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DEVELOPMENT OF A PREDICTIVE HABITAT EVALUATION MODEL FOR
GAILLARDIA AESTIVALIS (WALT.) ROCK. VAR. WINKLERI (CORY)
TURNER USING GPS, REMOTE SENSING AND GIS TECHNIQUES

by

DASYAM SAMUEL RAJASEKHAR, M.SC., M.Phil.

Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
in Partial Fulfillment
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Master of Science in Forestry

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DEVELOPMENT OF A PREDICTIVE HABITAT EVALUATION MODEL FOR
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ABSTRACT

Geographic Information Systems (GIS), Global Positioning Systems (GPS) and remote sensing techniques were utilized to characterize and subsequently predict potential habitat of *Gaillardia aestivalis* var. *Winkleri*, occurring in Hardin County, TX. Field investigations along with CIR positive aerial photographs were used to study local distribution and ecological requirements (soil, site, plant associations) of the plant. Data were obtained from paper maps, aerial photographs and a Landsat TM image.

Sites occupied by *G. aestivalis* var. *Winkleri* were characterized as having highly acidic soils with poor nutrient content, good drainage and rapid permeability. Along with soil types, vegetation also is an important factor in affecting distribution of the plant. Supervised classification of Landsat TM Image for vegetation classes produced satisfactory results as shown by error matrix. Spatial analysis of coverages were then used to produce potential habitat maps, classified either as favorable or unfavorable. The methodology employed in this study should be useful in conservation of *G. aestivalis* var. *Winkleri*, as well as other rare plant species.
ACKNOWLEDGMENTS

I am thankful to Dr. James C. Kroll for his invaluable guidance which helped me to successfully complete this work. I am indebted to him for his concern and thoughtfulness in introducing me to GIS and Remote Sensing field. I would also like to thank my committee members Drs. Victor S. Whitehead, David Creech and E. D. McCune. My heartfelt thanks are due to Dr. Whitehead for his patient guidance in Remote Sensing skills. On many an occasion, Mr. Kindness Israel solved unexpected systems problems allowing me to complete my GIS analysis. I owe my GPS knowledge to Mr. David Tracy.

I am very much thankful to Mr. Benjamin H. Koerth for his suggestions and editorial help on many occasions. I am also thankful to my fellow graduate students, especially Ms. Pei-yu Chin and all the staff members of the Institute for White-tailed Deer Management and Research. I would like to acknowledge with gratitude the staff and faculty of Arthur Temple College of Forestry who have rendered their help.

Special thanks go to staff of the Nature Conservancy, Silsbee, TX for allowing me to use their property and the facilities. I am thankful for Jason R. Singhurst of Texas Parks and Wildlife Department for suggesting this project, and to TX-GAP for providing 1991 Landsat data. Finally, I
would like to acknowledge with gratitude Temple-Inland Inc. for the use of their property and for their support.
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INTRODUCTION

The White firewheel (*Gaillardia aestivalis* (Walt.) Rock. var. *Winkleri*) belongs to the family Asteraceae. This rare plant occurs only in Hardin County, TX; and is ranked G5 S1 C2 by the Texas Parks and Wildlife Department (TP&WD 1995). Most of Hardin County lies within the Big Thicket (MacLeod 1972), a region noted for its high biological diversity. Although the population status is considered to be stable, it obviously is a rare species. The White firewheel is a variety currently classified by the U. S. Fish and Wildlife Service as a federal candidate (Category 2) for review and possible listing as endangered or threatened.

The species (Fig. 1) is a perennial, white flowered variety (Turner 1979). Sites favored by the plant have been characterized (Singhurst 1996) as having deep, loose sands in openings or less shaded regions of Bluejack oak (*Quercus incana*) and Pine-oak woodlands. The White firewheel occurs mostly within the Village Creek watershed; typically oak-farkelberry sandy lands with deep deposits of whitish sands (Ajilvsgi 1979).

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1 This Thesis conforms to the style recommended in Forest Science.
Figure 1. *G. aestivalis* var. *Winkleri*, White Firewheel
Singhurst (1996) surveyed 13 Hardin County populations of *G. aestivalis* var. *Winkleri*, recording coordinate location data for entry into Biological Conservation Database (BCD) of Texas Natural Heritage Program (TNHP; Austin, TX).

The restricted distribution of this rare plant species, and its apparent unique requirements, offer an excellent opportunity to study applications of Geographic Information Systems (GIS) in assessing habitat requirements and identification of potential relocation sites for threatened or endangered plant species. Geographic Information Systems have proved useful in identifying factors limiting plant distribution. GIS is defined as a system for capturing, storing, checking, manipulating, analyzing and displaying data spatially referenced to the Earth (Maguire 1992).

My study focused on 13 identified populations of *G. aestivalis* var. *Winkleri*; with special emphasis on those occurring on The Nature Conservancy's Roy E. Larsen Sandylands Nature Preserve and easements belonging to Temple-Inland Incorporated. The objectives of this study were:

1) to determine the habitat and site requirements of *G. aestivalis* var. *Winkleri* using data obtained by direct and remotely sensed measurements;

2) to construct a potential habitat suitability model using GIS analysis for this species; and,

3) to locate suitable areas for possible introduction sites.
LITERATURE REVIEW

Taxonomic Status

Gaillardia aestivalis var. Winkleri belongs to family Asteraceae. The plant is a misunderstood species with vague details of taxonomy (Singhurst 1996). Rock (1956) showed that G. lutea is synonymous with G. aestivalis. G. aestivalis var. Winkleri is perhaps closest to Gaillardia aestivalis var. flavovirens (C. Mohr) cronq. a taxon of eastern Texas and adjacent states (Turner 1979). Turner (1979) surmised G. aestivalis var. flavovirens in Texas arose from a rhizomatous tetraploid stock of G. aestivalis var. aestivalis. This in turn gave rise to G. aestivalis var. Winkleri; essentially an albino population of G. aestivalis var. flavovirens which has undergone some habitat selection and presumably local, if not regional, isolation.

Geographic Distribution and Habitat

G. aestivalis var. Winkleri occurs in Hardin County, TX. Singhurst (1996) described in detail the coordinate location of 20 populations of the plant. He located 12 new sites and obtained the coordinate data for entry into BCD.
Little information is known about the habitat structure, current distribution and range, potential range, primary threats, management requirements, and restoration potential (Singhurst 1996). Information on pollinators, seed dispersal, and germination requirements currently is being prepared by Tom Watson (University of Texas Herbarium monograph, Austin, TX) is in press.

