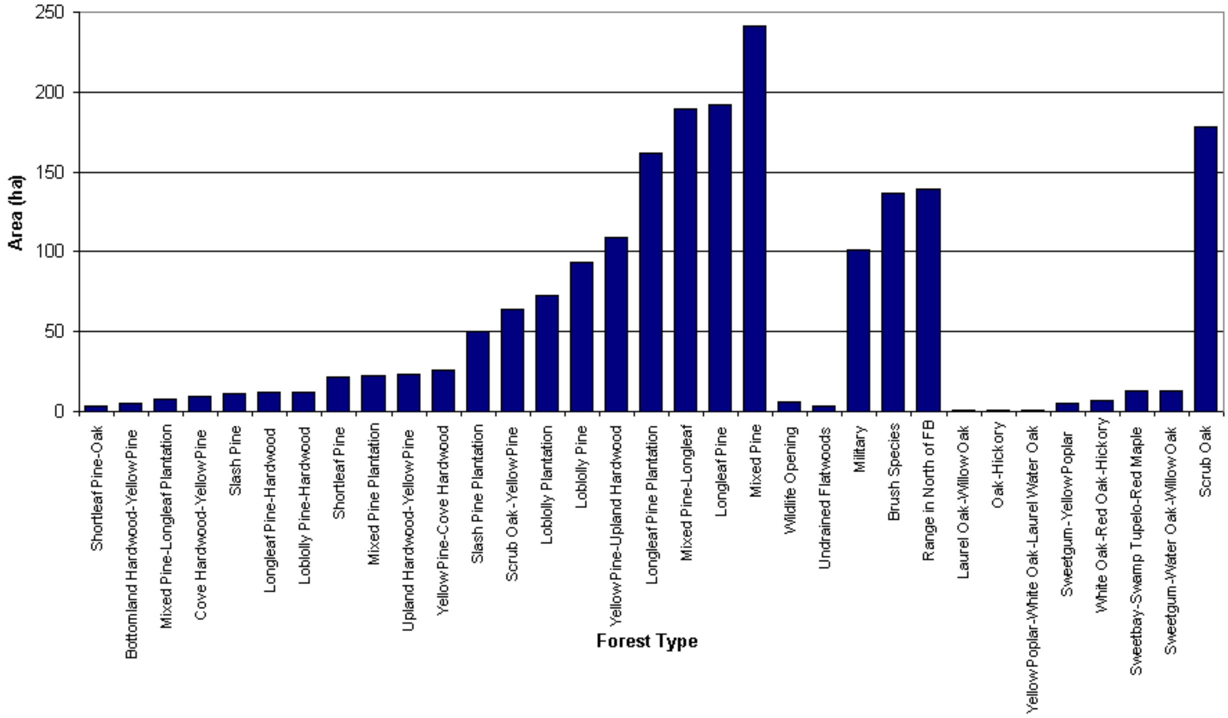
Potential Occurrence of *Baptisia lanceolata* at Fort Benning



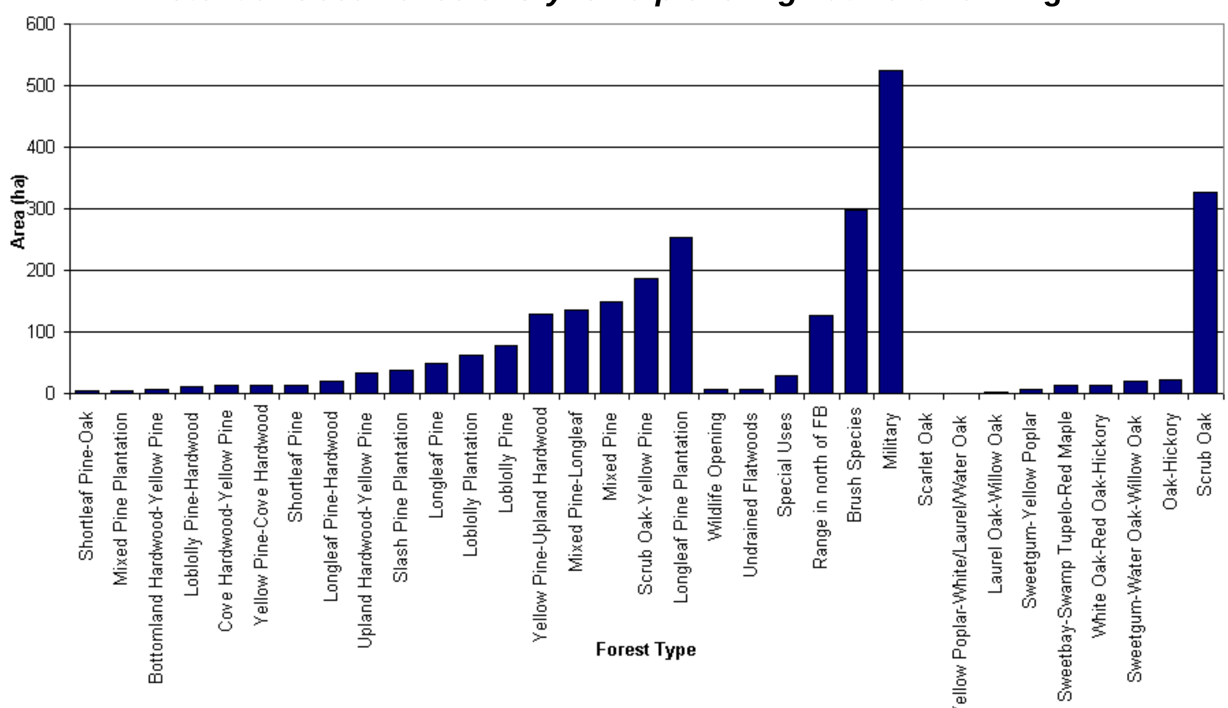
Potential Occurrence of *Chrysoma pauciflosculosa* at Fort Benning



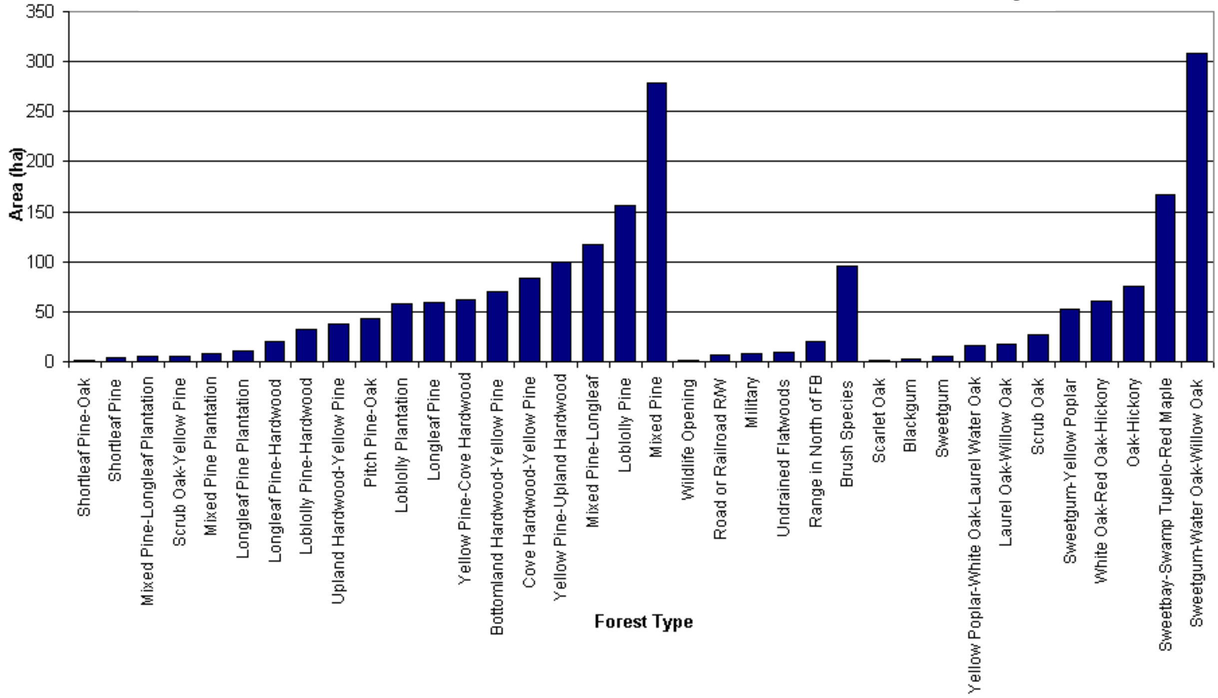
Potential Occurrence of *Phaseolus polystachios* at Fort Benning

