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OAK WILT RESEARCH AT FORT HOOD AND IMPACT ON GOLDEN CHEEKED WARBLER NESTING SITES

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ABSTRACT

Understanding how oak wilt can impact management activities has recently become an issue at Fort Hood, TX. Fort Hood is home to an endangered bird species, the golden cheeked warbler (GCW), *Dendroica chrysoparia*. The GCW uses juniper trees (*Juniperus ashei*) for building nests and feeds on Lepidoptera that exist in oak species. It's become a concern whether the oak wilt pathogen is affecting the GCW habitat, nesting and feeding activities. Two surveys were conducted in 2001 and 2002-2003. The 2001 survey used IKONOS 1-meter pan-sharpened satellite imagery for photo interpretation of mortality centers within the post perimeter. In 2002-2003, field surveys were conducted in five distinct categories (GCW/OW, non-GCW/OW, GCW/non-OW, and non-GCW/non-OW, GCW/NS). Decision tree analysis was used to determine important characteristics of GCW nesting habitat using collected field and independent data. Results of this study will help with management conflicts that occur between oak wilt control and conservation of endangered species habitat.

Key words: *Ceratocystis fagacearum, Dendroica chrysoparia*

The destructive tree fungus *Ceratocystis fagacearum* (Bretz) Hunt has been well documented throughout the U. S. In Texas, hundreds of acres and thousands of trees have been destroyed by this pathogen (see website at http://www.texasoakwilt.org). Not until recently has the impact of oak wilt on an endangered species and its habitat been evaluated. The endangered species of concern is the golden cheeked warbler (GCW, *Dendroica chrysoparia*). In 1990, at the time the GCW was designated an endangered species, a formal management plan for restoration of the GCW was proposed. This included research on the impact of oak wilt on the GCW habitat (Keddy-Hector 1992). Not until this study has this research initiative been addressed. The present study was conducted on the Fort Hood military base to assess the influence of oak wilt on this endangered species habitat and nesting site locations and to see if costly control measures for oak wilt are advised. This will be useful for managers responsible in making oak wilt management decisions.

DESCRIPTION OF FORT HOOD, TEXAS

Fort Hood is located in the hill country of central Texas covering portions of Bell and Coryell counties and is one of the largest army installations in the United States. Fort Hood covers 88,500 hectares (217,000 acres) and consists of a mix of grassland, open savannas, hardwood thickets, and dense oak-juniper stands (Dearborn et al. 2001). It also has constant ongoing, destructive, large-scale landscape activities. Fort Hood houses two full armored divisions (1st Calvary Division and the 4th Infantry Division), conducts full military training operations including large-scale troop and vehicle movements, allows cattle grazing under lease through cattlemen's associations, houses areas for public recreation and operates under the auspices of the endangered species act.

Fort Hood supports significant breeding populations of two endangered species; blacked-capped vireo (*Vireo atricapilla*) and the golden cheeked warbler and lies at the intersection of two Nature Conservancy ecoregions. The Nature Conservancy has recognized Fort Hood as a priority site and has been working with Fort Hood's endangered species management program since 1993 to lessen the impact on the fragile forest ecosystem that the various activities at Fort Hood have (see Nature Conservancy's website http://www.nature.org, Greene and Reempts, this proceedings).

INTERACTION OF GOLDEN CHEEKED WARBLER AND OAK WILT

The golden cheeked warbler is a migratory songbird that arrives in central Texas in early spring for breeding and leaves to its post-breeding grounds in Central America and southern Mexico in mid- to late June (Ladd and Gass 1999). The breeding and nesting requirements of the GCW are particularly dependent upon certain characteristics of the oak/juniper savannas of central Texas (Kroll 1980). GCW habitat is dependent on Ashe juniper (*Juniperus ashei*) and a variety of oak species that are dominated by Texas red oak (*Q. buckleyi*) and shin oak (*Quercus sinuata*) (Kroll 1980, Wahl et al. 1990). The GCW uses the shedding bark from mature Ashe junipers for nesting material and forages on lepidopteron insects that exist in high populations in oak canopies (Smith 1916, Simmons 1924, Pulich 1976, Kroll 1980, Ladd 1985 and Wahl et al. 1990). The GCW primarily nests in Ashe junipers but nests have also been found in Texas red oak, post oak (*Quercus stellata*), Texas ash (*Fraxinus texensis*) and live oak (*Quercus fusiformis*) trees in Fort Hood (Hayden et al. 2001).