GIS Applications

Tomlinson (1988) possibly created the first true GIS. Environmental Systems Research Institute (ESRI) launched ARC/INFO in 1982 (Rhind 1992). An accurate base map is the foundation upon which most GIS are built. Utilizing GPS control for a survey is a better technique for non-topographic mapping (Boston 1990). GPS is based on NAVSTAR (code name for satellite constellation on which the GPS is based) established by the U. S. Defense Department. GIS users are incorporating GPS into the data collection phase of their projects in increasing numbers (Kevany 1994).

Global Positioning Systems (GPS) technology, developed by the Department of Defense, enable accurate documentation of Cartesian coordinates anywhere on the earth's surface. Positions and boundaries can be located with 10-m or better accuracy while GPS receiver is continuously moving, and with 2-m or better accuracy with brief stops for repeated
sampling. Algorithms calculate geometric dilution of precision (GDOP), position dilution of precision (PDOP), horizontal dilution of precision (HDOP), and vertical dilution of precision (VDOP), and enable GIS to predict when errors will occur (Lass and Callihan 1993).

GPS surveys were used to accurately obtain state plane coordinate data for Wichita, KS Water and Sewer Department and transferred electronically into autoCAD (Pinkston and Graham 1995). Accuracy and precision of a simple GPS receiver and community base station system were estimated in a study conducted by August et al. (1994). Field data were collected with a three channel Trimble Pathfinder™ Basic portable receiver. PDOP was set at 4.0. Data used in differential correction were obtained from a Trimble Community Base Station system located at the Environmental Data Center, University of Rhode Island. Results indicated a relatively inexpensive three-channel GPS receiver, coupled with the capability to apply differential collection of field data, can produce accurate and precise locational data at medium scales of resolution (August et al. 1994). They found accuracy of differentially corrected GPS locations were within 6 m of true.

The Department of Defense (DOD) degrades accuracy of the GPS receiver's automatically calculated position fix by corrupting the satellites timing signals and data. This is called selective availability (SA). When SA is activated,
position fixes will be within 100 m (horizontal) of truth 95% of the time (Lange 1992). From data emitted by GPS satellites, receivers are able to calculate either two-dimensional (latitude and longitude) or three dimensional positions (latitude, longitude and altitude). There are two types of GPS receivers: navigation grade and the survey grade. To geo-reference a satellite image, a number of cultural features such as intersection of two roads should be identified on the image. Coordinates for these points should be collected with the GPS units and data exported to the image processing program (Lange 1992). Scanned color infrared aerial photographs were used for mapping forest tundra ecotones in Rocky Mountain National Park, CO (Baker et al. 1995). Ortho rectification was performed to make photographs nearly planimetric. They recommended use of GPS technology to reduce errors.

Welch et al. (1992) marked each GPS point with a metal stake and a 4 by 8 ft. sheet of plywood centered over the stake prior to each photographic flight. This made GPS points visible on the aerial photographs. Aerial photographs subsequently were scanned at 300 dots per inch (DPI) and rectified to GPS points and mosaicked together. GIS registration of data layers and overlay operations documented trends in land-use/land cover over time and supported the projection of future conditions of the Sapelo Island National Estuarine Research Reserve (Welch et al. 1992).
In one study (Morad et al. 1994) an aerial photograph was overlaid onto a calibrated digital cadaster using ARC/INFO software, to evaluate geometric integrity of image rectification. The study concluded no apparent improvement in image transformation quality was achieved as a result of reducing the root mean square error (RMS). Baker et al. (1995) scanned 31 color infrared photographs (CIR) and orthorectified them using the GRASS `i.ortho.rectify` program. This program effectively removes radial, tilt and relief distortion inherent in aerial photographs (Bolstad 1992).

MacKay-Shea mapped vegetation into 14 land cover classes for Woodside, CA 7.5' USGS quadrangle map and integrated Remote sensing/GIS methodology (1994). Gap analysis was used for this vegetation mapping.

Topographic features in a USGS digital elevation model (DEM) include slope, aspect and elevation. The USGS DEMs have a resolution of 30 m x 30 m. Garbrecht and Starks (1995) illustrated limitations and systematic errors in DEMs. They selected Lay County in south-central Nebraska to investigate the characteristics of depression wetlands and their contributing drainage areas. Isaacson and Ripple (1990) compared two DEMs for the Echo Mountain SE quadrangle in the Cascade Mountains of Oregon. Visual and statistical comparisons were made between 7.5 minute and 1-degree images using the variables elevation, slope, aspect and slope gradient. Stowe and Bolstad (1994) evaluated USGS and SPOT
DEM's for Blacksburg, VA. Sharper, finer-scaled topographic features were visible on the USGS DEM. Manipulation of DEM data by smoothing and filtering operations is not recommended because of the resultant degradation of data (Garbrecht and Starks 1995).

Remote Sensing Studies

Vegetation classification and mapping is best accomplished for large areas using remotely sensed data. The Land Satellite (Landsat) was designed in the 1960’s and launched in 1972 for broad scale observation of earth’s land areas (Campbell 1987). Later Landsat versions carried a Thematic Mapper (TM), recording seven spectral bands with a spatial resolution of 30 m x 30 m (Campbell 1987). Landsat TM scenes were used extensively for classification of forests and habitat studies.

Suitable spectral bands in Landsat TM image can be combined and transformed by subjecting data to Principal Component Analysis (PCA) (ERDAS 1992). Typically, for any pixel in a multispectral original image, brightness values or Digital Numbers (DN) are highly correlated from band to band, so there is much redundancy in the data set. PCA is used to compress multichannel image data by calculating a new coordinate system, so as to convert scene variance in the original data into a new set of variables, called principal
components (PC). Most image variance is confined within the first few channels (Qari 1991). Qari (1991) applied PCA on the six non-thermal bands (7,5,4,3,2, and 1) of Landsat TM data for the Al-Khabt (Saudi Arabia) test area. Visual inspections of PC color composites indicated the composite containing the first three PCs was the most informative.

GIS Mapping

In a study conducted by White et al. (1995), genus level mapping of mixed coniferous forest was achieved at 73 percent accuracy using an unsupervised classification of Landsat TM data. The same study also demonstrated spectral based, genus level maps can be modified with terrain data in a GIS to produce forest species maps at 58% accuracy.

In a study conducted by Franklin (1994), three digital images from Compact Airborne Spectrographic Imager (CASI) and the SPOT Panchromatic Linear Array (PLA) and Landsat TM sensors were compared and used to discriminate mixed and pure forest stand types in the subalpine region of Alberta, Canada. A DEM was used to increase classification accuracy. Wolter et al. (1995) developed forest cover classification Landsat TM data from early summer, in conjunction with four multi spectral scanner (MSS) data to capture phenological changes of various tree species. The Land Cover Map of Great
Britain was produced using supervised maximum-likelihood classification of Landsat TM data (Jones et al. 1994).