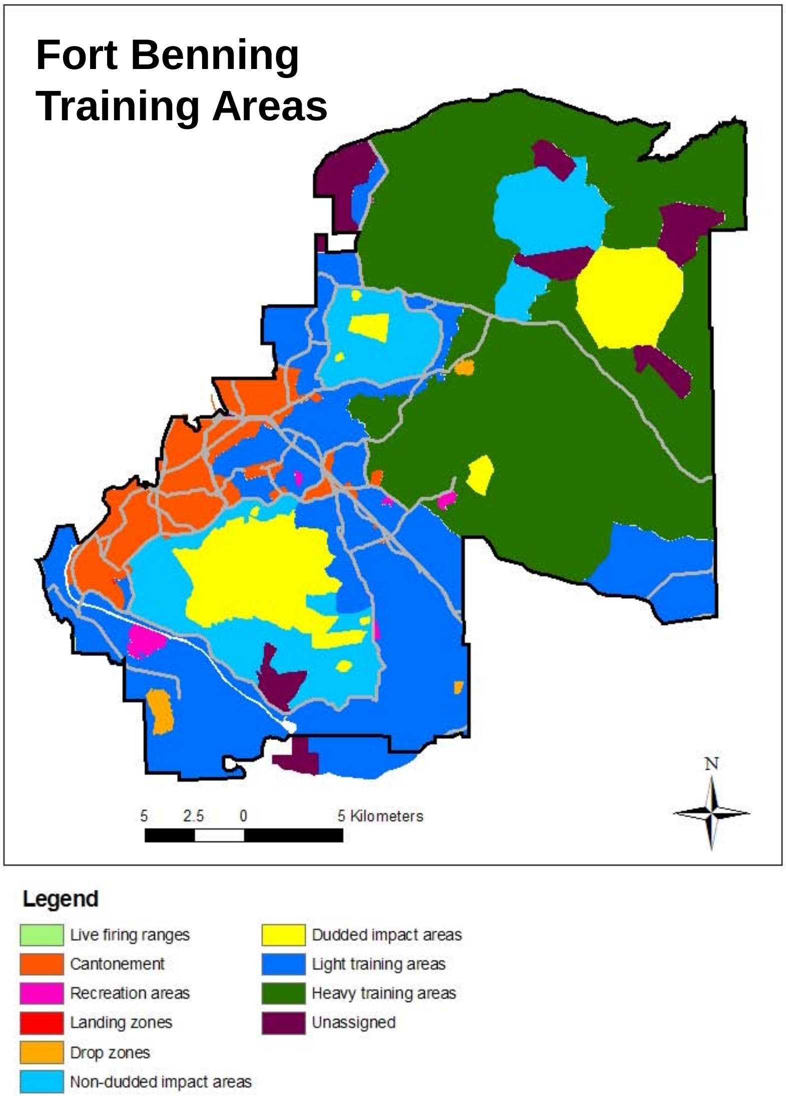


Potential Occurrence of *Stylisma pickeringii* at Fort Benning

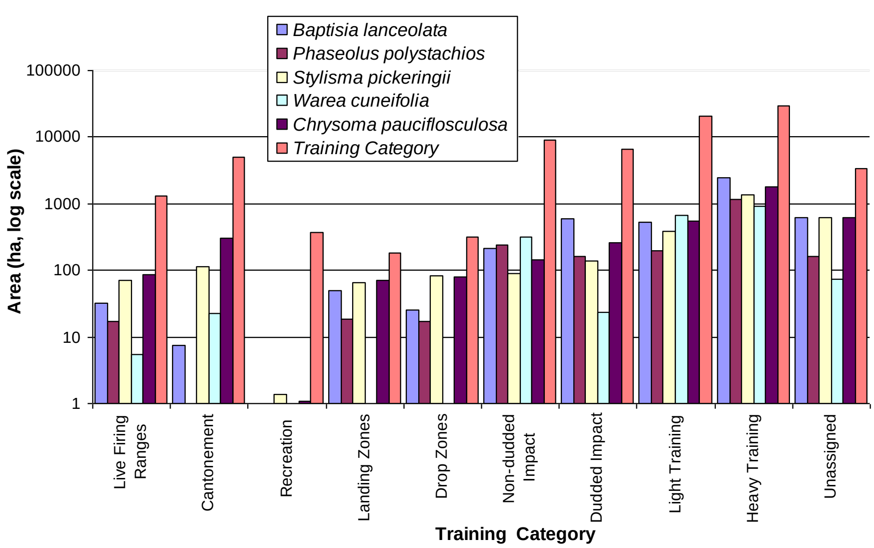


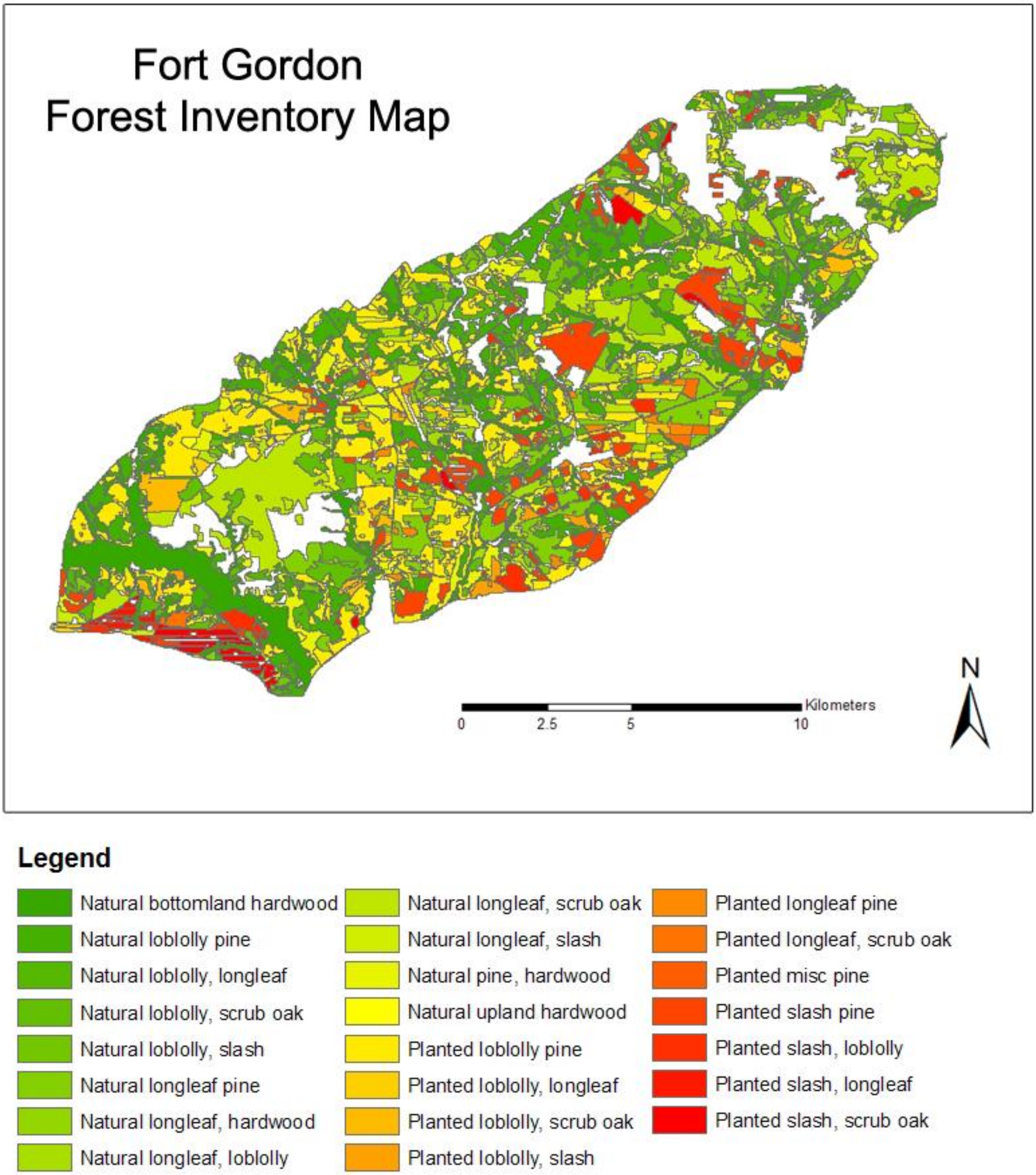
Potential Occurrence of *Warea cuneifolia* at Fort Benning

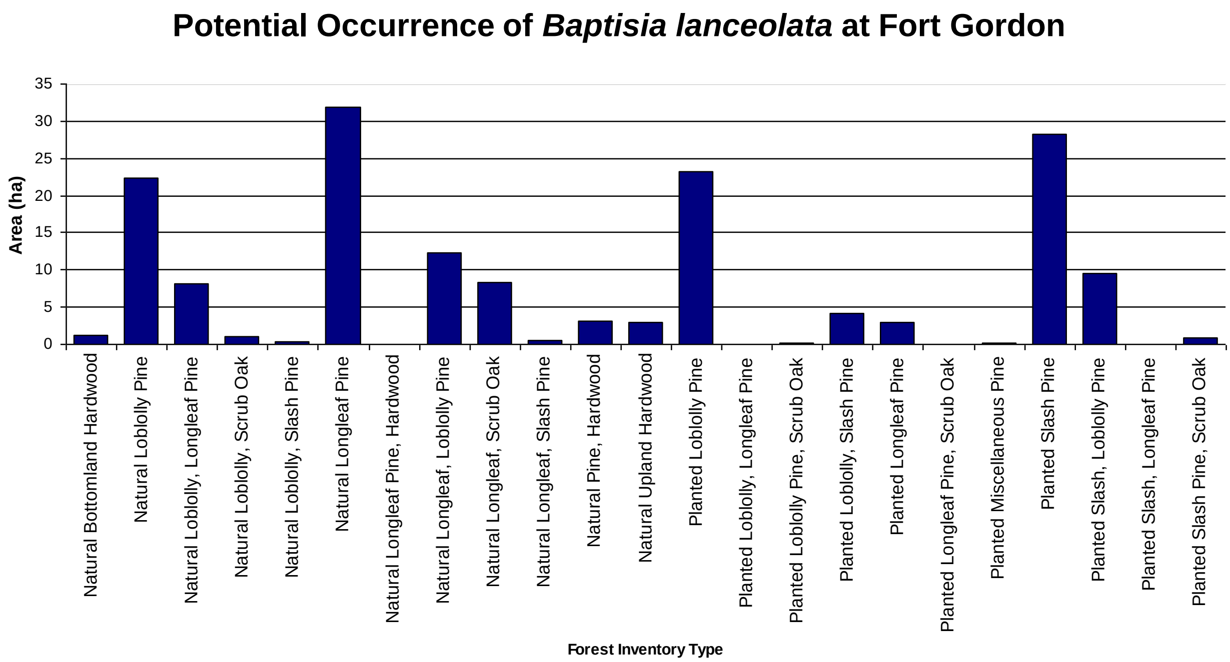


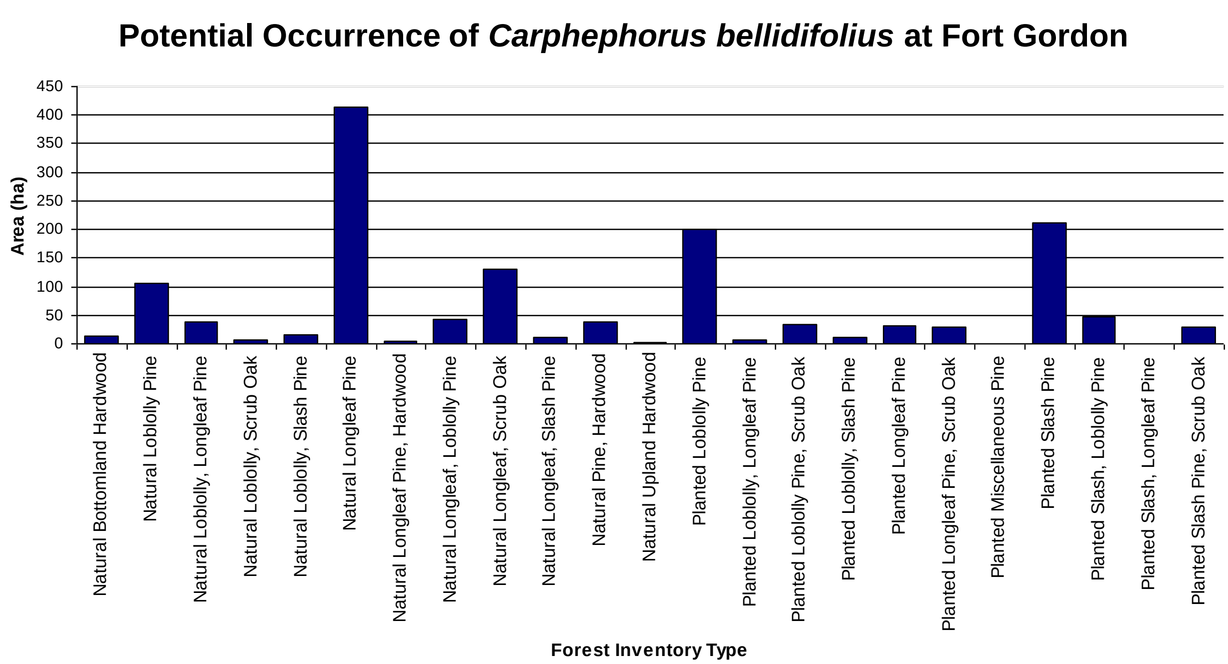


Potential Occurrence of TES Species by Training Area at Fort Benning

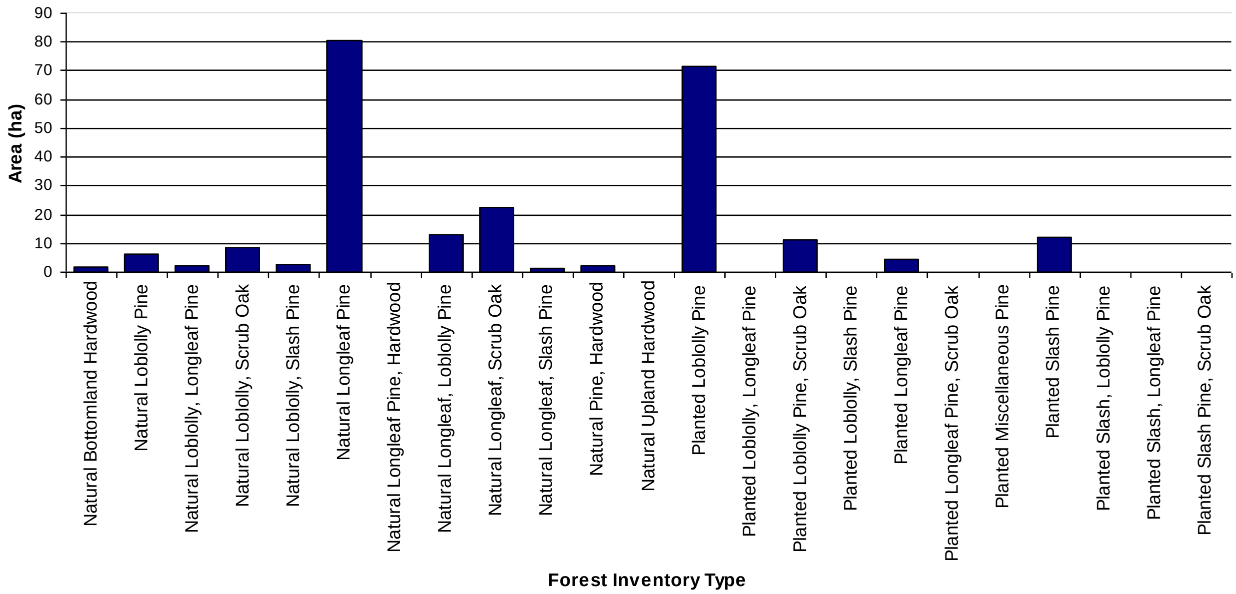



Fort Gordon
Forest Inventory Map
Kilometers
0
2.5
5
10
N
Legend
Natural bottomland hardwood
Natural loblolly pine
Natural loblolly, longleaf
Natural loblolly, scrub oak
Natural loblolly, slash
Natural longleaf pine
Natural longleaf, hardwood
Natural longleaf, loblolly
Natural longleaf, scrub oak
Natural longleaf, slash
Natural pine, hardwood
Natural upland hardwood
Planted loblolly pine
Planted loblolly, longleaf
Planted loblolly, scrub oak
Planted loblolly, slash
Planted longleaf pine
Planted longleaf, scrub oak
Planted misc pine
Planted slash pine
Planted slash, loblolly
Planted slash, longleaf
Planted slash, scrub oak

