Assessment of Oak Wilt Threat to Habitat of the Golden-Cheeked Warbler, an Endangered Species, in Central Texas

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Abstract

A major epidemic of oak wilt, caused by *Ceratocystis fagacearum* (Bretz) Hunt, has been killing trees in Central Texas for at least 40 years. This has created large and expanding canopy gaps in the vast, homogenous live oak woodlands (*Quercus fusiformis* Small) in the Edwards Plateau region of Texas. The changes in stand structure may have detrimental consequences for an endangered migratory songbird, the golden-cheeked warbler (GCW, *Dendroica chrysoparia* Sclater & Salvin). More information is needed to assess the direct impact of oak wilt on the GCW and how oak wilt control measures might affect bird populations.
In our study, two surveys with different objectives were conducted at the Fort Hood Military Installation in Central Texas. In 2001, IKONOS 1-meter pan-sharpened satellite imagery was used to assess the incidence and severity of oak wilt. The disease was found to be the cause of mortality in 69 percent of the sampled plots. Only a small proportion of the oak wilt centers (12 percent) were located in designated GCW habitat. A second survey was conducted in 2003-04 to determine the key characteristics of GCW nesting sites and how they compare to those of oak wilt centers. This systematic survey was based on randomly selected cluster sample plots stratified in five resource categories based on the presence or absence of oak wilt, GCW habitat, or GCW nesting sites, or both. Stand densities ranged from 90 trees/ha (GCW habitat, no oak wilt) to 1,298 trees/ha (GCW habitat, nesting site). Juniper (*Juniperus ashei* Buchh.) to oak ratios ranged from 0.24:1 (GCW habitat, no oak wilt) to 6.57:1 (GCW habitat, no oak wilt). Classification tree analysis was conducted to identify independent variables associated with the presence of nesting sites in GCW habitat. Key variables in the resulting model included road density, selected Landsat and SPOT 10 satellite imagery bands, elevation, and distance to roads. In terms of tree mortality, the impact of oak wilt on GCW home ranges may be minimal. Further analyses are needed to evaluate the impacts of other site disturbances caused by oak wilt, such as fragmentation and alterations in stand composition. The results of this project will be used to aid natural resource managers when conflicts occur between endangered species management and oak wilt control.

Keywords: *Ceratocystis fagacearum*, classification tree analysis, endangered species, Fort Hood, golden-cheeked warbler, oak wilt.

Introduction

Woodlands were sampled on Fort Hood Military Installation that were typical of the oak-juniper savanna ecosystem in central Texas. The tree disease oak wilt, caused by *Ceratocystis fagacearum* (Bretz) Hunt, is a common disturbance throughout the region. Oak wilt management is a viable option for reducing losses from the disease, but the decision to implement control options is not always obvious. Further information is needed to assess the benefits of controlling oak wilt when compared to the costs of deploying expensive and disruptive management tactics. Specifically, the objective of this project was to determine whether oak wilt is having a detrimental impact on endangered species habitat. This information would presumably be useful to natural resource managers responsible for oak wilt management decisions. The following topics describe the study site, the status of an endangered species that may be influenced by oak wilt management decisions, and the disease.

Characterization of Central Texas Ecosystem

Central Texas is a unique, fragile ecosystem increasingly pressured by multiple land use objectives. A description of this ecosystem is important for understanding the complex issues being faced by natural resource managers throughout the region. Central Texas is dominated by the Edwards