Cleynenbreugel (1990) used GIS for road extraction from high resolution satellite imagery (SPOT image). Marsh and Lee (1995) used multitemporal satellite data (MSS) to study the changing vegetation condition at Tanque Verde riparian area in Tucson, AZ. Maps depicting the nature and spatial extent of changing vegetation patterns were produced. Jensen et al. (1993) analyzed multiple date SPOT panchromatic data using digital image processing techniques to inventory spatial distribution of cattail and waterlilly beds in a freshwater reservoir located on the Savannah River Site in South Carolina. They created a land versus water mask from an 8-bit file using "on-screen" digitization. Jensen et al. (1995) inventoried the cattail and sawgrass distribution using historical remotely sensed data to document changes within the Florida Everglades Water Conservation Area 2A. They used Landsat MSS data (1976 and 1982) and SPOT HRV multispectral data (1987 and 1991) in their study.

Chavez et al. (1991) used Hue-Intensity-Saturation (HIS), PCA and High-Pass Filter (HPF) procedures to merge information contents of Landsat TM and SPOT data. Spectral characteristics in the data sets generated using three methods were compared with the spectral characters of the original TM data. Narayanan et al. (1992) measured active mid-infrared laser reflectance characteristics of 18
different bench-mark soil samples at various angles of incidence and wavelengths. Measurements indicated these soils had unique reflectance signatures in the 9- to 11-μm mid-infrared region. Burley and Brown (1995) applied PCA across 15 suitability overlays representing diverse landscape requirements to search for simplified explanations indicating the latent landscape structure.

GIS Habitat Modeling Studies


Destramppe (1995) tested a predictive model using GIS in a case study area of northwestern Jefferson County, WS. The predictiveness of each individual variable and combinations of variables were investigated through querying a GIS database. Application of a digital image classification strategy improved accuracy of natural grassland identification, compared to standard aerial photography and aerial survey methods. Training sites were used statistically in the hierarchical classification to develop quantitative spectral signatures to identify potential high
quality sites. If the location of few exemplary sites are known, hierarchical classification can be applied to large study areas to rapidly develop maps of sites with high natural area potential (Lauver 1993).

Herr and Queen (1993) developed a descriptive GIS model to identify potential nesting habitat of greater sandhill cranes (*Grus canadensis tabida*) in northwestern Minnesota. GIS technology, along with digital mapping of plant communities derived from satellite data, provided the means for characterizing potential nesting habitat according to landscape features. Roseberry et al. (1994) investigated spatial relationships of Conservation Reserve Program (CRP) fields to other land-use types using GIS software. In their study a digitized land-cover image and a data file were created using a combination of field mapping, visual interpretation of high altitude CIR photography and supervised classification of Landsat 5 TM scene. Computer simulation and habitat modeling were used to evaluate northern bobwhite (*Colinus virginianus*) habitat quality with and without CRP land (Roseberry et al. 1994). By combining a spatially explicit, individual-based population simulation model with a GIS, Liu et al. (1994) simulated potential effects of a U. S. Forest Service management plan on the population dynamics of Bachman’s Sparrow (*Aimophila aestivalis*) at the Savannah River Site, SC.
Westmoreland and Stow (1992) updated a portion of the land-use layer in a regional scale GIS using automated methods of image interpretation and classification. To structure visual interpretation of land use categories, an interactive program was written using ARC/INFO's Arc Macro Language (AML). Multiple map layers are required in GIS for flexibility in data modeling and efficient processing of data (Westmoreland and Stow 1992).
PROCEDURES

Study Area

The study was conducted at the Roy E. Larsen Sandylands Nature Preserve (= Sandylands Preserve) managed by the Nature Conservancy located in Hardin Co., TX (Fig. 2), on locations where Gaillardia aestivalis var. Winkleri were known to occur. Additional study sites were located at four cardinal directions for lands managed by the Nature conservancy under an easement agreement with Temple-Inland Inc. (T-I), a privately owned forest products company. The study area falls within the Village Creek watershed. Fig. 3 presents GIS coverage of the study area showing features such as roads, streams, etc. The preserve is characterized by diverse habitats, including baygall swamps, sloughs and bottom land hardwoods in lower elevations and well drained sand hills with pine/oak forest in uplands (Fig. 4). The climate is hot and humid in summer and cool and moist in winter. Mean annual precipitation is 122 to 142 cm (48 to 56 in.). Mean annual temperature ranges 19.4 °C to 20.55 °C (67 °F to 69 °F) (Weidenfeld 1996). The area was extensively planted with slash pine. The Nature Conservancy initiated a longleaf restoration program in 1978, by artificial planting.
Figure 2. Location of Study Area

- Texas Counties
- Hardin County
- Study Area
  - T-I Easement
  - Sandylands Preserve
  - FM 418
  - SH 327

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Stephen F. Austin State University
Figure 3. Study Area Boundary & Water Bodies

Projection: State Plane
Datum: Nad 83
Zone: 4203 (Texas Central)
Source: GPS Data
NAPP CIR Positive Aerial Photographs (2-5-95)

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Figure 4. Habitats in Study Area

Baygall

Mixed Hardwood-Pine

Bluejack Oak-Pine

Pine Sandhill
Soils and Topography

Soil formations of the study area (Fig. 5) are of three types: Alluvium, Fluviatile terrace deposits and Lissie formation (Barnes et al. 1992). The Alluvium containing clay, silt, sand and organic matter was formed during the Holocene. Fluviatile terrace deposits were formed during the Pleistocene, and contain gravel, sand and silt deposits. Lissie formations are Pleistocene in origin and comprised of clay, silt, sand and minor amounts of siliceous gravel the size of pebbles.

Soils range from fine sand to loamy sands and are excessively to poorly drained in flood plains (Weidenfeld 1996). Hardin County was mapped into 10 general soil categories as seen on USDA NRCS General Soil Map (1991). Fig. 6 is the GIS coverage of general soil units of Hardin Co. Currently the study area contains 11 described and three tentatively described soil series (Weidenfeld 1996). Each of these are described below. Physical properties of each are presented in Table 1, with characteristics specific to the A horizon given in Table 2.