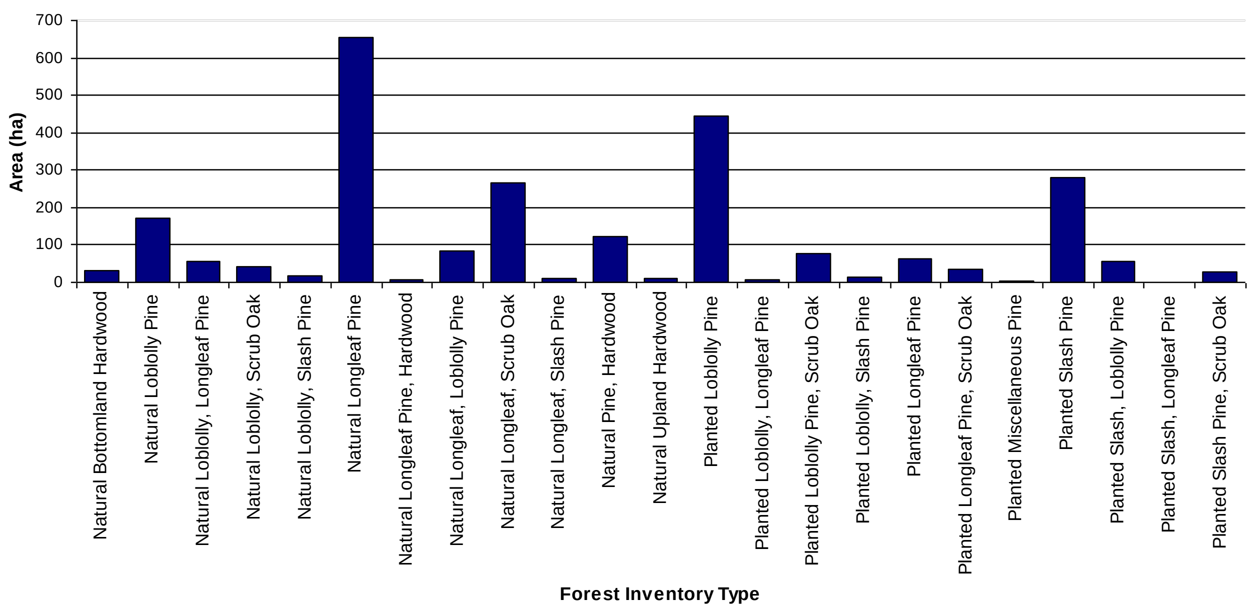

Potential Occurrence of *Baptisia lanceolata* at Fort Gordon
Area (ha)
35
30
25
20
15
10
5
0
Natural Bottomland Hardwood
Natural Loblolly Pine
Natural Loblolly, Longleaf Pine
Natural Loblolly, Scrub Oak
Natural Loblolly, Slash Pine
Natural Longleaf Pine
Natural Longleaf Pine, Hardwood
Natural Longleaf, Loblolly Pine
Natural Longleaf, Scrub Oak
Natural Longleaf, Slash Pine
Natural Pine, Hardwood
Natural Upland Hardwood
Planted Loblolly Pine
Planted Loblolly, Longleaf Pine
Planted Loblolly Pine, Scrub Oak
Planted Loblolly, Slash Pine
Planted Longleaf Pine
Planted Longleaf Pine, Scrub Oak
Planted Miscellaneous Pine
Planted Slash Pine
Planted Slash, Loblolly Pine
Planted Slash, Longleaf Pine
Planted Slash Pine, Scrub Oak
Forest Inventory Type


Potential Occurrence of *Carphephorus bellidifolius* at Fort Gordon
Area (ha)
450
400
350
300
250
200
150
100
50
0
Natural Bottomland Hardwood
Natural Loblolly Pine
Natural Loblolly, Longleaf Pine
Natural Loblolly, Scrub Oak
Natural Loblolly, Slash Pine
Natural Longleaf Pine
Natural Longleaf Pine, Hardwood
Natural Longleaf, Loblolly Pine
Natural Longleaf, Scrub Oak
Natural Longleaf, Slash Pine
Natural Pine, Hardwood
Natural Upland Hardwood
Planted Loblolly Pine
Planted Loblolly, Longleaf Pine
Planted Loblolly Pine, Scrub Oak
Planted Loblolly, Slash Pine
Planted Longleaf Pine
Planted Longleaf Pine, Scrub Oak
Planted Miscellaneous Pine
Planted Slash Pine
Planted Slash, Loblolly Pine
Planted Slash, Longleaf Pine
Planted Slash Pine, Scrub Oak
Forest Inventory Type

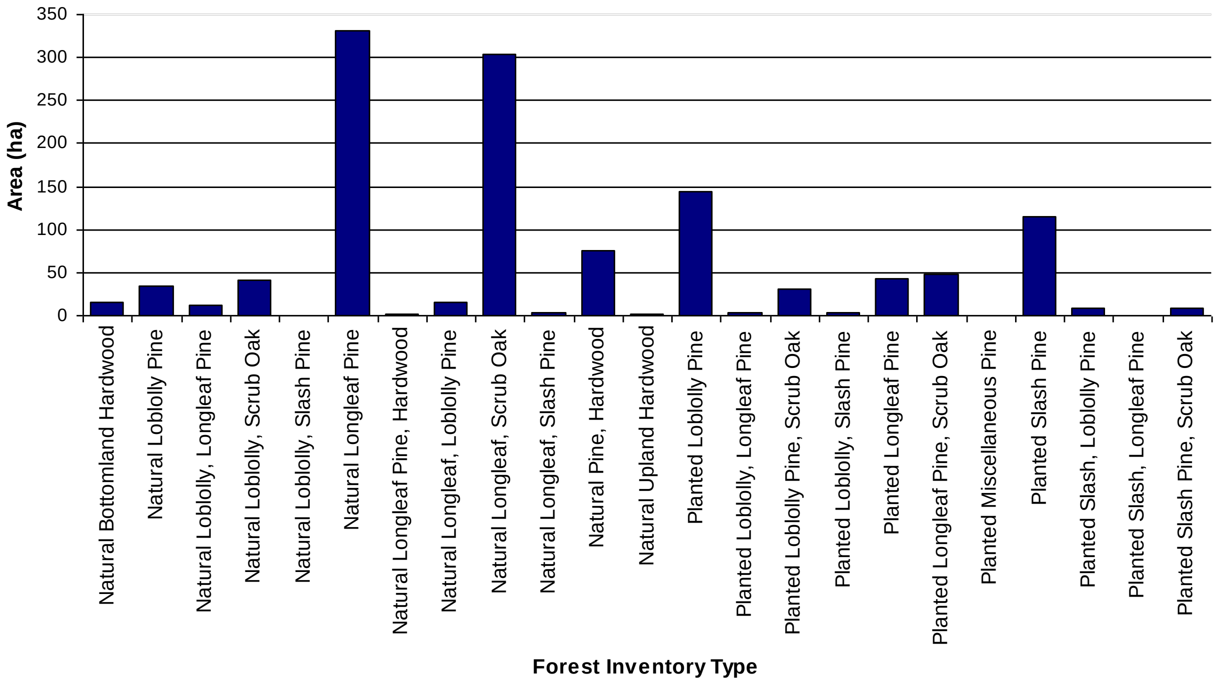
Potential Occurrence of *Liatris secunda* at Fort Gordon



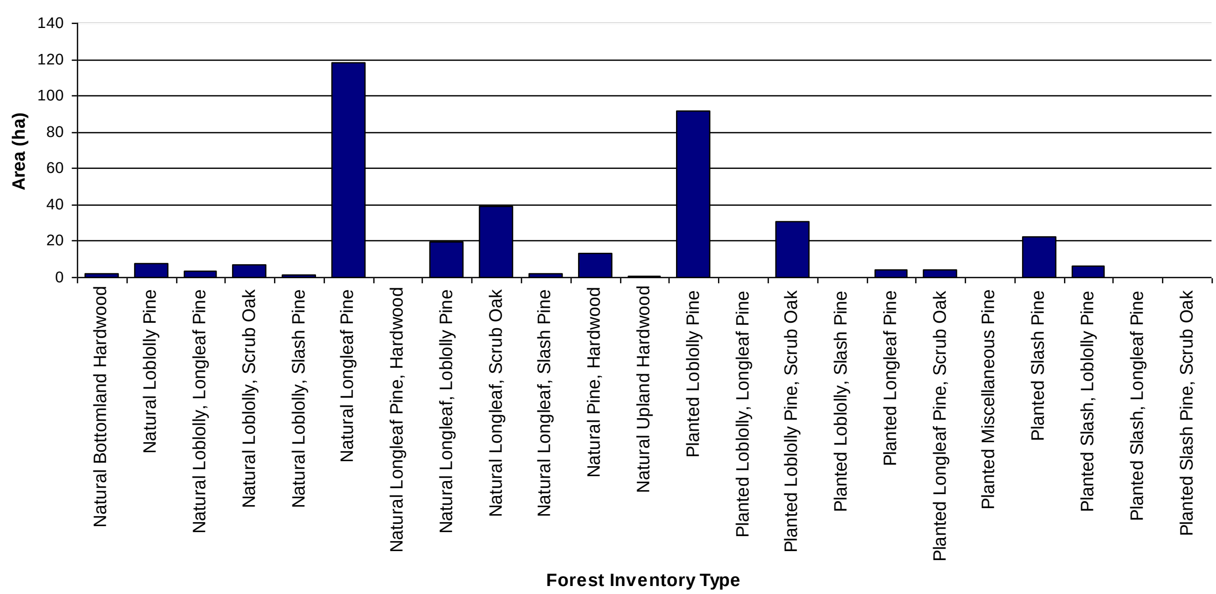
Potential Occurrence of *Nolina georgiana* at Fort Gordon