The GCW is attracted to more mesic areas within the juniper-oak complex, such as canyons and seepy hill sides where deciduous hardwood vegetation is more abundant (Hayden et al. 2001). Fort Hood has designated 21,850 ha (53,991 acres) or 24.7% total post as GCW habitat (Dearborn and Sanchez 2001). Urbanization, fragmentation of breeding habitats for agricultural purposes, and parasitism are the primary reasons given for the decline in GCW numbers throughout its northern range (USFWS 1990, Moses 1996). Other disturbances on the GCW habitat such as oak wilt need to be considered and require further study to determine if this disease of native oaks is partly responsible for the decline in the numbers of GCW.

Ceratocystis fagacearum, the fungus that causes oak wilt, is a destructive pathogen that kills hundreds of red and live oaks every year in Texas. Oak wilt is caused by a vascular pathogen that spreads through interconnected root systems in live oaks. In red oaks, a brief saprophytic phase is supported where means of overland spread occurs. These two means of spread, above and below ground, greatly influence the spatial pattern and rate of spread of this pathogen and can have a strong effect on the forest ecosystem. Oak wilt management also needs to be considered when determining how to control the pathogen on a large landscape scale. Large landscape control techniques would consist of destroying diseased red oaks and trenching to break up the root systems of live oaks infected with oak wilt (Appel 1995). These techniques are extremely costly and cause great disturbances to the area when applied. Natural resource managers must have a thorough understanding of the epidemiology, impact on the GCW habitat and biology, and predict long-term consequences of their actions. This is becoming increasingly difficult especially when managers must contend with complex multiple land-use objectives such as those that exist on Fort Hood. This research project provides the ability to predict the incidence and intensity of oak wilt and how it impacts the GCW habitat, which provides a valuable tool in the decision-making process.

METHODS AND MATERIALS

2001 Field Survey

To determine how oak wilt affects GCW habitat, the number of oak wilt centers on Fort Hood needed to be determined. In 2001, a photogrammetric survey followed by a ground survey of the delineated sites was conducted. IKONOS 1-meter pan-sharpened satellite imagery was obtained for Fort Hood, including a 1-mile (1.6 km) buffer around the post boundary (Pacific Meridian Resources, Emeryville, CA 94608). The imagery was co-registered to Orthophoto Quarter Quadrangles (DOQQ's) using the geographic information system ArcView (ESRI, 380 New York St., Redlands, CA 92373). Survey lines at 330 m spacing were transposed onto the satellite imagery. A trained technician selected the mortality areas on the map that were representative of tree mortality, with attempts to exclude as best as possible mortality areas caused by fire, brush-clearing, and unknown sources. Oak wilt mortality occurs in expanding centers so differentiating between oak wilt and other causes of mortality is relatively simple. Once the mortality polygons were completed, they were overlaid onto the imagery to be used for ground truthing. A random sample of 10% of the photointerpreted polygons was selected for diagnosis.

Oak wilt was diagnosed according to recognized symptoms of the disease in the field and by laboratory isolation of the pathogen when necessary (Appel 2001).

2003-2004 Survey and Classification Tree Analysis

One of the next goals was to characterize typical GCW nesting- and habitat sites and the impact of oak wilt. This goal was part of a larger project conducted in cooperation with the USDA Forest Service Forest Health Technology Enterprise Team, (FHTET, Ft. Collins, CO), which used the methodology of binary classification and regression tree analysis (CART) to model and predict oak wilt incidence and severity (see Downing et al., this proceedings). Tree-based modeling is an exploratory technique for uncovering structure in data (Clark and Pregibon 1992). Classification trees can explain the variation of a single response variable by one or more exploratory variables which are useful for ecological data that is often multifaceted, unbalanced and contains missing values. The result of this non-parametric technique is a classification tree used to explain the variation of a dependent or response variable by a collection of independent or explanatory variables (Baker et al. 1993, De'ath and Fabricius 2000).