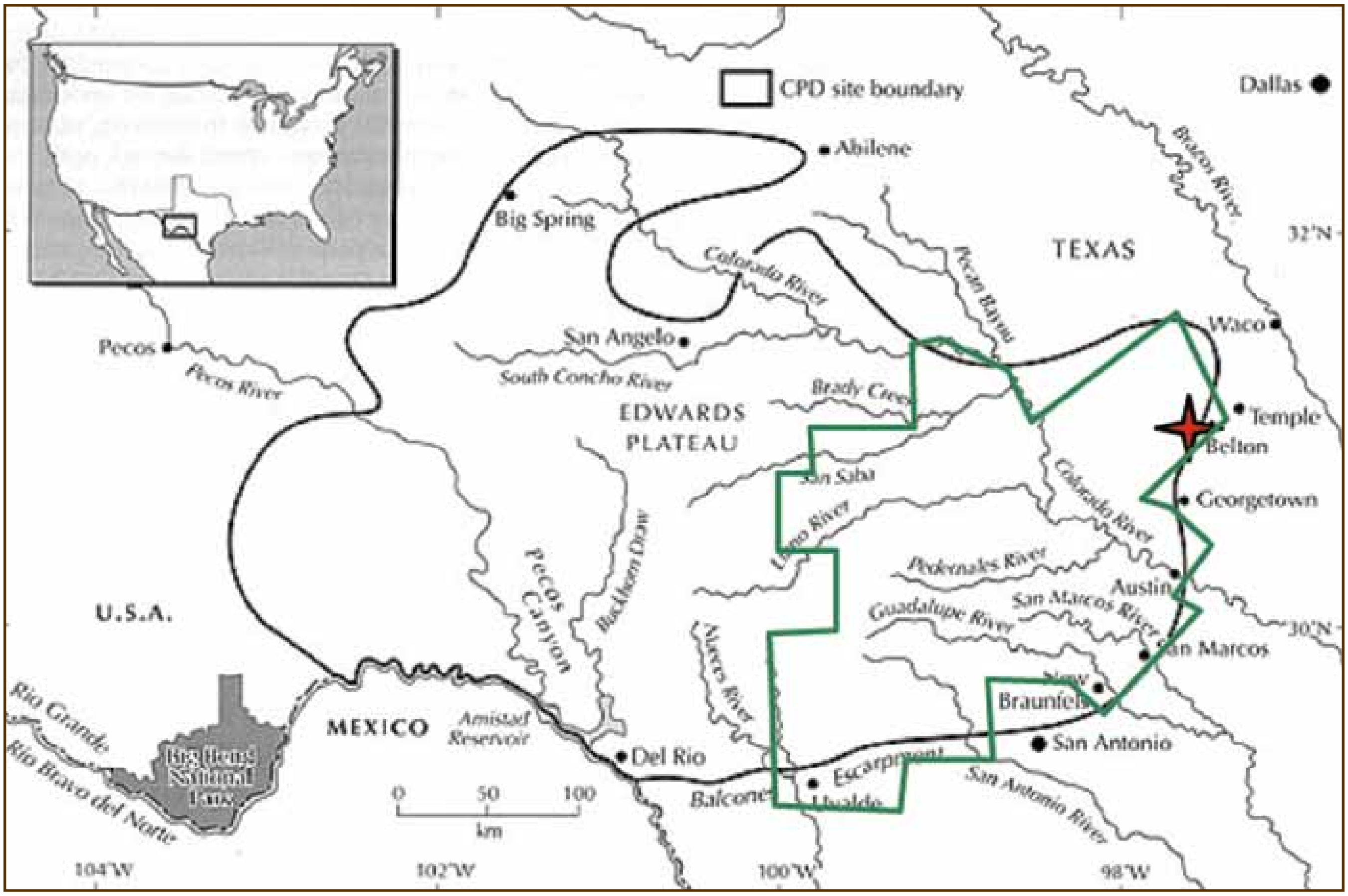

Figure 1—This map shows the region in Texas called the Edwards Plateau. Fort Hood is located with a red star, and the hill country is outlined in green.