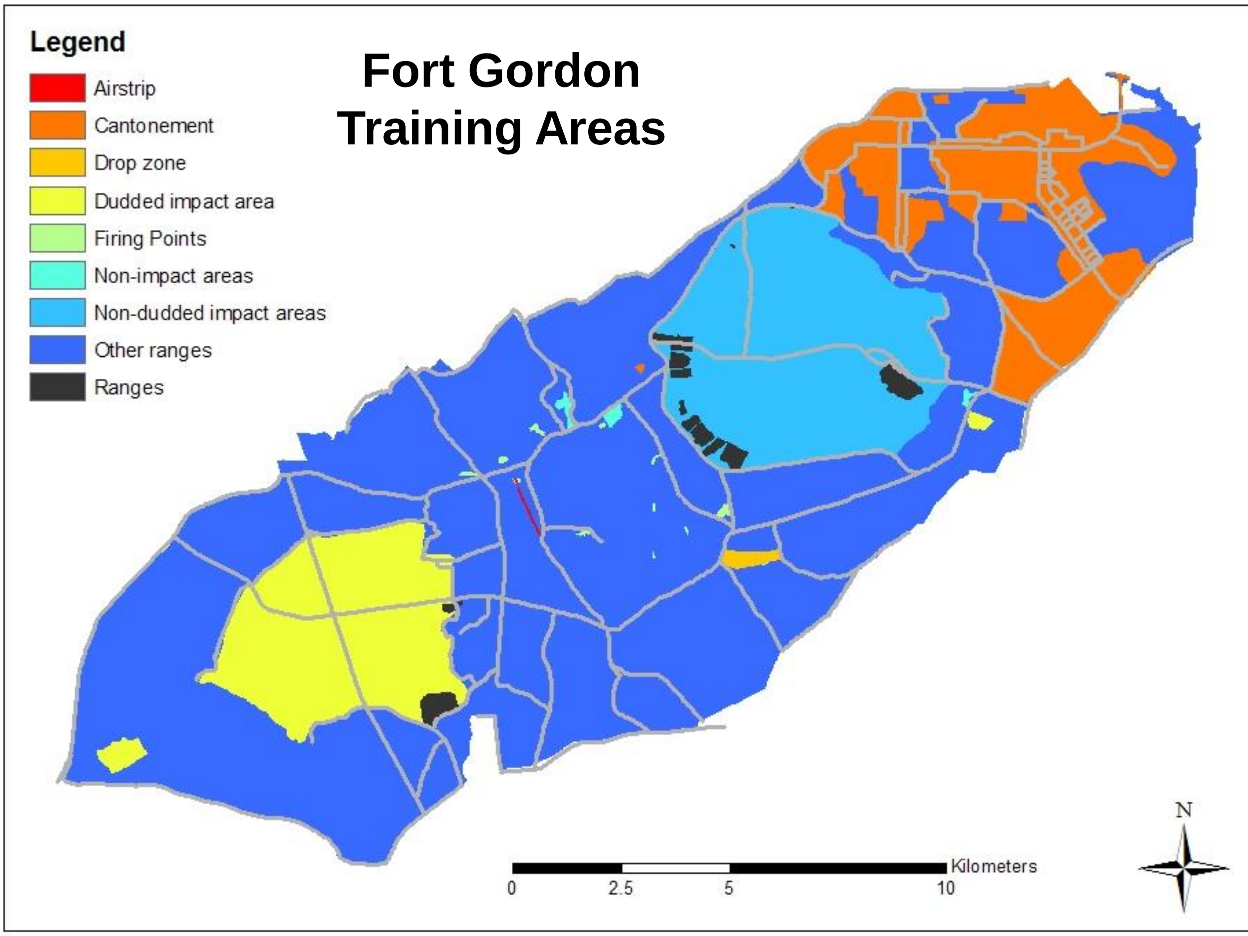


Potential Occurrence of *Stylisma pickeringii* at Fort Gordon

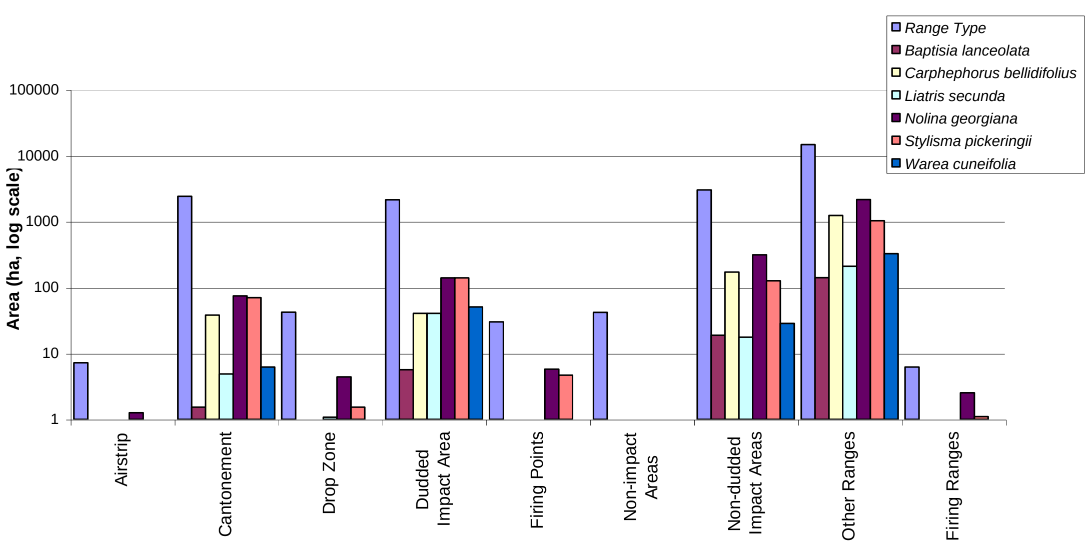


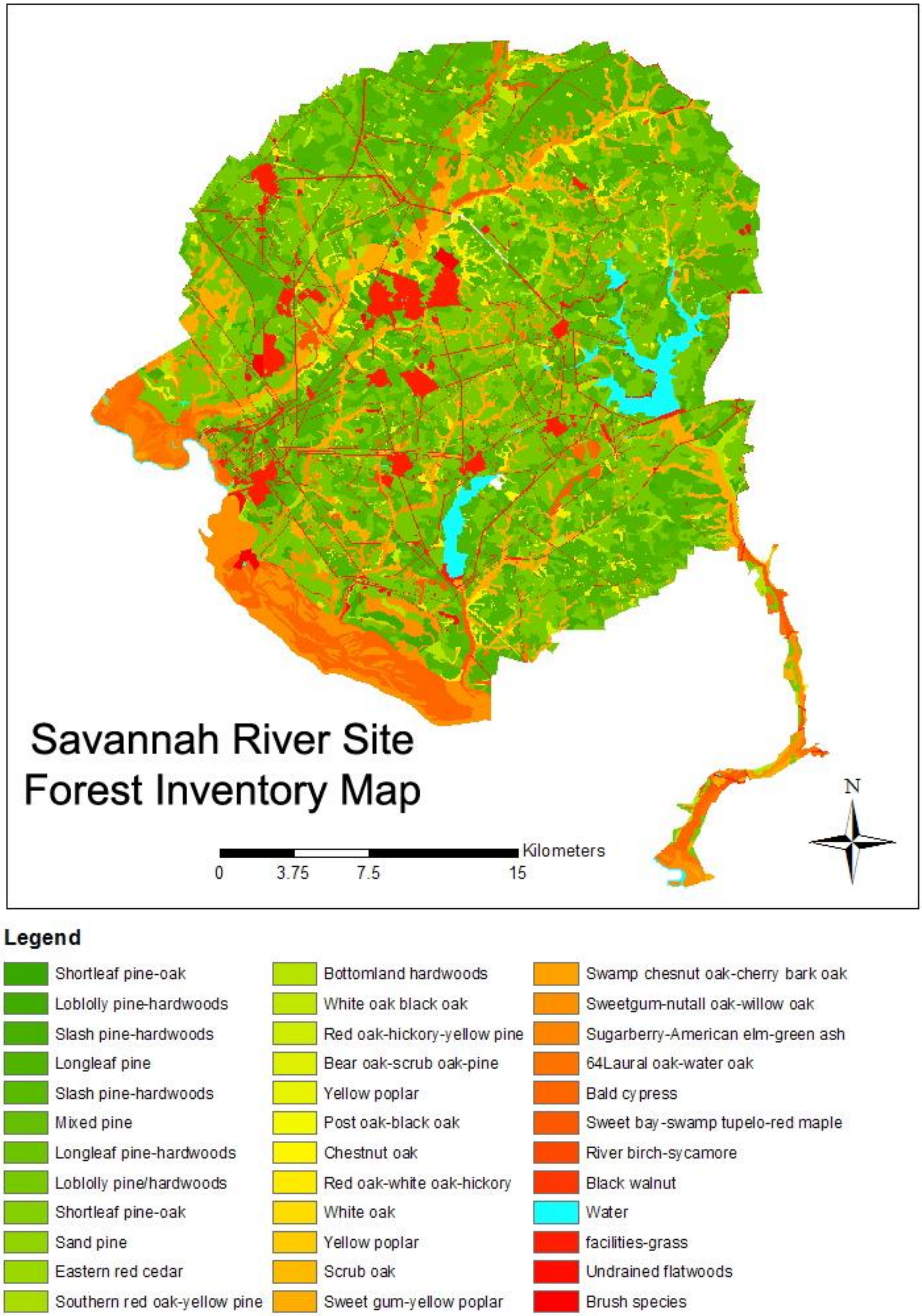
Potential Occurrence of *Warea cuneifolia* at Fort Gordon

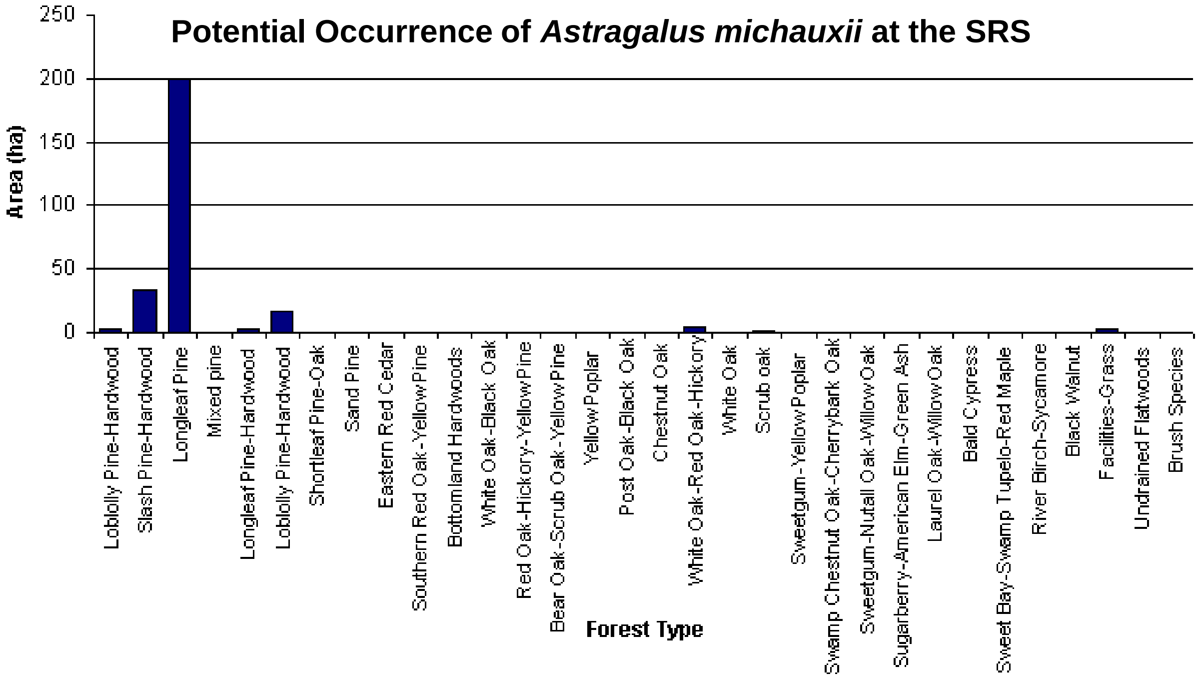


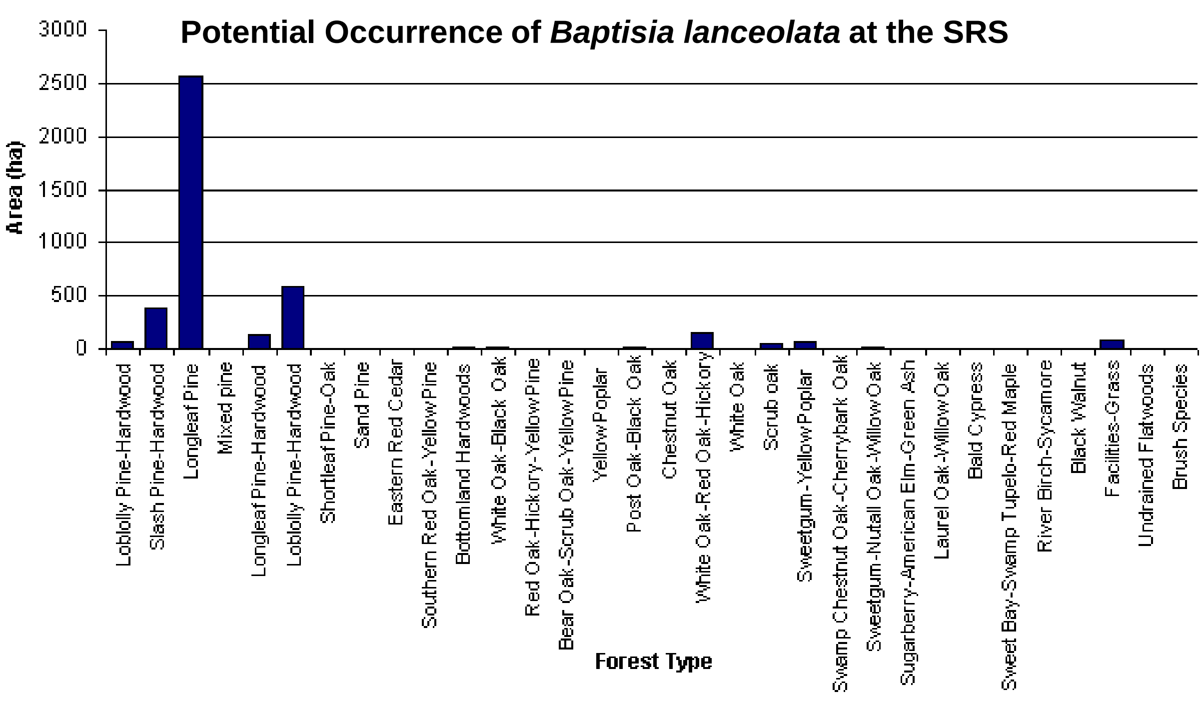


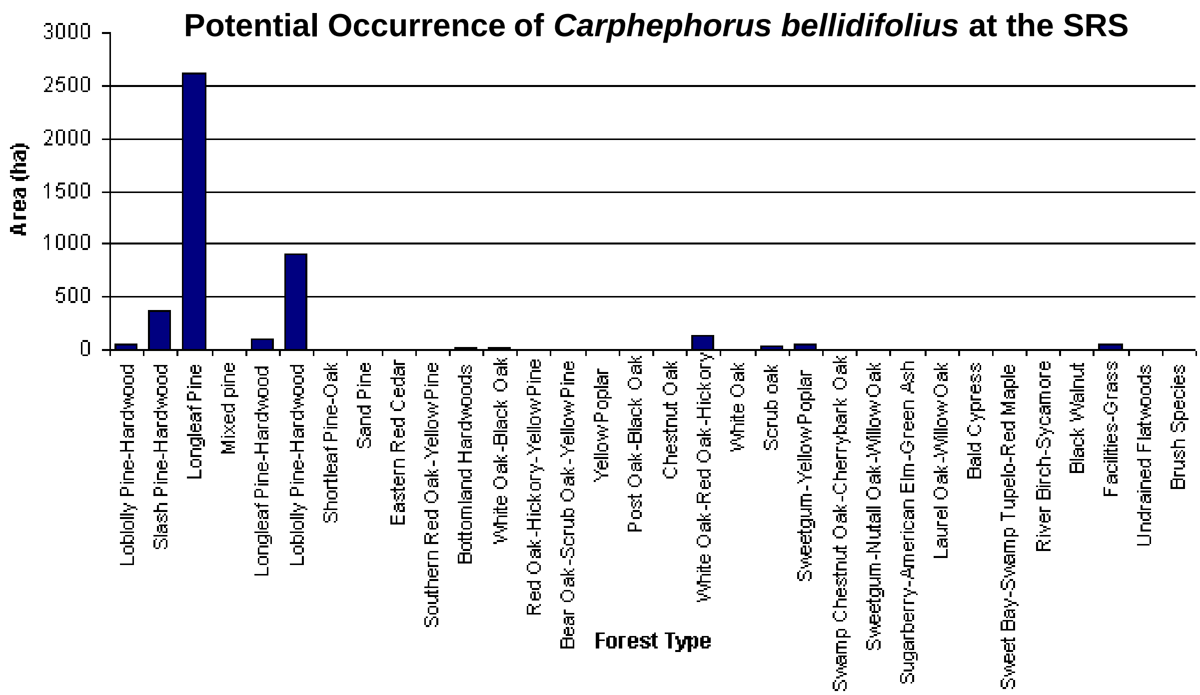
Potential Occurrence of TES Species by Training Area at Fort Gordon