The tree is constructed by repeatedly splitting the data into two mutually-exclusive groups that are each as homogeneous as possible but while also keeping the tree reasonably small (De'Ath 2000). To keep the trees as accurate as possible, a cross validation procedure is performed. This looks at the independent variables from the tree and calculates the amount of error produced by iteratively combining the independent variables. The result is a plot of the number of terminal nodes and misclassification error. The original tree is then pruned to the best model with the greatest number of terminal nodes and the least amount of classification error. FHTET used the dependent variable of presence or absence of oak wilt, whereas for this paper the presence or absence of nesting sites was used, but the field data gathered could be used for both analyses. Ancillary data used in the analysis was obtained from the Natural Resources Management Branch (ARMY) office at Fort Hood.

Sample plots (n=137) were randomly selected using a Sample Points Generator (SPGen), an ArcView application, from four land categories: 1) GCW habitat, non-oak wilt, 2) GCW habitat, oak wilt, 3) non-GCW habitat, oak wilt, and 4) non-GCW habitat, non-oak wilt. The fifth category of nesting sites (GCW/NS) that were known to be occupied by nesting pairs in 2002-2003 was subsequently added as an additional dependent variable for this paper's CART analysis. Independent variables for the model were derived from each of the four bands of 2003 SPOT 10 and each of the seven bands of Landsat TM satellite imagery and the eleven 30m grid themes (slope, elevation, aspect, soils, distance to roads, road density, distance to streams, stream density, distance to lake, forest savanna, and landform)

The grid themes were created by using the imagery bands and the ERDAS Imagine Software Grid Export function (ERDAS, Inc., ERDAS Imagine V8.5.1002. Atlanta, GA). Surveys were conducted by the USDA Forest Service, the Nature Conservancy, the Texas Forest Service, and Texas A&M University in 2003 - 2004. The cluster plots were distributed throughout the five sampling categories and each plot consisted of a 20m x 20m fixed square plot subdivided into 4 10m x 10m sub-plots. Data collected for each plot and subplot consisted of tree diameters, tree species identification, symptom development of infected trees, dominant overstory and understory species, and average tree height.

The classification tree was fitted to the spatial information database using S-PLUS © statistical software package (Insightful Corp, Seattle, WA 98109). Twenty-two independent variable grid themes and twenty-five data categories were used to construct the classification tree for comparing the nesting site data with the data from the GCW habitat with no oak wilt present (GCW/non-OW). This comparison was run with three sets of data: grid theme and field data (total data), grid theme data only (independent data), and field data only (field data).

An analysis of the total survey data was conducted as well to determine significant differences among the category types. These consisted of analysis of stand characteristics such as species frequency, size class differences, tree density, juniper to oak ratio, and age of junipers. Age of junipers was determined based on the regression formula presented by Kroll (1980) which used diameter measurements to determine the age of Ashe junipers. Multi-response Permutation Procedures (MRPP) and non-metric multidimensional scaling (NMS) were used by PC-ORD © for Windows version 4.01 (McCune and Mefford 1999) to determined differences of species composition and tree diameters among the 5 categories. Logarithmic transformation of the data was applied to perform linear regressions using proc glimmix in SAS © version 9.1 (SAS Institute Inc., Cary NC 27513) to determine differences in stand structure. Linear regressions tested yes, no relationships on the data (e.g., whether sites were oak wilt or GCW, and if sites were GCW or nesting sites)

RESULTS

2001 Field Survey

Photo interpretation of the IKONOS satellite imagery for tree mortality for the post plus the one-mile (1.6-km) buffer and the post without the buffer revealed 1,164 and 638 mortality polygons respectively (Fig. 1). The 10% sample, 119 plots, revealed that 60 (82%) mortality polygons within the post only were caused by oak wilt. Other minor factors that were attributed to tree death consisted of military ops, brush piles, blow downs, and fire. Of the 73 photo-interpreted sites that fell within the post perimeter, 12 (16%) were within GCW habitat and 7 (12%) were oak wilt. Six additional oak wilt centers were within 100 feet of golden cheeked warbler habitat. Extrapolating for the entire post, 9% of the mortality centers were estimated to be oak wilt within GCW habitat.