Plateau, a limestone-layered tableland lying between latitudes 29°-32° N and longitudes 97°30'-102°30' W (Figure 1). The region is known as the Texas Hill Country because the topography is highly dissected by canyons separated by flat or sloping divides. There are prodigious outcrops of Cretaceous limestone, and the thin soils are mostly stony clay loam (Davis and others 1997, Jordan 1970). Rainfall is sparse at around 35 in per year, resulting in a low, semiarid temperate, semievergreen forest interspersed with grassland savanna. Historically, the Edwards Plateau was on the southern range of the Great Plains grassland prairie, but fire control and overgrazing have significantly changed the landscape (Reisfeld 1992). The dominant trees occur in large expanses and include live oak (*Quercus fusiformis* Small), Ashe juniper (*Juniperus ashei* Buchh.), and mesquite (*Prosopis glandulosa* Torr.) (Burns and Honkala 1990, Hayden and others 2001). Primary land uses are ranching, tourism, retirement urbanization, wildlife and hunting leases, and farming. In the past few decades, relatively low land costs have encouraged a doubling of population size owing to light industrial development and subdividing formerly large ranches into small ranchettes for retirement and tourism. The Edwards Plateau is a region of biological transition at the limits of the natural ranges of numerous plant and animal species. Many of these are threatened and endangered species.

Characterization of the Study Site: Fort Hood, Texas

There are no significant Federal parks or reserves in the Texas Hill Country. Opportunities for large-scale conservation management are limited. One exception is the largest Army installation in the United States, Fort Hood, covering 88,500 acres in Bell and Coryell Counties (Figure 2).