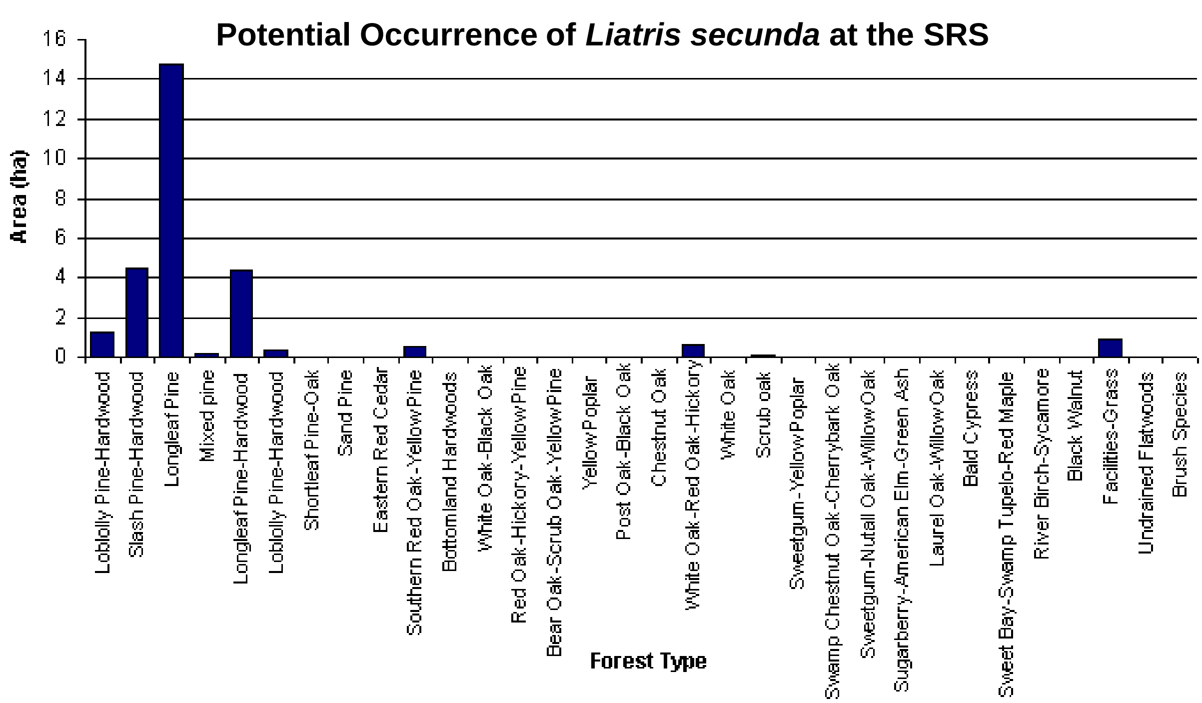


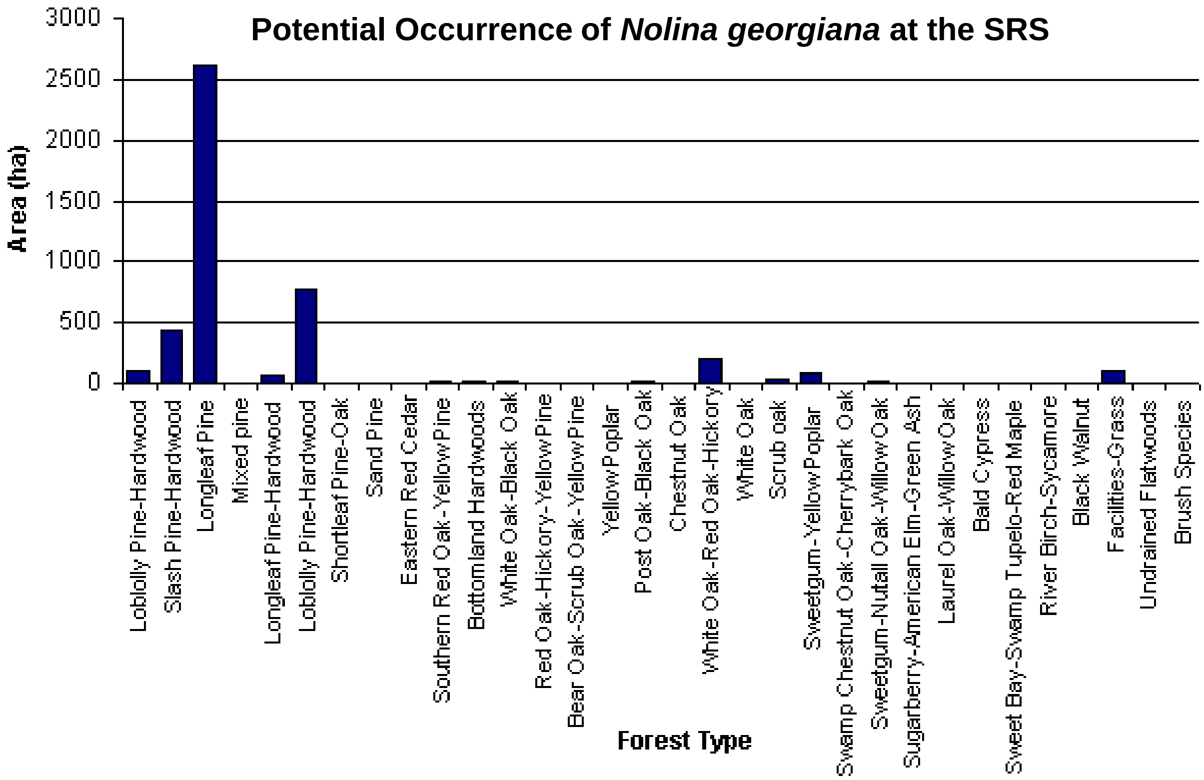

Savannah River Site
Forest Inventory Map
Kilometers
0
3.75
7.5
15
N
Legend
Shortleaf pine-oak
Loblolly pine-hardwoods
Slash pine-hardwoods
Longleaf pine
Slash pine-hardwoods
Mixed pine
Longleaf pine-hardwoods
Loblolly pine/hardwoods
Shortleaf pine-oak
Sand pine
Eastern red cedar
Southern red oak-yellow pine
Bottomland hardwoods
White oak black oak
Red oak-hickory-yellow pine
Bear oak-scrub oak-pine
Yellow poplar
Post oak-black oak
Chestnut oak
Red oak-white oak-hickory
White oak
Yellow poplar
Scrub oak
Sweet gum-yellow poplar
Swamp chesnut oak-cherry bark oak
Sweetgum-nutall oak-willow oak
Sugarberry-American elm-green ash
64Laural oak-water oak
Bald cy press
Sweet bay -swamp tupelo-red maple
River birch-sy camore
Black walnut
Water
facilities-grass
Undrained flatwoods
Brush species

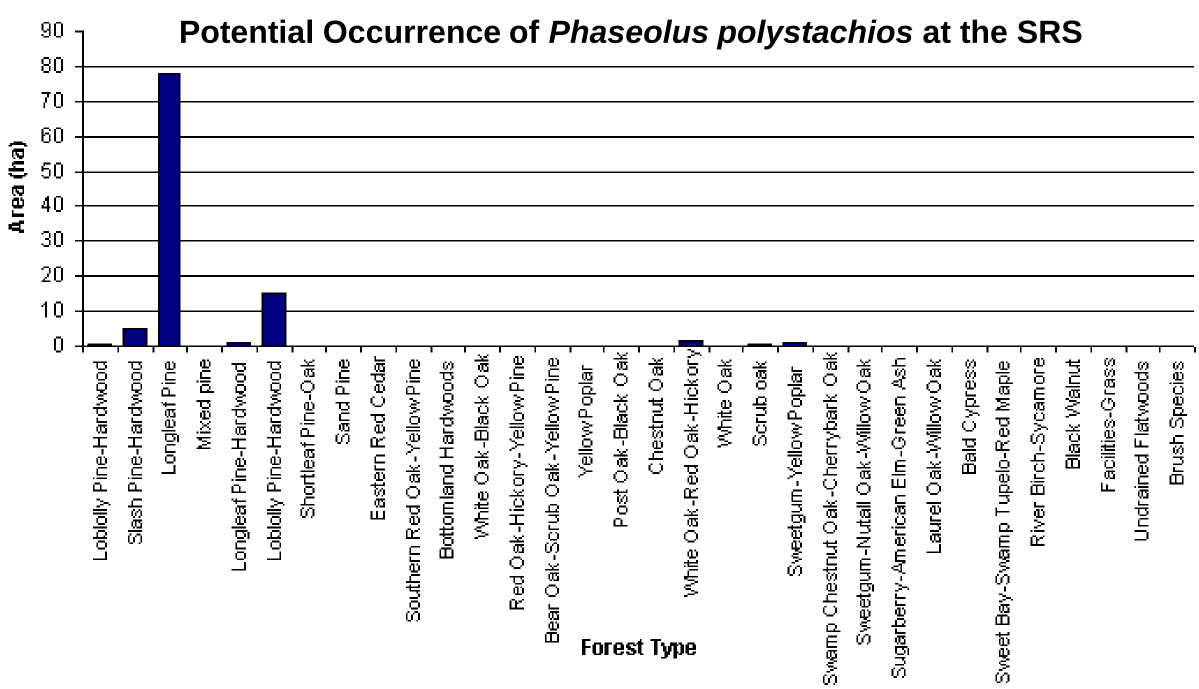

Potential Occurrence of *Astragalus michauxii* at the SRS
Area (ha)
250
200
150
100
50
0
Loblolly Pine-Hardwood
Slash Pine-Hardwood
Longleaf Pine
Mixed pine
Longleaf Pine-Hardwood
Loblolly Pine-Hardwood
Shortleaf Pine-Oak
Sand Pine
Eastern Red Cedar
Southern Red Oak-YellowPine
Bottomland Hardwoods
White Oak-Black Oak
Red Oak-Hickory-YellowPine
Bear Oak-Scrub Oak-YellowPine
YellowPoplar
Post Oak-Black Oak
Chestnut Oak
White Oak-Red Oak-Hickory
White Oak
Scrub oak
Sweetgum-YellowPoplar
Swamp Chestnut Oak-Cherrybark Oak
Sweetgum-Nutall Oak-WillowOak
Sugarberry-American Elm-Green Ash
Laurel Oak-WillowOak
Bald Cypress
Sweet Bay-Swamp Tupelo-Red Maple
River Birch-Sycamore
Black Walnut
Facilities-Grass
Undrained Flatwoods
Brush Species
Forest Type

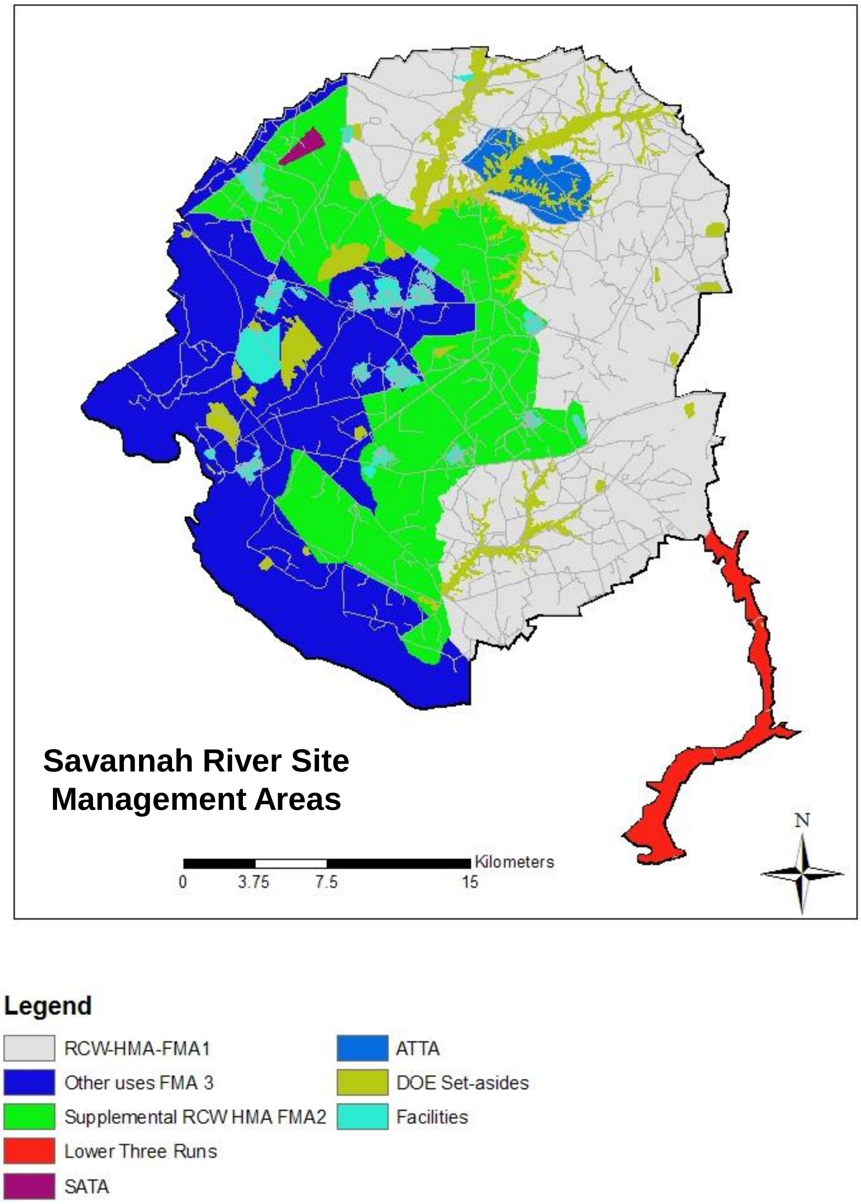

Potential Occurrence of *Baptisia lanceolata* at the SRS
Area (ha)
3000
2500
2000
1500
1000
500
0
Loblolly Pine-Hardwood
Slash Pine-Hardwood
Longleaf Pine
Mixed pine
Longleaf Pine-Hardwood
Loblolly Pine-Hardwood
Shortleaf Pine-Oak
Sand Pine
Eastern Red Cedar
Southern Red Oak-YellowPine
Bottomland Hardwoods
White Oak-Black Oak
Red Oak-Hickory-YellowPine
Bear Oak-Scrub Oak-YellowPine
YellowPoplar
Post Oak-Black Oak
Chestnut Oak
White Oak-Red Oak-Hickory
White Oak
Scrub oak
Sweetgum-YellowPoplar
Swamp Chestnut Oak-Cherrybark Oak
Sweetgum-Nutall Oak-WillowOak
Sugarberry-American Elm-Green Ash
Laurel Oak-WillowOak
Bald Cypress
Sweet Bay-Swamp Tupelo-Red Maple
River Birch-Sycamore
Black Walnut
Facilities-Grass
Undrained Flatwoods
Brush Species
Forest Type