2003-2004 Field Survey

Stand characteristics. Nesting sites (GCW/NS) had the highest stand density (n=1296) (Table 1). Nesting sites (65%) and GCW habitat only (GCW/non-OW) (77%) had the highest juniper composition, compared to non-GCW/OW (14%) (Table 1). The number of live oak stems was considerably lower in GCW/NS (n=34) and GCW/non-OW (n=38) compared to non-GCW/OW (n=260) (Table 2). The juniper to oak (J:O) ratio varied among the plot types, but GCW nesting sites and GCW/non-OW had the highest J:O ratio. Sites that contained only oak wilt outside of the GCW habitat had the lowest juniper to oak ratio (Table 1).

The numbers of mature Ashe juniper were higher in GCW habitat and nesting sites when compared to non-GCW habitat (Table 3). Nesting sites and GCW/non-OW sites tended to have more trees in the mature age classes (>50 years) then did the GCW/OW sites.

Linear regression analysis was performed on the five categories (GCW/NS, GCW/non-OW, GCW-OW, non-GCW/non-OW, non-GCW/OW). Significant differences ($p<0.0450$) in diameters in nesting sites when compared with GCW habitats were found. MRPP analysis on the interaction of species between the five categories revealed that there were distinct differences ($p=0.0000$) among categories with regard to species composition. Species composition was further tested by NMS analysis which revealed the species of most importance for nesting sites were juniper and shin oak (Fig. 2).

Classification tree model. This model was used for the survey data on nesting sites (GCW/NS) in 2004 and from the data collected in 2003 and 2004 from one of the sample plot categories (GCW/non-OW) (Figure 3). The dependent variable was the nesting sites which were assigned the value of 1 while the GCW/non-OW sites were assigned the value of 0. This analysis included both the field and the independent data (total data). The resulting classification tree had an accuracy of 98.2% with 8 terminal nodes (Fig. 4). Discriminating variables included road density, Landsat band 6, elevation, distance to roads, and Spot band 3. Low road density accounted for most of the variance (62%) in the nesting site locations, followed by Landsat band 6 (43%), elevation greater than 247 m (30%), distance to roads (6%), and spot band 3 (3%). Based on the model, the best and most favorable nesting sites were at locations with a low road density (<586.5), an elevation greater then 247.5 m, and distance to roads of less then 91.5 m. When road density was high (>969.5 m) and distance to roads greater than 91.5 m, the probability of GCW nesting site habitat was low.

DISCUSSION

Numerous oak wilt sites exist on the Fort Hood post and some fall within and near golden cheeked warbler habitat. Photointerpretation was a reasonably accurate technique for identifying oak wilt mortality centers on satellite imagery. Though some error existed, this process could be more refined and accurate with time and experience in photo interpretation. Oak wilt proved to be the dominant cause of tree mortality on the post. Fire could be considered a greater mortality feature, even more so then oak wilt, in the specific locations where it occurred. The comparison of fire and oak wilt on stand type should be considered for future study.

Characterizations of golden cheeked warbler habitat and nesting sites have been previously described in the literature (Pulich 1976, Kroll 1980, Dearborn et al. 2001). Preferred GCW habitat consists of a climax forest type comprising mature dominant Ashe juniper and a variety of oak species. Ashe junipers are considered mature when they are greater then 50 years old (Kroll 1980). In our survey plots, both the nesting sites and GCW habitat fulfilled these requirements for mature Ashe juniper. Similar numbers of Ashe junipers in all age classes were also found in GCW/non-OW and GCW/NS. When oak wilt was present, there were fewer junipers in general and fewer junipers in the mature category, suggesting that stands with GCW have a different stand structure than those with oak wilt.

Dearborn and Sanchez (2001) found that GCW nest patches in Fort Hood were found in high densities of small, young junipers. Kroll (1980) found that GCW habitat in the Meridian state recreation area had high numbers of small Bigelow oak (*Quercus durandii breviloba*). A significant difference between our plots was the presence of numerous small-diameter shin oak in nesting sites when compared to GCW habitat. The presence of these small diameter shin oaks and the higher ratio of junipers to oaks would coincide with what Dearborn and Sanchez (2001) and Kroll (1980) found for preferred GCW habitat and nesting sites. Sites where oak wilt was present had much lower densities of trees, suggesting a different stand structure exists for GCW nesting site habitat and oak wilt locations.