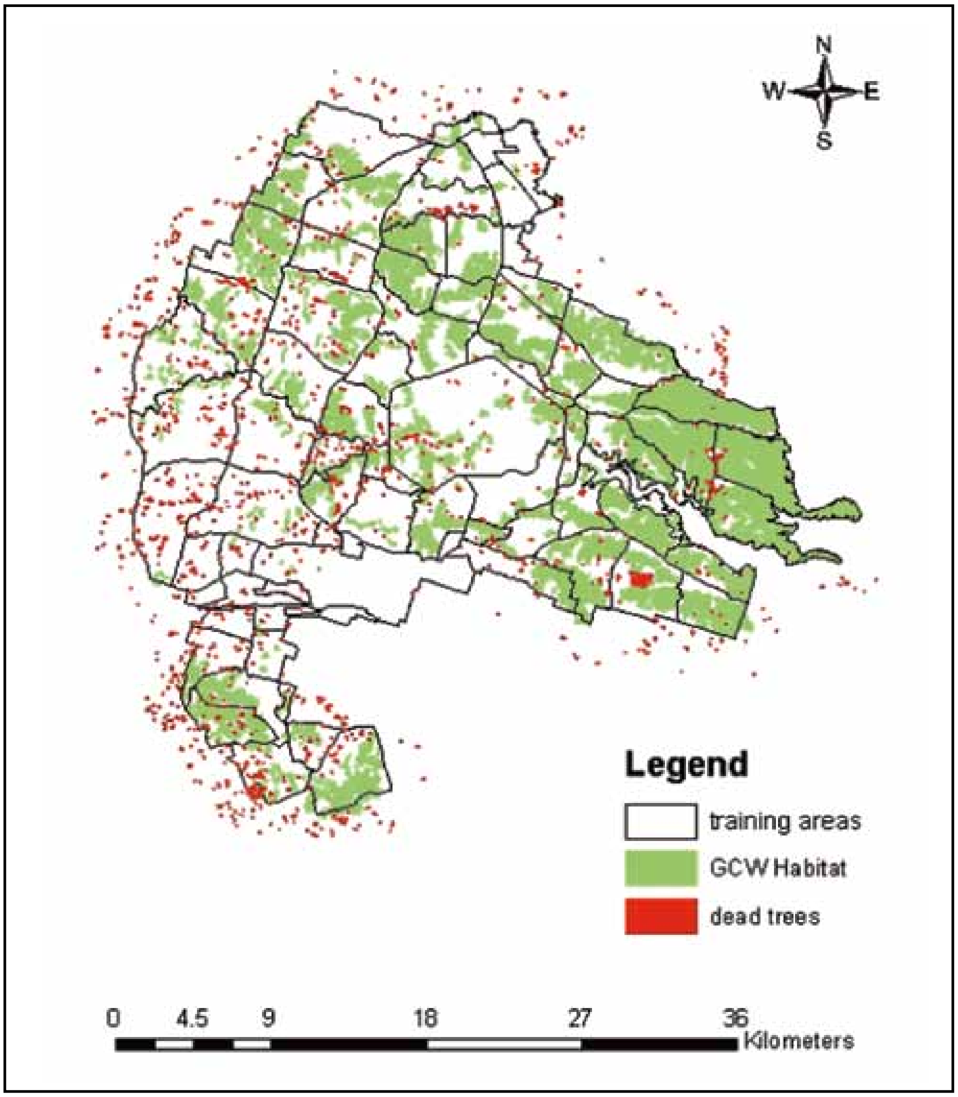

Figure 2—Photointerpreted polygon, training areas, and golden-cheeked warbler habitat at Fort Hood, Texas.

Fort Hood, the home to two U.S. Army divisions, has the advantage of being under a single management authority and operates under the auspices of the Endangered Species Act. Fort Hood was originally established on privately held ranchland, consisting of 65 percent perennial grassland and 30 percent forest/woodlands (Hayden and others 2001). A full range of military training operations is conducted at Fort Hood, including large-scale troop and vehicle movements, live-fire weapons exercises on extensive training ranges, and realistic air attack and air transport missions. Also, there are large expanses of cattle grazing under lease through cattlemen's associations. Sections of Fort Hood are available for public recreation, including water sports, hunting leases, mountain biking, off-road vehicles, and hiking. Soil compaction, vegetation damage, and erosion are just a few of the disturbances having an impact on the fragile Fort Hood topography (Chenault 2005). Land management activities at Fort Hood are conducted under plans designed to protect and mitigate effects on the habitats of a number of endangered species while repairing rangeland and adapting sites for military training activities. These multiple land use objectives often conflict, providing an ideal location for studying the consequences of controlling oak wilt within endangered species habitat.

Association between Golden-Cheeked Warbler and Oak Wilt

A migratory songbird inhabiting Fort Hood, the endangered golden-cheeked warbler (GCW, *Dendroica chrysoparia*), is of particular interest to conservation specialists, wildlife experts, and military planners. The original listing of the GCW as threatened and endangered was in 1990 (USFWS 1990). The breeding and nesting requirements of the GCW are particularly dependent upon certain characteristics of the oak/juniper savannas of central Texas (Kroll 1980). As a migrating species, the GCW overwinters in Central America and southern Mexico and returns to Texas in the spring for 3 to 4 months (Ladd and Gass 1999). While in Texas, the warbler inhabits woodlands comprising mature junipers with shedding bark that is used for nesting. Oaks are required for foraging because they support high populations of Lepidopteran insects during the breeding season (Kroll 1980). Feeding and breeding GCW habitats may be considered one and the same. These warblers forage for insects in oak tree canopies within their home ranges (Kroll 1980, Pulich 1976, Simmons 1924, Smith 1916, Wahl and others 1990), and nests have been found in Ashe juniper, Texas red oak (*Quercus buckleyi* Buckl.), post oak, (*Q. stellata* (Wangenh.)), Texas ash (*Fraxinus texensis* (Gray) Sarg.), and live oak trees in Fort Hood (Hayden and others 2001). Suitable habitat usually consists of steep canyon slopes or rugged terrain (Moses 1996) with some proximity to a source of water. About 21 850 ha, or 24.7 percent of the total installation, is designated GCW habitat (Dearborn and Sanchez 2001). Urbanization, fragmentation of breeding habitats for agricultural purposes, and predators are the primary reasons given for the decline in GCW numbers throughout its northern range (Moses 1996, USFWS 1990). Although the additional woodland disturbance caused by oak wilt is mentioned in the GCW recovery plan as a factor with the potential to impact GCW populations, it needs further study (Keddy-Hector 1992).

Ceratocystis fagacearum is a destructive pathogen causing enormous losses of oaks throughout Central Texas (see Web site of the Texas Forest Service http://www.texasoakwilt.org). In terms of numbers, live oak is the species most severely affected by oak wilt. The fungus grows through connected root systems of live oak resulting in large, expanding patches of dead and dying trees. In red oaks (gen. *Quercus*, subgenus Erythrobalanus) such as Texas red oak, the pathogen can grow briefly as a saprophyte forming fungal pads under the bark, thus making spores available to insect vectors. These two modes of transmission, through roots and by insect vectors, strongly influence the spatial distribution of the disease. Root transmission in live oaks kills larger numbers of trees, but insect transmission initiates new disease centers.