Potential Occurrence of *Carphephorus bellidifolius* at the SRS
Area (ha)
Forest Type
Loblolly Pine-Hardwood
Slash Pine-Hardwood
Longleaf Pine
Mixed pine
Longleaf Pine-Hardwood
Loblolly Pine-Hardwood
Shortleaf Pine-Oak
Sand Pine
Eastern Red Cedar
Southern Red Oak-Yellow Pine
Bottomland Hardwoods
White Oak-Black Oak
Red Oak-Hickory-Yellow Pine
Bear Oak-Scrub Oak-Yellow Pine
Yellow Poplar
Post Oak-Black Oak
Chestnut Oak
White Oak-Red Oak-Hickory
White Oak
Scrub oak
Sweetgum-Yellow Poplar
Swamp Chestnut Oak-Cherrybark Oak
Sweetgum-Nutall Oak-Willow Oak
Sugarberry-American Elm-Green Ash
Laurel Oak-Willow Oak
Bald Cypress
Sweet Bay-Swamp Tupelo-Red Maple
River Birch-Sycamore
Black Walnut
Facilities-Grass
Undrained Flatwoods
Brush Species

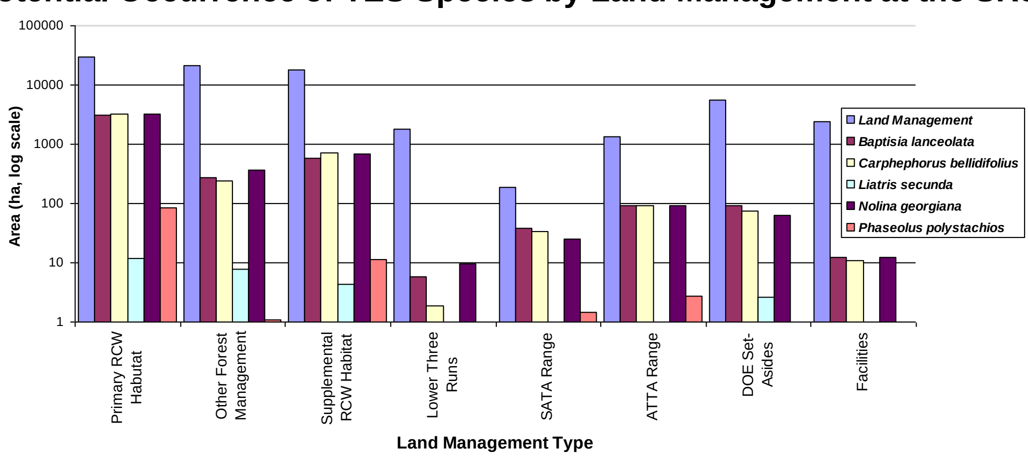

Potential Occurrence of *Liatris secunda* at the SRS
Area (ha)
Forest Type
Loblolly Pine-Hardwood
Slash Pine-Hardwood
Longleaf Pine
Mixed pine
Longleaf Pine-Hardwood
Loblolly Pine-Hardwood
Shortleaf Pine-Oak
Sand Pine
Eastern Red Cedar
Southern Red Oak-Yellow Pine
Bottomland Hardwoods
White Oak-Black Oak
Red Oak-Hickory-Yellow Pine
Bear Oak-Scrub Oak-Yellow Pine
Yellow Poplar
Post Oak-Black Oak
Chestnut Oak
White Oak-Red Oak-Hickory
White Oak
Scrub oak
Sweetgum-Yellow Poplar
Swamp Chestnut Oak-Cherrybark Oak
Sweetgum-Nutall Oak-Willow Oak
Sugarberry-American Elm-Green Ash
Laurel Oak-Willow Oak
Bald Cypress
Sweet Bay-Swamp Tupelo-Red Maple
River Birch-Sycamore
Black Walnut
Facilities-Grass
Undrained Flatwoods
Brush Species


Potential Occurrence of Nolina georgiana at the SRS
Area (ha)
3000
2500
2000
1500
1000
500
0
Loblolly Pine-Hardwood
Slash Pine-Hardwood
Longleaf Pine
Mixed pine
Longleaf Pine-Hardwood
Loblolly Pine-Hardwood
Shortleaf Pine-Oak
Sand Pine
Eastern Red Cedar
Southern Red Oak-YellowPine
Bottomland Hardwoods
White Oak-Black Oak
Red Oak-Hickory-YellowPine
Bear Oak-Scrub Oak-YellowPine
YellowPoplar
Post Oak-Black Oak
Chestnut Oak
White Oak-Red Oak-Hickory
White Oak
Scrub oak
Sweetgum-YellowPoplar
Swamp Chestnut Oak-Cherrybark Oak
Sweetgum-Nutall Oak-WillowOak
Sugarberry-American Elm-Green Ash
Laurel Oak-WillowOak
Bald Cypress
Sweet Bay-Swamp Tupelo-Red Maple
River Birch-Sycamore
Black Walnut
Facilities-Grass
Undrained Flatwoods
Brush Species
Forest Type

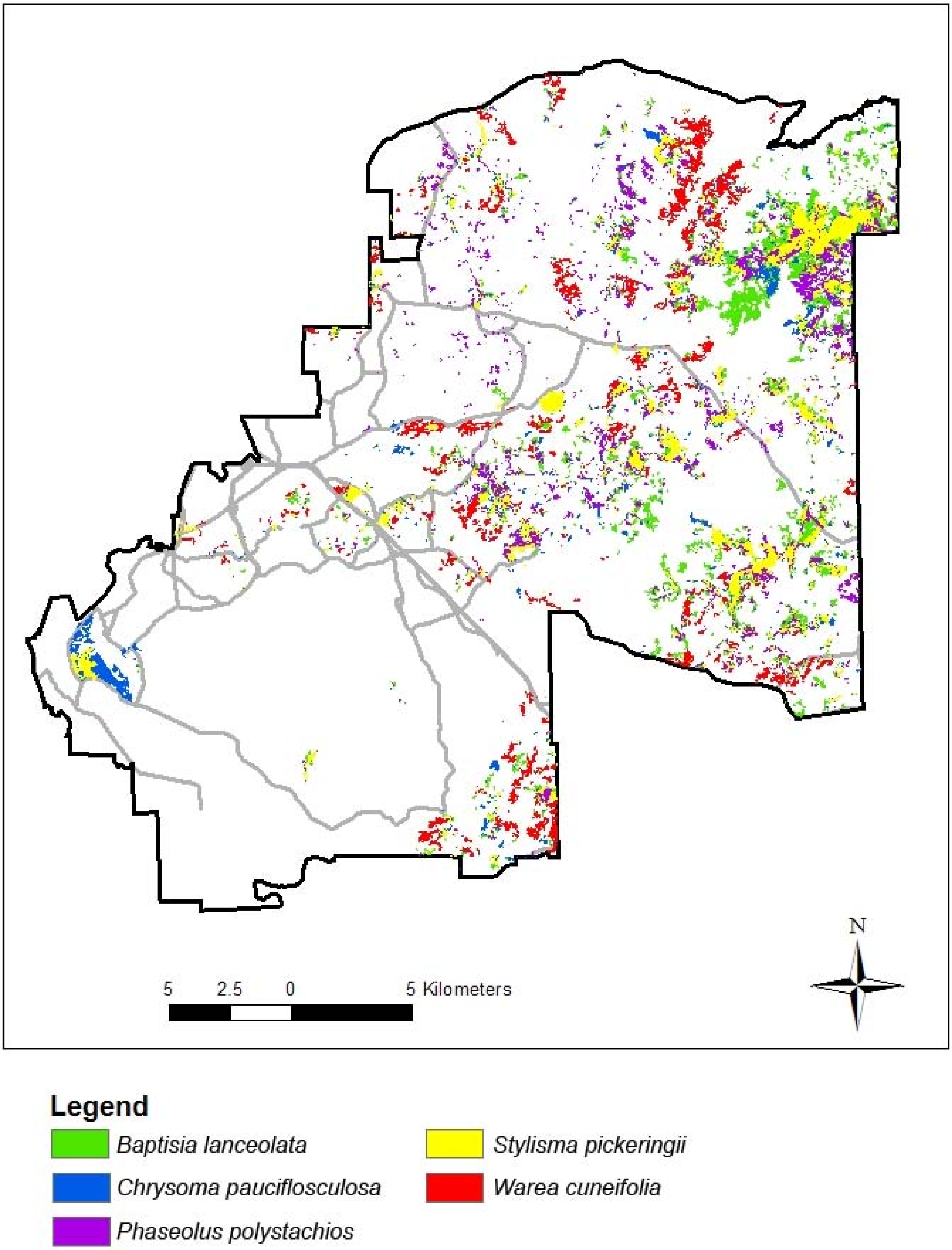

Potential Occurrence of Phaseolus polystachios at the SRS
Area (ha)
90
80
70
60
50
40
30
20
10
0
Loblolly Pine-Hardwood
Slash Pine-Hardwood
Longleaf Pine
Mixed pine
Longleaf Pine-Hardwood
Loblolly Pine-Hardwood
Shortleaf Pine-Oak
Sand Pine
Eastern Red Cedar
Southern Red Oak-YellowPine
Bottomland Hardwoods
White Oak-Black Oak
Red Oak-Hickory-YellowPine
Bear Oak-Scrub Oak-YellowPine
YellowPoplar
Post Oak-Black Oak
Chestnut Oak
White Oak-Red Oak-Hickory
White Oak
Scrub oak
Sweetgum-YellowPoplar
Swamp Chestnut Oak-Cherrybark Oak
Sweetgum-Nutall Oak-WillowOak
Sugarberry-American Elm-Green Ash
Laurel Oak-WillowOak
Bald Cypress
Sweet Bay-Swamp Tupelo-Red Maple
River Birch-Sycamore
Black Walnut
Facilities-Grass
Undrained Flatwoods
Brush Species
Forest Type