The Besner Series consists of well drained, moderately permeable soils formed in alluvial sediments. Slopes range from 0-5%.
Figure 5. Soil Series of Study Area

Projection: State Plane
Datum: NAD 83
Zone: 4203 (Texas Central)
Source: GPS Data
Soil Map, USDA NRCS Staff (Kountze)

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Figure 6. General Soil Units of Hardin County

Soil Units
- Aris-Aldine-Anahuac
- Bienville-Besner-Molliville
- Estes
- Kirbyville-Otanya-Waller
- Mantachie Owentown
- Otanya-Kirbyville
- Otanya-Kirbyville-Evadale
- Sorter-Dallardsville
- Vamont-Beaumont
- Waller-Kirbyville

Projection: Stateplane
Datum: NAD 83
Zone: 4203 (Texas Central)
Source: USDA NRC9 General Soil Map

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<td>rapid</td>
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<tr>
<td>Betis</td>
<td>thermic Psammentic paleudults</td>
<td>excessive</td>
<td>rapid</td>
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<tr>
<td>Bibb</td>
<td>thermic Typic Fluvaquents</td>
<td>poor</td>
<td>moderate</td>
</tr>
<tr>
<td>Olive</td>
<td>thermic Umbric Fragiaquults</td>
<td>poor</td>
<td>very slow</td>
</tr>
<tr>
<td>Kimble</td>
<td>thermic Aquic Fragiudults</td>
<td>good</td>
<td>slow</td>
</tr>
<tr>
<td>Dallardsville</td>
<td>thermic Aquic Paleudults</td>
<td>poor</td>
<td>slow</td>
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<tr>
<td>Crevasse Series</td>
<td>sand</td>
<td>single grain</td>
<td>loose</td>
</tr>
<tr>
<td>Betis Series</td>
<td>loamy fine sand</td>
<td>fine granular</td>
<td>soft &amp; very friable</td>
</tr>
<tr>
<td>Bibb Series</td>
<td>sandy loam</td>
<td>fine granular</td>
<td>friable</td>
</tr>
<tr>
<td>Olive Series</td>
<td>silt loam</td>
<td>fine &amp; medium granular</td>
<td>slightly hard &amp; friable</td>
</tr>
<tr>
<td>Kimble Series</td>
<td>fine sandy loam</td>
<td>medium sub angular blocky</td>
<td>slightly hard &amp; very friable</td>
</tr>
<tr>
<td>Dallardsville Series</td>
<td>very fine sand</td>
<td>fine granular</td>
<td>soft &amp; very friable</td>
</tr>
<tr>
<td>Bienville Series</td>
<td>loamy fine sand</td>
<td>fine granular</td>
<td>very friable</td>
</tr>
<tr>
<td>Otanya Series</td>
<td>fine sandy loam</td>
<td>medium granular</td>
<td>soft &amp; very friable</td>
</tr>
<tr>
<td>Tyden Series</td>
<td>silt loam</td>
<td>weak platy</td>
<td>decomposed leaf litter</td>
</tr>
<tr>
<td>Molville Series</td>
<td>loam</td>
<td>medium granular</td>
<td>slightly hard &amp; friable</td>
</tr>
<tr>
<td>Gallime Series</td>
<td>fine sandy loam</td>
<td>medium sub angular blocky</td>
<td>soft &amp; very friable</td>
</tr>
<tr>
<td>Tonkawa Series</td>
<td>fine sand</td>
<td>fine granular</td>
<td>soft &amp; very friable</td>
</tr>
<tr>
<td>Besner Series</td>
<td>fine sandy loam</td>
<td>medium granular</td>
<td>slightly hard &amp; very friable</td>
</tr>
<tr>
<td>Manco Series</td>
<td>silt loam</td>
<td>fine sub angular blocky</td>
<td>slightly hard &amp; friable</td>
</tr>
</tbody>
</table>
The Betis Series consists of somewhat excessively drained, rapidly permeable soils formed in thick sandy deposits of marine sediments. Slopes range from 0-12%.

The Tyden Series (tentative series) consists of very poorly drained, slowly permeable soils formed in sandy and loamy sediments on nearly level terraces of rivers and streams. Slopes range from 0-1%.

The Bibb Series consists of poorly drained, moderately permeable soils formed in stratified loamy and sandy alluvium. Slopes range from 0-2%.

The Crevasse Series consists of excessively drained, rapidly permeable soils formed in sandy alluvium. Slopes range from 0-5%.

The Olive Series (tentative series) consists of very poorly drained, very slowly permeable soils formed in loamy and sandy sediments in low depressional areas. Slopes range from 0-1%.

The Kimble Series consists of moderately well drained, slowly permeable soils formed in loamy sediments nearly level uplands. Slopes range from 0-1%.

The Dallardsville Series consists of poorly drained, moderately slowly permeable soils formed in thick loamy sediments on marine terraces. Slopes range from 0-3%.
The Bienville Series consists of excessively drained, moderately rapidly permeable soils formed in sandy coastal sediment. Slopes range from 0-5%.

The Otanya Series consists of moderately well drained, slowly permeable soils formed in thick beds of unconsolidated loamy coastal plain sediments. Slopes range from 0-5%.

The Molville Series consists of poorly drained, slowly permeable soils formed in thick stratified sandy and loamy sediments. Slopes range from 0-1%.

This Gallime Series consists of well drained, moderately permeable soils formed in loamy acid alluvial sediments. Slopes range from 1-5%.

The Tonkawa Series consists of excessively drained, rapidly permeable sandy upland soils. Slopes range from 0-35%.

The Manco Series (tentative series) consists of poorly drained, moderately permeable soils formed in loamy alluvial sediments. Slopes range from 0-1%.

History

Periodic natural fires were widespread over the entire area. Native Americans and early settlers continued the practice for hunting and grazing purposes. Natural communities changed significantly due to logging from 1850-60 (Gunter 1993) and later due to fire suppression from 1915
(Cozine 1976). Fire intolerant species (e.g., Ilex vomitoria, Q. incana, etc.) subsequently were established. Increased light reaching the forest floor, plus fire suppression, resulted in a dense shrub understory. Fire resistant species such as longleaf pine were suppressed due to competition from fire intolerant species. Slash pine (a non-native species) was introduced around 1960, replacing much of the longleaf pine.

Field Data

Sample plot locations were determined by the size of the plant colonies. A single plot at the center of the colony was used where colonies were small. Small plant colonies contained < 50 individuals and occupied around 25 m² area. A stratified random sampling method was employed where the colonies were large. The area was divided into cells each 30 m X 30 m, using a field compass and pacing. From the approximate center of each cell a foot ruler was spun and released. A point then was established 5 m in the direction the foot ruler was pointing. Sampling was conducted at this point. Forest characteristics were evaluated using variable radius plots (Husch et al. 1972). Two wedge prisms were used for tree and shrub measurements. A 5 basal area factor (BAF) wedge prism was used to sample trees and shrubs having
Table 3. List of Variables collected from *G. aestivalis* var. Winkleri Colonies.