Oak Wilt Management Concerns and Objectives

Oak wilt control on a landscape scale involves removal of large numbers of trees, both healthy and diseased, and digging deep trenches on the perimeters of disease centers. These measures prevent inoculum formation and spread of the pathogen through root connections (Appel 1995). They are expensive and result in a great deal of environmental disruption in order to successfully control the disease. Resource managers must therefore be able to assess the potential impact of the disease and the benefits resulting from costly control measures. Given the conflicting land management objectives throughout the central Texas region, the decision to undertake oak wilt control on the landscape level can be difficult to make. We have initiated long-term studies on Fort Hood to assess the impact of oak wilt on GCW habitat and to contribute this knowledge in the oak wilt management decision process.

Methods and Materials

Separate surveys were conducted to assess the incidence of oak wilt on Fort Hood and to determine the effects of the disease on GCW populations. Each of the surveys incorporated satellite imagery into a geographic information system, ground surveys, and data analysis with various statistical approaches.

2001 Survey

The goal of the 2001 survey was to estimate the incidence of oak wilt at Fort Hood. In order to complete a survey of the entire installation with a minimum of personnel, IKONOS 1-m pan-sharpened satellite imagery was obtained for Fort

Hood that included a buffer area extending 1 mi beyond the boundary (Pacific Meridian Resources, Emeryville, CA 94608). Survey lines separated by 330 m were transposed on the images utilizing the geographic information system ArcView (ESRI, 380 New York St., Redlands, CA 92373). Fort Hood is parceled by training areas (Figure 2), which were also used to aid photointerpretation. Images of the entire post were interpreted by a trained technician to select and map live and red oak mortality, presumably from oak wilt. Attempts were made to exclude brush clearing, wildfire, and obvious sources of mortality other than oak wilt. The imagery was coregistered to Orthophoto Quarter Quadrangles (DOQQS), and the mortality polygons were transposed to maps for ground truthing. A random sample of 10 percent of the photointerpreted polygons was selected for diagnosis. Oak wilt was diagnosed according to recognized symptoms of the disease in the field and laboratory isolation of the pathogen when necessary (Appel 2001).

2003–04 Survey

One of the goals of the second survey was to characterize typical GCW nesting sites and assess the threat posed by oak wilt to GCW populations. This goal was part of a larger project conducted in cooperation with the USDA Forest Service (USFS) Forest Health Technology Enterprise Team (FHTET, Fort Collins, Colorado) that focused on methodology to model and predict oak wilt incidence and severity. The tool being tested for these purposes was binary classification and regression tree analysis (CART) (Baker and others 1993, De'ath and Fabricius 2000). This nonparametric statistical technique results in a classification tree intended to explain variation of a dependent or response variable by a collection of independent, or explanatory variables. The dependent variable for the FHTET model was the presence or absence of oak wilt. Cluster sample plots (n = 80) were randomly selected using a Sample Points Generator (SPGen), an ArcView application, from four land classification 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. A fifth category consisting of known nesting sites (GCW/NS) was subsequently added as an additional dependent variable for a separate CART analysis. Plots in this category were known to have been occupied by GCW nesting pairs during 2002–03, in contrast to plots in the other four categories. In these latter plots, GCW habitat was designated according to stand characteristics based on aerial photography and ground surveys. Designated GCW habitat is characterized as having high densities of mature junipers, the availability of deciduous hardwoods (primarily oaks), and a proximity to water (Hayden and others 2001). Independent variables for the model were derived from two sources of satellite imagery (2003 Spot 10 and Landsat TM satellite imagery) and geographic information system (GIS) files in the format of grid themes to be used in the ArcView program, e.g., slope, elevation, aspect, soils, distance to roads, road density, distance to streams, streams density, distance to lake, forest savanna, and landform. Ancillary data for Fort Hood were obtained from the Natural Management Branch office at Fort Hood. The classification tree was fitted to the spatial information database using the S-PLUS© statistical software package (Insightful Corp., Seattle, WA 98109).