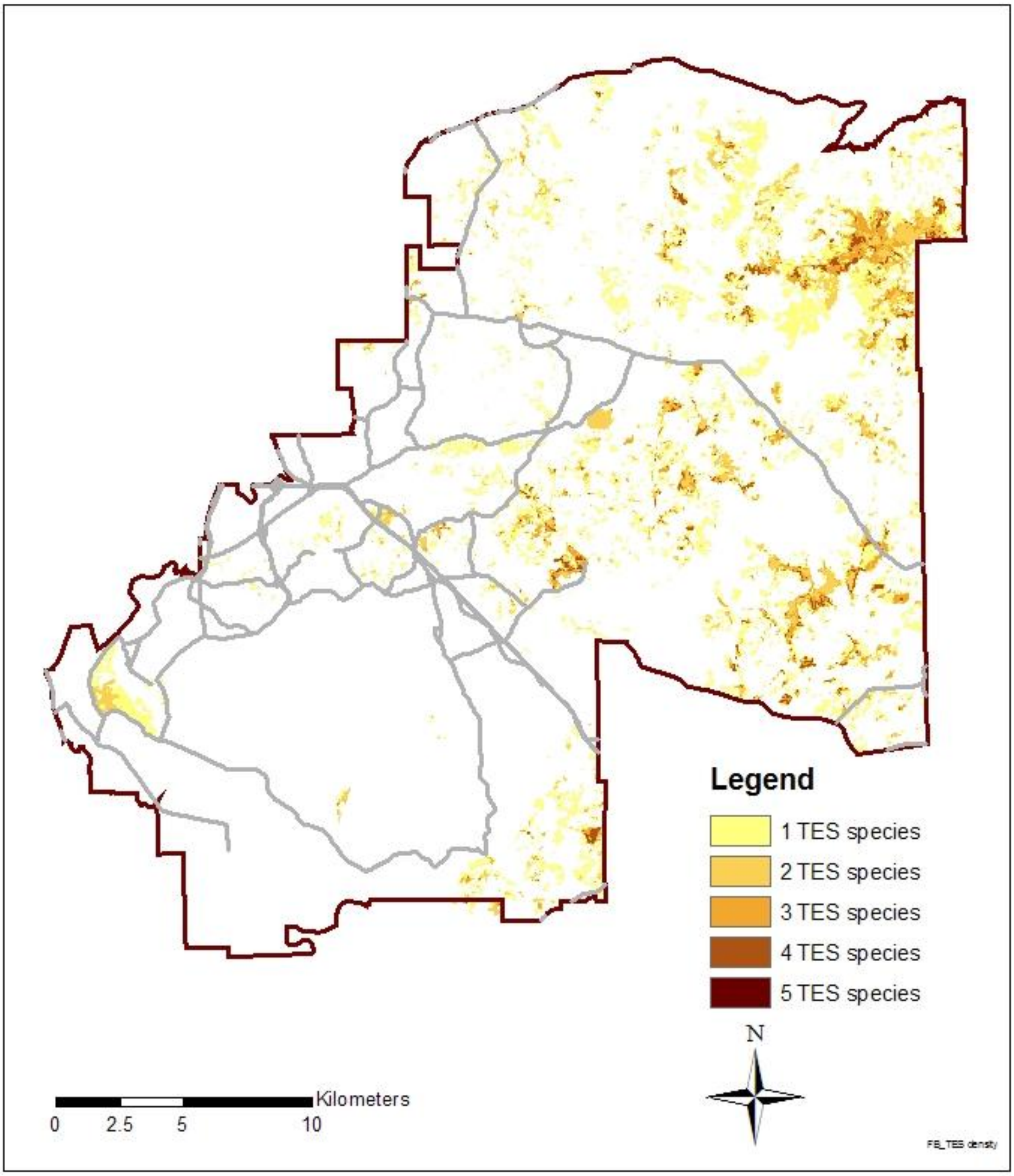
Potential Occurrence of TES Species by Land Management at the SRS

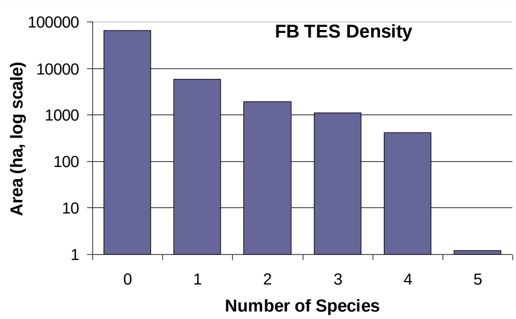


Appendix A.8.5. Composite maps of potential habitat for multiple sandhills plant TES species on Fort Benning, Fort Gordon, and the Savannah River Site, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils associated with known TES population locations.

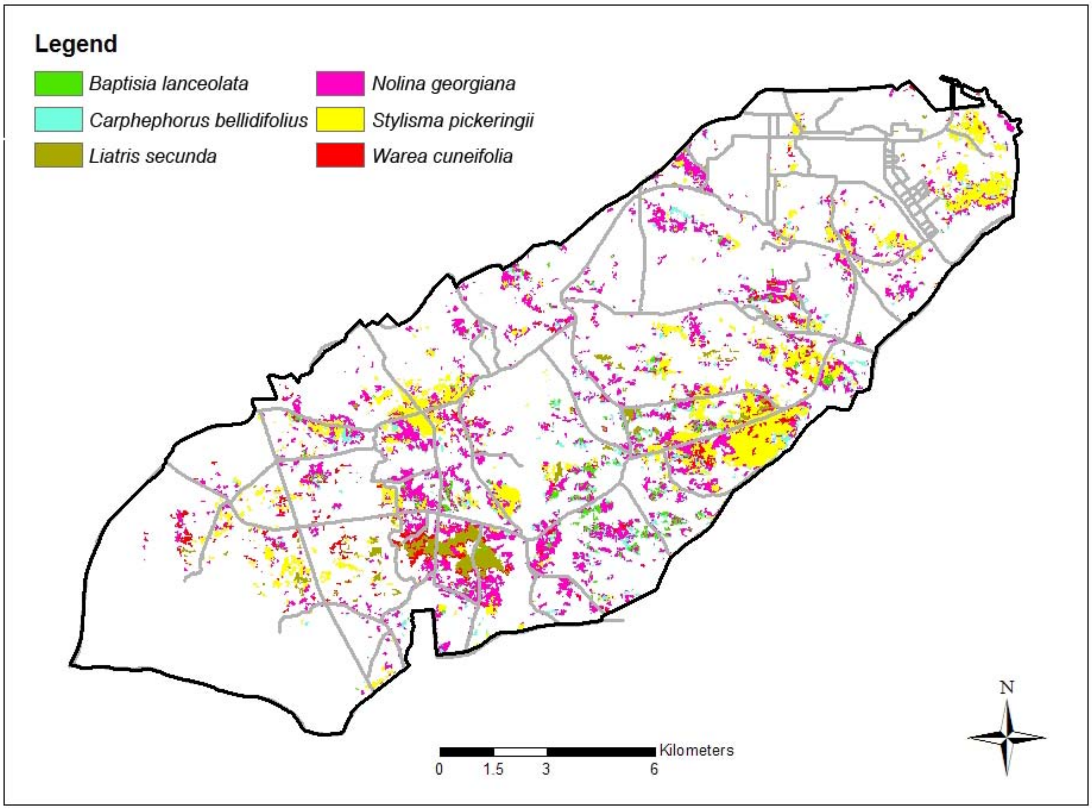


Potential habitat for sandhills plant TES species on Fort Benning, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.

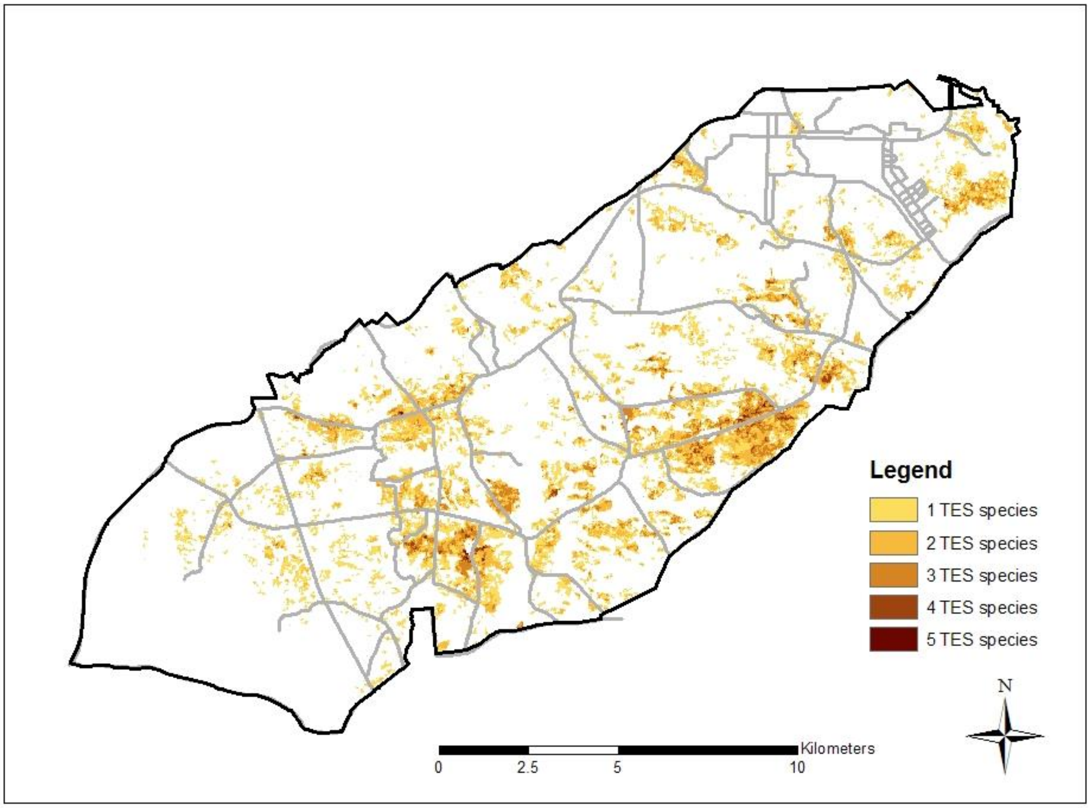


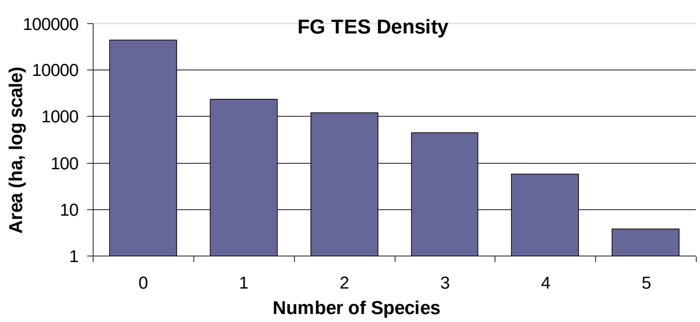


Potential species richness of sandhills TES plants at Fort Benning.

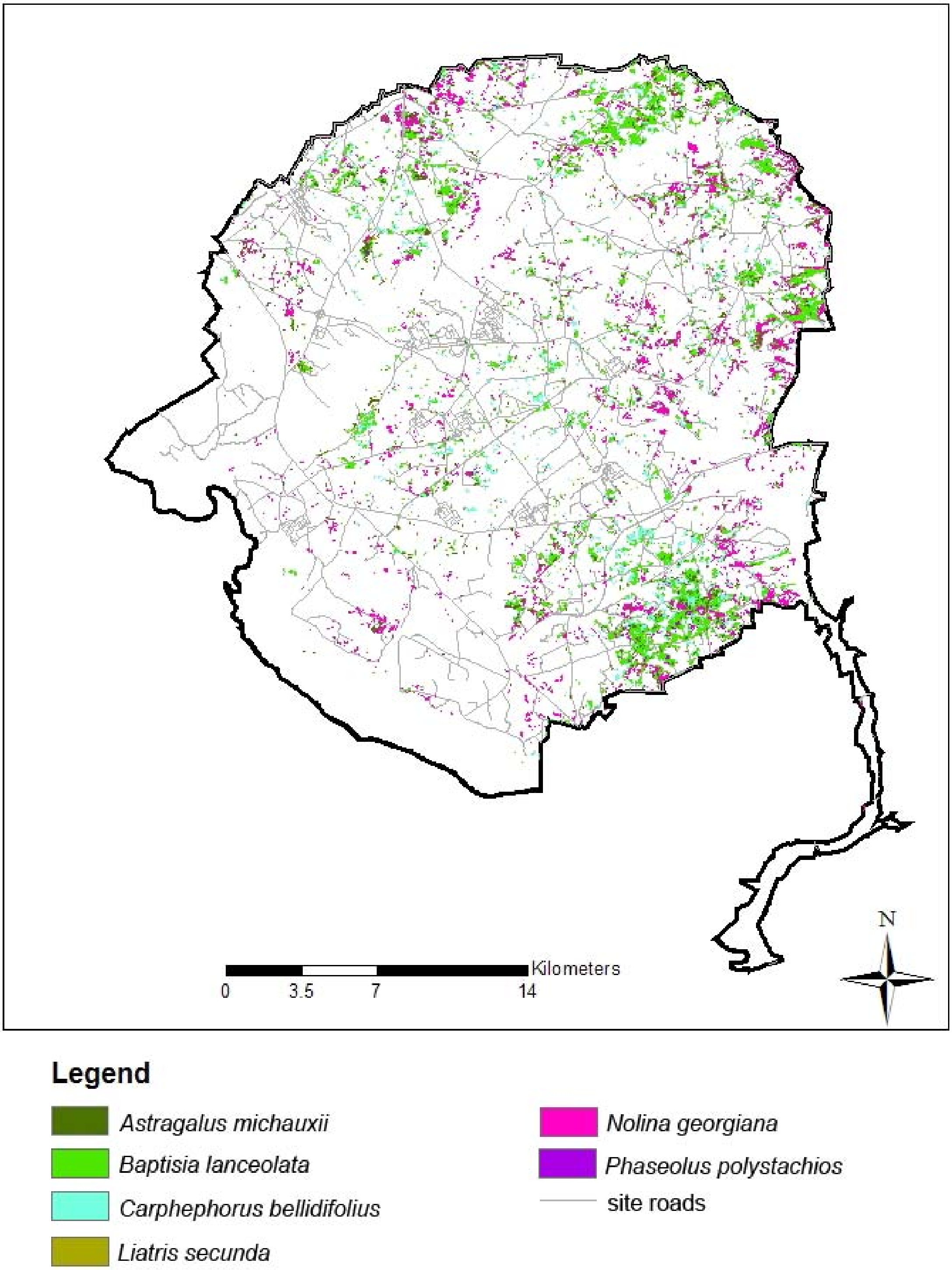


Potential habitat for sandhills plant TES species on Fort Gordon, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Troup and Lakeland) associated with known population locations.