<table>
<thead>
<tr>
<th>Location</th>
<th>Variable</th>
<th>Method of Measurement</th>
<th>Unit Of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Soil</td>
<td>Physical Feel</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Soil pH</td>
<td>Soil Testing</td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laboratory, SFASU</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nutrients N, P &amp; K</td>
<td>Soil Testing</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laboratory, SFASU</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slope</td>
<td>Suunto™ Clinometer</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Aspect</td>
<td>Field Compass</td>
<td>degrees</td>
</tr>
<tr>
<td>Overstory</td>
<td>Canopy Closure</td>
<td>Ocular</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>DBH</td>
<td>Diameter Tape &amp;</td>
<td>cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caliper</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>Visual Estimation</td>
<td>ft.</td>
</tr>
</tbody>
</table>

diameters at breast height (DBH) of less than 10.16 cm (4 in.). Another wedge prism having 15 BAF was used to sample trees with DBH larger than 10.16 cm.

Percentage canopy closure was estimated at each plot by ocular estimation (Kroll unpublished). Tree species and measurements were recorded at each sampling point using the wedge prisms. DBH of trees was measured using a diameter tape or caliper for smaller DBHs. Tree height was estimated visually to about 5 ft. precision. Percentage slope was
measured using a Suunto™ Clinometer. Aspect was measured using a field compass. Trees/acre, basal area (BA) and relative frequency were calculated according to Avery et al. (1994).

Morphological characteristics of soils such as color, texture, structure and consistency were recorded at each plot. Bagged soil samples were sent to The Soil Testing Laboratory, SFASU Agriculture Department to test for pH, salinity and macro nutrient content (N, P & K).2

GPS Data

The Trimble Navigation Systems Path Finder™ (Trimble Navigation Co., Sunnyvale, CA) was used to mark locations accurately. Point data were collected using the Trimble GPS Rover™, deploying the external antenna. A minimum of 185 points were collected for each location. Maximum Positional Dilution of Precision (PDOP) was set at 6. Data were collected in "Land Mode." All positions were collected in 3D settings only.

GPS points were collected at the peripheral points of the study area boundary. Reference points also were collected at road intersections, vegetation boundaries and gas

2 At no time were specimens of Gaillardia aestivalis var. Winkleri disturbed in the collection of the above data. Care was taken to avoid trampling or soil disturbance next to each plot.
pipelines etc. These locations were used for geo-
rectification of color infra-red (CIR) aerial photographs. GPS points were collected for geo-rectification of the Landsat TM image. Man-made linear features such as roads, rights-of-way, canals, etc. are clearly distinguishable on thematic images. GPS points were collected at these intersections also.

Once data were collected, files were down-loaded into a Gateway 2000 personal computer, using the PFINDER™ software (Trimble Navigation Co., Sunnyvale, CA). Differential corrections were performed using data obtained from the community base station at Stephen F. Austin State University to obtain an estimated accuracy of ±2-10m. The mcorr400 program was used to perform differential corrections of the Rover and base station data. Averaging corrected files was performed using the ssfmean program. Corrected files were output into ARC format. Files were transferred to ARC/INFO (ESRI) using File Transfer Protocol (FTP). Point coverages were produced using the GENERATE command. Using PROJECTDEFINE command, coverages then were projected to Projection state plane and datum nad 83. Units of measure were in feet. Coverages were used only after building them as point coverage by using BUILD <point> command.
February, 1995 color infra-red (CIR) positive aerial photographs of the study area were obtained from The Aerial Photography Field Office of USDA Natural Resources Conservation Service (NRCS). 1991 Landsat TM data were obtained from Texas-GAP. The satellite image was geo-referenced with the help of ground control points (GCPs). GCPs were collected using the Trimble Pathfinder™. GCPs were collected at all four corners and peripheral areas occurring under the Landsat TM scene. The GCP editor in the ERDAS IMAGINE (ERDAS 1991) software was used to register and rectify the Landsat TM image. After all GCP coordinates were entered, the transformation function was performed using the nearest neighbor algorithm. This produced the least distortion of the output data. The root mean square (RMS) error and RMS error contribution were calculated for each GCP. Results were displayed in the GCP editor table. The RMS error was reduced to < 1 (one pixel = 30 meters) by moving the GCPs around. The output image was projected to state plane and nad83. The part of image encompassing Hardin County was subset using area of interest (AOI) tools and utility menu:

Principal component analysis (PCA) was carried out on the geo-referenced, subset Landsat TM in IMAGINE to combine the bands and to use only one digital output. Built-in
algorithms calculate eigen vectors and eigen values from the spectral space (ERDAS 1982). This reduced data redundancy.
The first three principal components were output as a single layer and used for further analysis.

Supervised classification was performed on this single layer image. Since the analyst has prior knowledge of the site conditions during this process, this allows greater control. Sites on the image where plant populations were recorded were "trained" using the signature editor in IMAGINE. Onsite knowledge and aerial photographs were used to demarcate the "training fields". Aerial photographs were used for ground-truthing purposes. Using the training fields as classes, supervised classification was performed with parallelepiped limits for the signatures and maximum likelihood for overlap data. Unclassified data remained as unclassified using this combination. Satisfactory error matrix was produced by combining and deleting classes. This signature file was used to perform image classification. It was possible then to discriminate between spectral properties of forest types associated with Gaillardia aestivalis var. Winkleri. The classified image was converted to a grid using IMAGEGRID command in ARC (ESRI 1991). The default item in the INFO file was grid-code. Grid-code = 0 was ignored for analysis. The grid was converted into a polygon coverage using the GRIDPOLY command in ARC. The resultant polygon coverage was used for further GIS analysis in ARC.
The CIR positive photographs of study area were scanned in Adobe Photoshop 2.5™ in TIFF format and transferred to ARC. The TIFF file was imported into IMAGINE as an image file with red, blue and green bands and geo-referenced using the GCP editor. GCP coordinates were entered using the keyboard; RMS error was < 1 pixel. This geo-referenced CIR positive aerial photograph of the study area was used for "heads-up" digitization and GIS analysis in ARC.