Previous research on juniper and hardwood composition for GCW habitat has shown that good GCW habitat had a juniper composition of 14-50% and a hardwood composition of 20-70% (Hayden 2001). Good habitat at Meridian State Recreation Area was reported to have 52% Ashe juniper, 33% shin oak and 5% Texas oak (Kroll 1980). Our results showed that GCW/NS habitat in Fort Hood had 65% juniper and 35% hardwood composition. Habitat containing only

GCW habitat had the same trend of having a higher percentage of junipers and low percentage of hardwoods. Interestingly, when oak wilt is present, the composition of juniper decreases and oaks increases, which would preclude different stand structures for these two habitat types (GCW nesting site and oak wilt locations).

Live oaks dominated the oak wilt sites whether GCW habitat was present or not, whereas in GCW nesting sites the composition of live oaks was reduced. Sites where live and red oaks are both dominate were characteristic of oak wilt sites with no GCW. To support a high incidence of oak wilt requires a live oak host type to support root to root spread and red oaks to provide the inoculum source in the form of fungal mats. The proportion of red oaks is fairly consistent among the habitat types so the amount of inoculum that would be produced could be considered uniform.

From the results, it appears that live oaks have different site requirements then the habitat found in GCW sites and thus the threat of oak wilt in critical habitat is less then predicted. This is further supported by NMS analyses which determined that juniper and shin oak were the most important species in nesting sites and live and red oaks were not present in significant numbers. This again supports the conclusion that GCW nesting habitat and sites with oak wilt have different stand structures. This stand structure in which shin oak is one of the dominate stand components of GCW nesting habitat was found for Fort Hood; other areas where GCW exist in Texas may have a different major oak component. Further research needs to be completed at these other locations (i.e., Balcones Canyonland Preserve and Meridian State Park Recreation Area).

The classification tree analysis proved to be an excellent technique for determining the factors that are influential in distinguishing GCW nesting sites. Our tree revealed that preferred nesting site locations would be in areas with low road density and high elevations. These results are consistent with research that shows GCW prefers large blocks of unfragmented tracks of land (Ladd 1985, Moses 1996), though this belief is contentious. Conflicting opinions exist that GCW co-evolved as an edge species that inhabits the interfaces between grassland and juniper-oak stands (Kroll 1980). Kroll found when large homogenous blocks of land exist, GCW territories usually occur along the outer edges and habitat should consist of Ashe junipers along streams and hill crests. The expansion of oak wilt centers that cause patches and create edge effects needs to be further studied to see how the disease relates to GCW besides loss of host type.

Oak wilt causes many forms of disruption such as creating patches, edge effects, changing stand structure (tree composition, size classes, and density). More research is needed on the effects of oak wilt and GCW habitat and nesting locations so land managers can be more confident in making critical decisions regarding the need to control this disease. The amount of disruption created by implementing the control techniques also needs to be taken into consideration.

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Table 1: Stand structure of the five sample plot categories for the 2003-2004 survey on Fort Hood, TX.

Category[a]	Tree /Hectare	% Juniper	% Hardwood	J:O Ratio
GCW/non-OW	886	77	23	6.57:1
GCW/OW	639	56	44	1.66:1
Non GCW/ non-OW	90	45	54	2.48:1
Non GCW OW	570	14	86	0.24:1
GCW/NS	1298	65	35	3.16:1

[a] GCW/non-OW = Golden cheeked warbler no oak wilt,
GCW/OW = golden cheeked warbler with oak wilt,
Non GCW/non-OW = no golden cheeked warbler, no oak wilt,
Non GCW/OW = no golden cheeked warbler with oak wilt,
GCW/NS = golden cheeked warbler nesting site.

Table 2. Total number of trees and proportion of total for the five tree species sampled in the five sample plot categories for the 2003-2004 survey on Fort Hood, TX.

Species[b]	GCW/OW	GCW/ non-OW	non-GCW/ non-OW	non-GCW/ OW	GCW/NS
DH	55 / 0.11	115 / 0.12	42 / 0.37	190 / 0.26	185 / 0.15
J	301 / 0.62	762 / 0.78	52 / 0.45	105 / 0.13	806 / 0.65
LO	103 / 0.21	38 / 0.04	8 / 0.07	260 / 0.33	34 / 0.02
RO	72 / 0.15	58 / 0.06	13 / 0.11	165 / 0.23	122 / 0.10
WO/SO	6 / 0.01	20 / 0.02	0 / 0	10 / 0.01	99 / 0.08

[b] DH = Deciduous hardwood, J = Juniper, LO = Live oak, RO = Red oak, WO/SO = White oak/Shin oak.