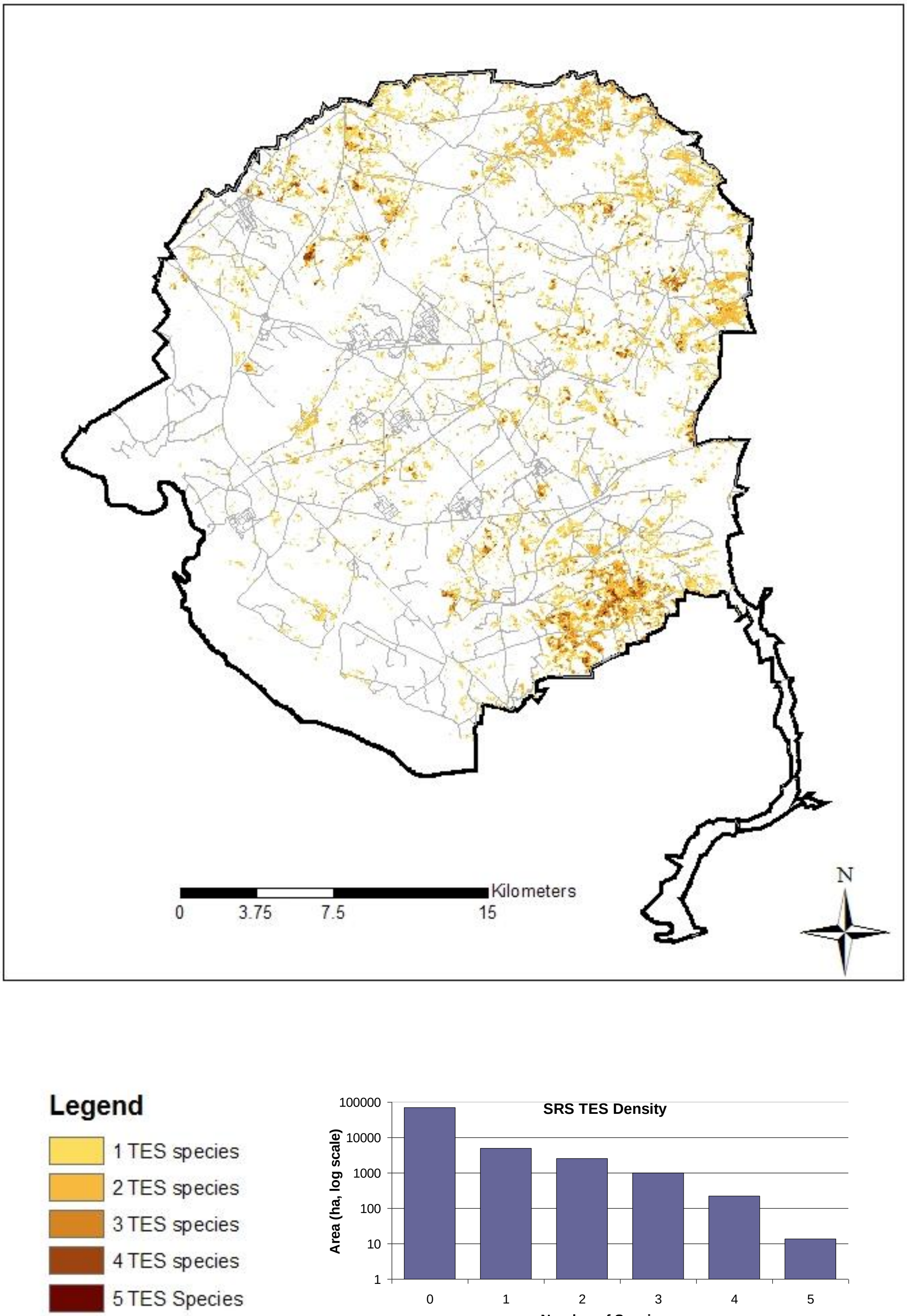




Potential species richness of sandhills TES plants TES at Fort Gordon.



Potential habitat for sandhills plant TES species on the Savannah River Site, as defined from Landsat-7 enhanced thematic mapper plus (ETM+) imagery for two time periods (December 2002 -- leaf off and April 2003 -- leaf on) and soils (Blanton, Vauclause-Ailey, Dothan, and Lakeland) associated with known population locations.



Potential species richness of sandhills TES plants at the Savannah River Site.

9. Appendix B. Technical Publications

Papers Published in Peer-reviewed Journals:

Collins, B., R. Sharitz, K. Madden and J. Dilustro. 2005. Comparison of sandhills and mixed pine hardwood communities at Fort Benning, Georgia. Southeastern Naturalist 5:93-102.

Squire, A. R., S.-M. Chang and R. R. Sharitz. 2007. Reproductive ecology of a federally endangered legume, *Baptisia arachnifera*, and its more widespread congener, *Baptisia lanceolata*. American Journal of Botany 94:228-236.

Tuberville, T. D., E. E. Clark, K. A. Buhlmann and J. W. Gibbons. 2005. Translocation as a conservation tool: site fidelity and movement of repatriated gopher tortoises (*Gopherus polyphemus*). Animal Conservation 8:349-358.

Conference Proceedings:

Harper, S. J. and R. R. Sharitz. 2005. Delineating sandhill communities: The use of advanced techniques to extract features from satellite imagery. Pages 123-136 in Proceedings of the 4th Southern Forestry and Natural Resources GIS Conference. P. Bettinger, et al. (eds.). University of Georgia Warnell School of Forest Resources. Athens, GA.

Balbach, H., R. Sharitz, D. Imm, T. Tuberville and G. Wein. 2007. Strategy for *in situ* conservation of at-risk and declining sandhills species. Proceedings 3rd Global Botanic Gardens Congress, Botanic Gardens Conservation International, Surrey, UK.

Published Technical Abstracts:

Sharitz, R. R., S. Harper, D. Imm, B. Collins, K. Madden, T. Tuberville, J. Dilustro and J. Westervelt. 2002. Impacts of military training and land management on threatened and endangered species in the southeastern Fall Line/Sandhills community. Partners in Environmental Technology Technical Symposium & Workshop. Organized by SERDP and ESTCP, Washington, DC.

Harper, S., K. Madden, R. Sharitz and D. Imm. 2003. Adaptive management of sandhills communities on federal lands in the Fall Line ecoregion. International Association of Landscape Ecology. Banff, Canada.

Madden, K., S. Harper and R. Sharitz. 2003. Comparisons of tree composition, canopy openness, and soil characteristics between and among Fall Line sandhills communities. Southeastern Biology 50:192.

Madden, K., R. Sharitz, D. Imm and S. Harper. 2003. Tree composition and soil characteristics of Fall Line sandhill communities. Ecological Society of America. Savannah, GA.

Harper, S., K. Madden, R. Sharitz and D. Imm. 2003. Adaptive management of sandhill communities on federal lands in the Fall Line ecoregion. Ecological Society of America, Savannah, GA.

Madden, K., R. Sharitz, D. Imm and S. Harper. 2003. Tree composition and soil characteristics of Fall Line sandhill communities. Natural Areas Conference. Madison, WI.

Sharitz, R. R., S. Harper, D. Imm, B. Collins, K. Madden, T. Tuberville, J. Dilustro and J. Westervelt. 2003. Impacts of military training and land management on threatened and endangered species in the southeastern Fall Line/Sandhills community. Partners in Environmental Technology Technical Symposium & Workshop. Organized by SERDP and ESTCP, Washington, DC.

Sharitz, R. R., S. Harper, D. Imm, B. Collins, K. Madden, T. Tuberville, J. Dilustro and J. Westervelt. 2004. Impacts of military training and land management on threatened and endangered species in the southeastern Fall Line/Sandhills community. Partners in Environmental Technology Technical Symposium & Workshop. Organized by SERDP and ESTCP, Washington, DC.

Madden, K., S. Harper and R. Sharitz. 2004. Comparisons of tree composition, canopy openness, and soil characteristics between and among Fall Line sandhill communities. Southeastern Biology. 51:169.

Madden, K, R. Sharitz, and D. Imm. 2004. Comparisons of vegetation and soil composition of select sandhill plant TES populations of three military installations. Society for Conservation Biology. New York, NY.

Harper, S. J. and R. R. Sharitz. 2004. Advances in the identification and delineation of ecological features from aerial photographs and satellite imagery. Ecological Society of America, Portland, OR.

Sharitz, R., S. Harper, D. Imm, K. Madden, B. Collins.2004. Comparisons of vegetation and environmental characteristics of southeastern sandhill TES plant populations. Ecological Society of America. Portland, OR.

Dilustro, J., R. Sharitz, S. Harper, K. Madden, B. Collins and T. Tuberville 2004. Effects of land management and military training activities on Threatened and Endangered species in the southeastern Fall Line sandhills community. Soil Science Society of America. Seattle, WA.

Sharitz, R. R., S. Harper, K. Madden, D. Imm, B. Collins, T. Tuberville, and J. Westervelt. 2005. Land management and military use effects on southeastern Fall Line sandhills communities and associated TES species. Partners in Environmental Technology. SERDP and ESTCP Annual Technical Symposium, Washington, DC.

Tuberville, T. D., J. P. Nestor, S. H. Bennett, K. A. Buhlmann, J. W.Gibbons and R. R. Sharitz. 2005. Effects of forestry practices on movement patterns and space use by gopher tortoises. SERDP Technical Symposium on Threatened, Endangered and At-Risk Species. Washington, DC.

Imm, D. W., S. A. Turner, K. R. Madden, C. Kwit and B. S. Collins. 2005. Successes and pitfalls of applying gradient-based probability models over scales. North American Forest Ecology Workshop. Aylmer, Quebec.

Squire, A. R. and R. R. Sharitz. 2005. Reproductive ecology of federally endangered *Baptisia arachnifera* and its more widespread congener, *Baptisia lanceolata*. International Association for Ecology and Ecological Society of America. Montreal, Quebec.

Madden, K., R. Sharitz, D. Imm and S. Turner. 2005. Comparisons among habitat variables of TES plants of the southeastern Fall-line Sandhills. International Association for Ecology and Ecological Society of America. Montreal, Quebec.

Sharitz, R. R., S. Harper, K. Madden, D. Imm, B. Collins, T. Tuberville, and J. Westervelt. 2005. Land management and military use effects on southeastern Fall Line sandhills communities and associated TES species. Partners in Environmental Technology. SERDP and ESTCP Annual Technical Symposium, Washington, DC.

Stoddard. S. T. 2006. Critical extinction thresholds: The role of dispersal behavior. International Association for Landscape Ecology, San Diego, CA.

Sharitz, R. R., K. Madden and D. Imm. 2006. Habitat characteristics of TES plants of the southeastern Fall Line sandhills region. Southeastern Biology 53: 204.

Imm, D., R. Sharitz, K. Madden and B. Collins. 2006. A predictive habitat-based model for nine rare sandhill plant of the southeastern US. Ecological Society of America. Memphis, TN.

Imm, D.W., R. R. Sharitz, K. Madden, B. Collins, and G. Wein. 2006. Performance of a predictive habitat model for nine southeastern plant species of concern: Integrated effects of military training, land management, and the environment. Partners in Environmental Technology. SERDP and ESTCP Annual Technical Symposium, Washington, DC.

Duval, W. L. and R. R. Sharitz. 2007. Clonal integration and disturbance in a woody shrub. Southeastern Biology 54:201-202.

Sharitz, R. R., H. E. Balbach, G. R. Wein, D. W. Imm and K. R. Madden. 2007. A strategy for conservation of rare plants in the southeastern Fall Line sandhills. Ecological Society of America, San Jose, CA.

Balbach, H., R. Sharitz, D. Imm and T. Tuberville. 2007. Strategy for in-situ conservation of at-risk and declining sandhills species. American Society for Agronomy. New Orleans, LA.

Sharitz, R. R., D. W. Imm, H. E. Balbach, G. R. Wein and K. R. Madden. 2007. A strategy for threatened, endangered and sensitive plant species of the southeastern Fall Line sandhills. Partners in Environmental Technology. SERDP and ESTCP Annual Technical Symposium, Washington, DC.

Sharitz, R. R., D. W. Imm, H. E. Balbach and T. D. Tuberville. 2008. Conservation of threatened, endangered and sensitive plant species on federal lands in the southeastern Fall Line sandhills. Partners in Environmental Technology. SERDP and ESTCP Annual Technical Symposium, Washington, DC.

M.S. Theses or Ph.D. Dissertations:

Squire, A. R. 2005. Reproductive ecology of two Coastal Plain legumes: *Baptisia arachnifera* and *Baptisia lanceolata*. M.S. Thesis, University of Georgia, Athens, GA.

Duval, W. L. 2008. Integration in a clonal woody shrub, *Vaccinium stamineum*. Ph.D. Dissertation, University of Georgia, Athens, GA.

DuRant, J. A. 2008. Reproduction and germination in four rare plants of the southeastern Fall Line sandhills M.S. Thesis, University of Georgia, Athens, GA. (in preparation).