GIS Data

A digital highway map of Hardin County was downloaded from Texas Natural Resources Information Systems (TNRIS) internet web site. The map was in DXF format and converted to ARC coverage using DXFARC command. The coverage was projected into state plane nad83. This coverage was used to geo-rectify the scanned TIFF image files of USGS 7.5 minute quads. Line coverage of 5 feet contour lines was produced using "heads-up" digitization. Heads-up digitization is a process where geo-referenced image files were opened as a back environment and arcs drawn into the coverage tracing features in the back environment. Both the coverage and the image then must be of the same coordinate system. Topographic analysis of the study area was done using TIN (triangular irregular network) program in ARC/INFO.
Elevation values were assigned to all contour lines in INFO database by adding an item, "elevation." A TIN file was produced from the contour coverage using CREATETIN command. Weed tolerance should be kept at appropriate value to ensure optimum number of polygons. Polygon coverage was created from the TIN file by automated process using TINARC command. This coverage has polygons with elevation, aspect and slope values. Slope and aspect analysis then was performed. RESELECT command was be used to select desired classes of slope and aspect. Then CALCULATE command was employed to obtain the percentage area of each class.

General soil units coverage was manually digitized using a digitizing tablet from USDA NRCS paper maps. Suitable classes of soils were demarcated and a suitability coverage made for spatial analyses. The soil survey staff of USDA NRCS (Hardin Co.) supplied a soil map of the study area. This paper map was scanned, geo-referenced and digitized to produce soil suitability coverage to be used for GIS analysis.

The scanned and geo-referenced CIR photograph was used for producing cultural, water bodies and vegetation coverages. Coverages of the study area were made with the help of Nature Conservancy personnel.

All polygon coverages obtained were evaluated according to suitability. These coverages were overlain using various spatial analysis techniques in ARC/INFO. Commands such as
ERASE, IDENTITY, UNION, INTERSECT etc. were used to perform spatial analysis and overlay operations. UNION command retains items belonging to both the attribute tables in the resultant attribute table. Hence more detailed GIS analysis could be performed.

Field testing of the model was done by randomly selecting 25 points on the habitat suitability map and investigating these positions on the field. At each point physical properties of soils and vegetation were visually observed to determine the habitat suitability and conformity to GIS classification. A comparison was made between the field observation and the habitat map.
RESULTS

Vegetative Characteristics of Study Plots

A total of 50 sampling locations were located on Sandylands Preserve as well as the adjacent easement lands. There was high variation in canopy coverage; ranging from 0% to 85% ($\bar{x}=39.4 \pm 3.86$ SE (Standard Error)). Table 4 presents composition of trees greater than 4" DBH (15 BAF wedge prism). Loblolly pine was the dominant species occupying 60% of the canopy followed by Longleaf pine (12%). Together they accounted for nearly 70% of all canopy. Loblolly pine also had the highest basal area (39.6 sq. ft. per acre), again followed by Longleaf pine (8.4 sq. ft. per acre). Other softwoods accounted for 77% of basal area and the rest was hardwoods in this class.

Table 5 presents composition of trees less than 4" DBH (5 BAF wedge prism). Bluejack oak ($Q. incana$) was the most dominant species (37.5%), followed by black hickory ($Q. texana$) and post oak ($Q. stellata$). Together they accounted for nearly 75% of all trees in this class. Bluejack oak showed the highest basal area (6.9 sq. ft. per acre) followed by black hickory and post oak (3.1 sq. ft. per acre). Hardwoods accounted for around 83% of the basal area.
Table 4. Composition of Trees Having DBH > 4" at 50 Plots

<table>
<thead>
<tr>
<th>Species</th>
<th>Common Name</th>
<th>Trees/acre</th>
<th>BA/acre in sq. ft.</th>
<th>Relative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinus taeda</td>
<td>Loblolly pine</td>
<td>105.20</td>
<td>39.60</td>
<td>0.579</td>
</tr>
<tr>
<td>Pinus palustris</td>
<td>Longleaf pine</td>
<td>25.28</td>
<td>8.40</td>
<td>0.123</td>
</tr>
<tr>
<td>Pinus echinata</td>
<td>Shortleaf pine</td>
<td>7.04</td>
<td>0.90</td>
<td>0.013</td>
</tr>
<tr>
<td>Pinus elliottii</td>
<td>Slash pine</td>
<td>19.00</td>
<td>2.70</td>
<td>0.039</td>
</tr>
<tr>
<td>Quercus incana</td>
<td>Bluejack oak</td>
<td>29.00</td>
<td>4.20</td>
<td>0.061</td>
</tr>
<tr>
<td>Quercus stellata</td>
<td>Post oak</td>
<td>8.46</td>
<td>3.60</td>
<td>0.052</td>
</tr>
<tr>
<td>Quercus falcata</td>
<td>Southern red oak</td>
<td>1.75</td>
<td>0.90</td>
<td>0.013</td>
</tr>
<tr>
<td>Carya texana</td>
<td>Black hickory</td>
<td>55.67</td>
<td>3.30</td>
<td>0.048</td>
</tr>
<tr>
<td>Liquidambar styraciflua</td>
<td>Sweetgum</td>
<td>10.67</td>
<td>2.10</td>
<td>0.031</td>
</tr>
<tr>
<td>Ilex vomitoria</td>
<td>Yaupon</td>
<td>38.82</td>
<td>0.90</td>
<td>0.039</td>
</tr>
</tbody>
</table>

Site Characteristics of Study Plots

Variation in slope was not high; ranging from flat to 10% (\( \bar{x} = 2.6 \pm 0.32 \)); however most plots were classified as "flat." Aspect for the remaining plots included: N (4%), NE (10%), E (10%), SE (4%), S (10%), SW (20%), W (12%), and NW (4%). Soils usually were light colored to dark gray. Texture ranged from sand to sandy loam. Soil structure was loose for all the plots and did not show any blockiness or clod formation. The soil was very friable, with no elasticity
Table 5. Composition of Trees Having DBH < 4" at 50 Plots

<table>
<thead>
<tr>
<th>Species</th>
<th>Common Name</th>
<th>Trees/acre</th>
<th>BA/acre in sq. ft.</th>
<th>Relative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinus taeda</td>
<td>Loblolly pine</td>
<td>75.52</td>
<td>2.40</td>
<td>0.130</td>
</tr>
<tr>
<td>Pinus palustris</td>
<td>Longleaf pine</td>
<td>22.95</td>
<td>0.30</td>
<td>0.016</td>
</tr>
<tr>
<td>Pinus echinata</td>
<td>Shortleaf pine</td>
<td>5.47</td>
<td>0.20</td>
<td>0.011</td>
</tr>
<tr>
<td>Pinus elliottii</td>
<td>Slash pine</td>
<td>7.76</td>
<td>0.20</td>
<td>0.011</td>
</tr>
<tr>
<td>Quercus incana</td>
<td>Bluejack oak</td>
<td>283.85</td>
<td>6.90</td>
<td>0.375</td>
</tr>
<tr>
<td>Quercus stellata</td>
<td>Post oak</td>
<td>90.04</td>
<td>3.10</td>
<td>0.168</td>
</tr>
<tr>
<td>Carya texana</td>
<td>Black hickory</td>
<td>151.5</td>
<td>3.80</td>
<td>0.206</td>
</tr>
<tr>
<td>Liquidambar styraciflua</td>
<td>Sweetgum</td>
<td>6.11</td>
<td>0.20</td>
<td>0.011</td>
</tr>
<tr>
<td>Ilex vomitoria</td>
<td>Yaupon</td>
<td>38.82</td>
<td>0.90</td>
<td>0.045</td>
</tr>
<tr>
<td>Vaccinium arboreum</td>
<td>Farkelberry</td>
<td>7.76</td>
<td>0.20</td>
<td>0.011</td>
</tr>
<tr>
<td>Morus rubra</td>
<td>Red mulberry</td>
<td>3.79</td>
<td>0.10</td>
<td>0.005</td>
</tr>
</tbody>
</table>

or plasticity.