Table 3: Age classes of Ashe juniper species for GCW habitat type, GCW nesting type and non GCW habitat type classes, Fort Hood, TX.

Age Class	GCW/non OW	GCW/OW	Nesting Sites	Non-GCW Habitat
10-20	170	93	190	54
21-30	112	70	170	24
31-40	156	60	112	38
41-50	64	24	83	6
51-60	103	17	69	22
61-70	29	5	46	3
71-80	39	14	39	3
81-90	16	6	29	1
91-100	28	3	15	2
101-110	9	4	9	1
111-120	13	3	13	0
121-130	3	0	12	0

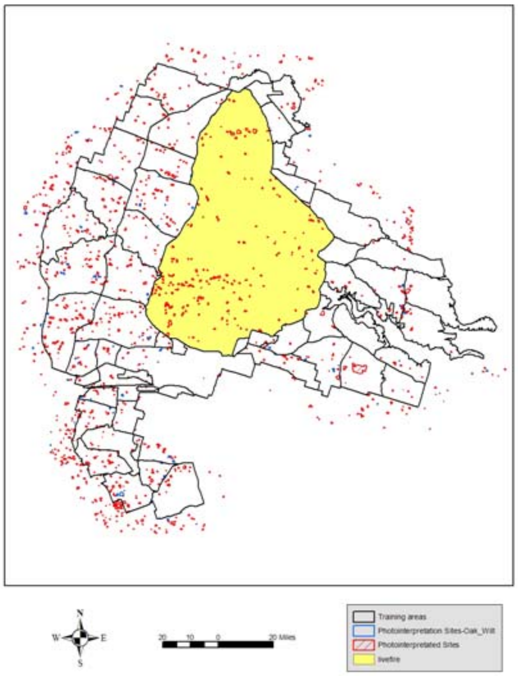

Figure 1: Mortality centers determined by photo interpretation, located on Fort Hood, TX.

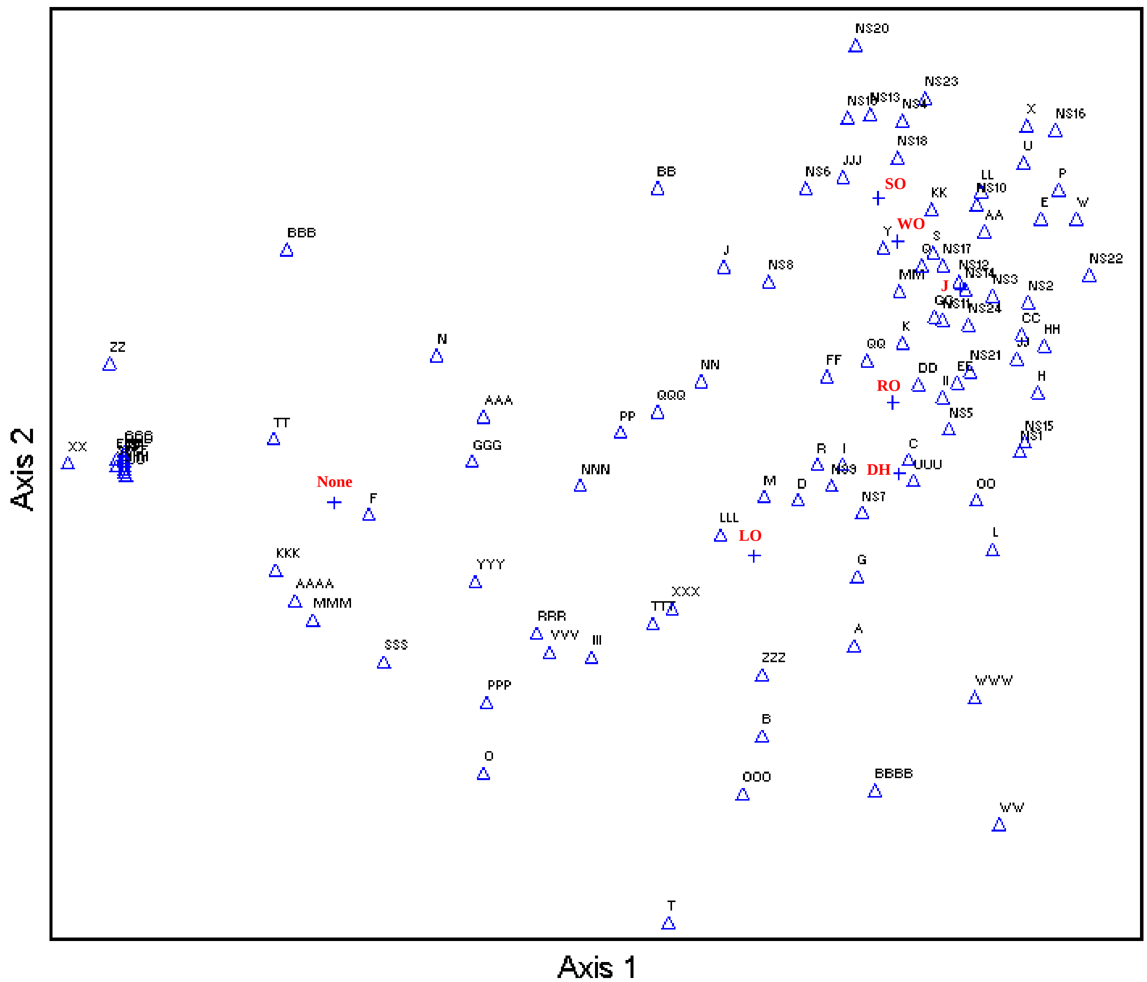

Figure 2: Non-metric multidimensional scaling (NMS) scatter plot to show the important species that are in golden cheeked warbler nesting sites, Fort Hood, TX.

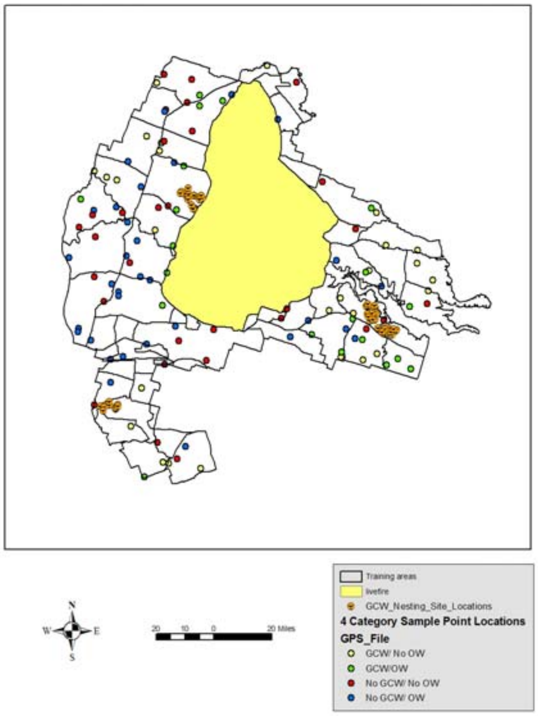

Figure 3: Locations of the five sampled plot categories located on Fort Hood, TX.

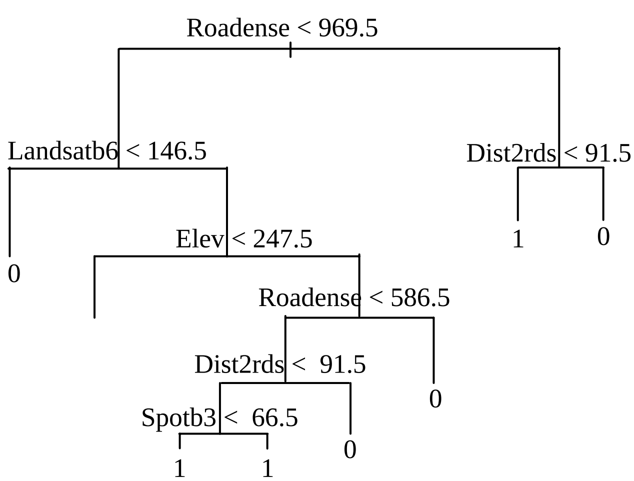

Figure 4: Classification tree model of GCW nesting site characteristics and map of predicted GCW nesting site habitat on Fort Hood, TX.