All plots had acidic soils, with pHs ranging from 4.5 to 6.3 ($\bar{x}=5.51 \pm 0.05$). Salinity for all plots was very low. Soil nitrogen ranged from 1-13 ppm ($\bar{x}=2.82 \pm 0.4$). Soil phosphorous ranged from 1-13 ppm ($\bar{x}=5.63 \pm 0.8$). Soil potassium ranged from 10-40 ppm ($\bar{x}=22.49 \pm 1.12$). Table 6 presents the results of soil analysis.
Table 6. Results of Soil Analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Mean</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>White-Gray</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Consistency</td>
<td>Loose</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Texture</td>
<td>Sand-Sandy Loam</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>pH</td>
<td>4.5-6.3</td>
<td>5.51 ±0.05</td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>Very Low</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>N</td>
<td>1-13 ppm</td>
<td>2.82 ±0.32</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>1-13 ppm</td>
<td>5.63 ±0.40</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>10-40 ppm</td>
<td>22.49 ±0.80</td>
<td></td>
</tr>
</tbody>
</table>

Image Data

During the supervised classification of the satellite data in IMAGINE, training fields were marked using the area of interest (AOI) tools. The training fields were marked on the Landsat TM image that was subjected to principal component analysis. Each training field was added to the signature editor as a separate class. All the classes were combined to produce four final classes. They are pine-hardwood, sandhill pine, mesic uplands and bluejack oak-pine. The supervised classification was evaluated using the error matrix. Table 7 presents the error matrix expressed in pixel counts; while Table 8 provides the error matrix as percentage. Error matrices suggested a relatively high degree
Table 7. Error Matrix for Supervised Classification in Pixels.

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Pine-Hardwood</th>
<th>Sandhill Pine</th>
<th>Mesic Uplands</th>
<th>Bluejack Oak-Pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine-Hardwood</td>
<td>25</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Sandhill Pine</td>
<td>2</td>
<td>15</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Mesic Uplands</td>
<td>5</td>
<td>1</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Bluejack Oak-Pine</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>114</td>
</tr>
<tr>
<td>Column Total</td>
<td>32</td>
<td>18</td>
<td>24</td>
<td>119</td>
</tr>
</tbody>
</table>

Table 8. Error Matrix for Supervised Classification Expressed as Percentages.

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Pine-Hardwood</th>
<th>Sandhill Pine</th>
<th>Mesic Uplands</th>
<th>Bluejack Oak-Pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine-Hardwood</td>
<td>78.12</td>
<td>11.11</td>
<td>12.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Sandhill Pine</td>
<td>6.25</td>
<td>83.33</td>
<td>0.00</td>
<td>4.20</td>
</tr>
<tr>
<td>Mesic Uplands</td>
<td>15.62</td>
<td>5.56</td>
<td>87.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Bluejack Oak-Pine</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>95.80</td>
</tr>
<tr>
<td>Column Total</td>
<td>99.99</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

of accuracy (Percentage Correct = 90.6). Anderson et al. (1976) reported that accuracies of 85% are required for satisfactory use of land use data for resource management. A classification that uses very broad classes can achieve high values as far as Percentage Correct values are concerned. Such high values may be difficult to achieve for detailed classification.
GIS Analysis

Topography

Elevation was not taken into consideration since the study area was between 25 ft. to 75 ft. above mean sea level (MSL). Slope analysis was done from the TIN coverage produced from digitizing the 5 ft. interval contour lines of the USGS 7.5' quads. About 55.3% of the study area has a slope between 0 to 10°. About 22.1% of it is flat. About 15.5% has a slope between 1 to 20°. 4.3% has a slope between 2 to 30°. Nearly 1.3% has a slope between 3 to 40°. 0.7% has slope between 4 to 50°. 1.3% has a slope between 5 to 100°. The remaining 0.355 of the study area has slope greater than 100°.

Aspect analysis was done from the same TIN coverage. Nearly 22.4% of the study area showed no aspect (flat). 9.94% was facing North, 12.5% North East, 10.1% East, 5.2% South East, 6% South, 14.9% South West, 12.6% west and 6.3% North West.

Soils

Tonkawa series and Betis series soil polygons of the study area (cf., Fig. 5) were selected for overlay analysis. Tonkawa series was given a higher weightage and habitat falling under this is given high suitability during overlay analysis. Habitat falling under Betis series was given moderate suitability during overlay analysis.
Bienville-Besner-Molliville and Mantachie Owentown units of Hardin County (cf., Fig. 6) were selected for overlay analysis. Bienville-Besner-Mollville unit was given a higher weightage and habitat falling under this is given high suitability during overlay analysis. Habitat falling under Mantachie Owentown unit of Hardin County was given low suitability during overlay analysis.

**Vegetation**

On the basis of field investigation and CIR positive aerial photograph analysis, the study area was divided into nine general types of vegetation. Isolated water bodies of Village Creek covered with trees are classified as sloughs. Hardwoods along the moist stream banks and bottomlands are classified as mesic hardwoods. Areas showing somewhat equal proportions of major hardwoods and pines are classified as mixed hardwood-pine. Areas dominated by bluejack oak with pines are classified as bluejack oak-pine. Upland sandy areas with pines as dominant trees are classified as pine sandhill. Pine dominated areas are classified as pine. Lower elevations and depressions where there is an accumulation of water and subsequent stagnation resulting in a wetland like conditions are classified as baygall. Area of Stagnant waterbodies like ponds with floating vegetation are classified as floating vegetation. Emergent vegetation on the peripheral parts of the stagnant water bodies is classified as bald cypress/
emergent vegetation. Figure 7 is a GIS coverage of the vegetation types of the study area.

Habitat occurring under pine sandhill communities was given high suitability during overlay analysis. Habitat falling under bluejack-pine was given moderate suitability during overlay analysis. Habitat under mixed hardwood pine was given low suitability during overlay analysis.

**Final Output**

All the spatial analysis was performed in ARC/INFO. The final output for the study area has three habitat suitability classes. They are high potential, moderate potential and low potential. Soil and vegetation coverages of the study area were overlaid using UNION command. The high potential habitat was derived by using the SELECT command on common INFO items Tonkawa series and pine sandhill. The INFO items are the database classes in coverages built using the INFO command. The moderate potential habitat was derived by using SELECT command on common INFO items bluejack-pine and Betis series. The low potential habitat was derived from by using SELECT command on common items mixed hardwood pine and Tonkawa series. Figure 8 presents the habitat suitability of *Gaillardia aestivalis* var. *Winkleri* for the study area.

The final output for the Hardin county has two habitat suitability classes, high potential and low potential. Polygon coverage of Hardin Co. derived from classified Landsat TM image was overlaid with the Hardin County soil
Figure 7. Vegetation Types of Study Area

- Open water
- Slough
- Mesic Hardwoods
- Mixed Hardwood-Pine
- Bluejack Oak-Pine
- Pine Sandhill
- Pine/Wetland Pine
- Baygall/Swamp
- Floating Vegetation
- Bald Cypress/Emergent Vegetation
- Power Line
- Railway Line
- Road
- Village Creek

Projection: State Plane
Datum: Nad 83
Zone: 4203 (Texas Central)
Source: NAPP CIR Positive Aerial Photographs (2-5-95)
Field Investigation
Jason Singh (TP&WD)
Staff, The Nature Conservancy

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GIS Laboratory
Arthur Temple College of Forestry
Stephen F. Austin State University
Figure 8. Potential Habitat Classes for *G. aestivalis* var. *Winkleri* for The Study Area.

- **Water Bodies**
- **Boundary Lines**
- **High Potential**
- **Moderate Potential**
- **Low Potential**

Projection: State Plane
Datum: Nad 83
Zone: 4203 (Texas Central)
Source: NAPP CIR Positive Aerial Photographs (2-5-95)
USDA NRCS Soil Map
Field Investigations
Staff, The Nature Conservancy
Jason Singhurst (TP&WD)

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coverage using UNION command. The high potential habitat was derived by using SELECT command on common items grid-class 1 and Bienville-Besner-Molville soil unit. The low potential habitat was derived by using SELECT command on common items grid-class 1 and Mantachie Owentown soil unit. Non habitat was the area with no potential. Figure 9 presents the habitat potential of Gaillardia aestivalis var. Winkleri in Hardin County. Field verification of data indicated 70.5% of habitat is classified correctly.
Figure 9. Potential Habitat of *G. aestivalis* var. *Winkleri* for Hardin County (see Pocket at the end)
DISCUSSION

The GIS analysis used in this study proved useful in assessing ecological requirements of *G. aestivalis* var. Winkleri within the study area, as well as, classifying potential habitats. However, field investigations were conducted only within the Sandylands Preserve and adjacent easement lands. Ground truthing of other potential habitats on private lands was not conducted, due to restricted access. Preferred habitats are characterized as predominantly pine overstory, with a hardwood understory and well drained, rapidly permeable sandy soils. Bluejack oak appears to be the most dominant hardwood species. Apparently, exclusion of fire from these sites led to the abundant bluejack oak understory.

Apparently, white firewheels are a shade tolerant species. Slope and aspect did not greatly influence on the distribution; however, steep slopes adjacent to stream banks did not appear to offer suitable habitat. Soil properties may be the most important factors determining distribution of white firewheels. Populations were found only on well-drained, rapidly permeable soils that were uniformly acidic, with poor macro nutrient (N, P & K) content (cf., Table 6).

Field verification of the model indicated 70.5% of the potential habitat as correctly classified for the study area.
Traditional habitat studies rely on field investigations, paper maps and aerial photographs. To classify large areas by these methods is time consuming and may compromise positional accuracy of the output. Mosaicing aerial photographs and joining maps may lead to geometric, as well as, geographic errors due to different projections and scales. Though such errors can be reduced by optical instruments, the procedures are cumbersome. The power of GIS lies in its ability to accurately project multiple data layers and to perform topological querying and analysis among different data layers. Classifying vegetation by remotely sensed methods is more efficient and requires only ground truthing.

Approximately 14.3% of the study area and 1.45% of Hardin Co. showed good potential habitat. Potential habitat for the study area was dispersed (cf., Fig. 8). Potential habitat for Hardin Co. was along the Village Creek watershed and near the Neches River (cf., Fig. 9). Unfortunately, effects of fire on distribution of white firewheels in the study area could not be analyzed in GIS due to unavailability of fire unit maps. Hence an important variable may be missing in this study. A better habitat map for Hardin Co. could have been made if a detailed County soil map was published.

Topographic data such as DEMs, Digital Ortho Quads (DOQ) or Digital Line Graphs (DLG) are yet unavailable. Planimetrically correct ortho photographs of the study area are also not available. Vector module in ERDAS IMAGINE is not
available (for GIS laboratory) limiting scanned images resolution and restricting raster to vector conversions. Availability of these data and software components increases data efficiency and convenience. Present coverages can be used for future studies for the study area if fire unit and silvicultural treatment maps are available.

It is recommended a 10 m buffer be used while performing management practices for the potential habitat sites. Periodic prescribed burning of potential habitat sites is recommended to prevent bluejack oak and yaupon from dominating the understory for high potential sites. Silvicultural thinnings are recommended where canopy closure is high. Introduction or reintroduction of these plants in high potential sites should be tried. From field investigation, it appears trailing phlox (Phlox nivalis ssp. texensis) and white firewheels are sharing the same habitat, hence it is recommended any management plan follow an integrated approach.
CONCLUSIONS

1) *Gaillardia aestivalis* var. *Winkleri* appears to be a shade tolerant species, limited to strongly acidic soils with good drainage and rapid permeability. Pine sandhill, mixed hardwood-pine and oak-pine communities are preferred. Slope and aspect does not appear to influence distribution.

2) The habitat suitability classification map produced in this study can be useful for management purposes.

3) The methodologies used and developed can be applied to future studies on endangered, threatened or sensitive plant and animal communities.

4) Habitat suitability maps produced in this study for Hardin Co. will be useful in locating introduction or reintroduction sites for *G. aestivalis* var. *Winkleri*. 
LITERATURE CITED


ERDAS 1991. ERDAS IMAGINE On-line Help, ERDAS Inc. Atlanta, GA.


Kroll J. C., __. Unpublished.


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This thesis follows the style recommended in Forest Science.