Systematic surveys by ground crews from the USFS, the Nature Conservancy, the Texas Forest Service, and Texas A&M University were conducted in the summers of 2003 and 2004. Cluster sample plots were distributed throughout the four sampling categories. Each sample consisted of a 20-m by 20-m fixed plot subdivided into four subplots. Data collected for plots and subplots consisted of tree diameters, tree species identification, symptom development of infected trees, dominant overstory and understory species, and average tree height. In 2003, 80 systematic fixed plots were surveyed with equal numbers of plots in each of the four categories. In 2004, an additional 33 fixed plots were surveyed to increase sampling intensity, bringing the total to 28, 21, 32, and 32, in each of the four categories, respectively. Unlike the 2001 survey, all plots were located within the boundaries of Fort Hood. For the present study, the response or dependent variable was the presence of a GCW nesting site. The 24 GCW nesting site locations from 2002 and 2003 were obtained from the Nature Conservancy and surveyed in 2004 in the manner identical to the procedure described for the sample cluster plots. These plots were treated as a separate category resulting in five different categories for the analysis.

A preliminary analysis of the total survey data was conducted to determine frequencies of species, their sizes, and their densities in the various habitat categories. Tree species included deciduous hardwoods other than oaks (DH), live oaks (LO), red oaks (RO), shin oaks (*Q. sinuata* Walt.) and other white oaks (SO/WO), and junipers (J). Typical DHs at Fort Hood include cedar elm (*Ulmus crassifolia* Nutt.), walnut (*Juglans* spp.), hackberry (*Celtis* spp.), and Texas ash (*Fraxinus texensis* (Gray) Sarg.). The dominant red oaks are Texas red oak and blackjack oak (*Q. marilandica* Muenchh.). The primary white oak, other than shin oak, is post oak. The ratio of juniper to oak was also calculated for each habitat category.

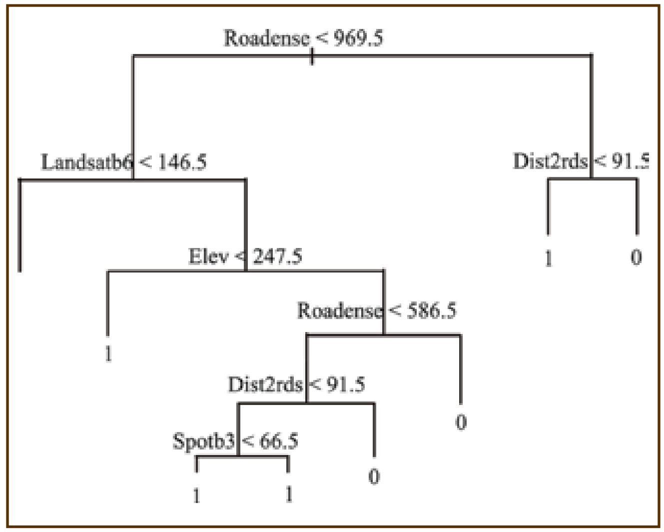

Figure 3—Classification tree model of golden-cheeked warbler (GCW) nesting-site characteristics.

Classification Tree Analysis

Tree-based modeling is an exploratory technique for uncovering structure in data (Clark and Pregibon 1992) and has been used with ecological data that are complex, unbalanced, and contain missing values. Classification trees explain variation of a single response variable by one or more explanatory variables. The response variable can either be categorical (classification trees) or numeric (regression trees) (De'ath and Fabricius 2000). The categorical response variable used in this analysis of Fort Hood data was the presence or absence of GCW nesting sites. The tree is constructed by repeatedly splitting the data in two mutually exclusive groups, each of which are as homogeneous as possible. The objective for classification trees is to partition the response variable (GCW nesting sites) into subsets of homogeneous groups while also keeping the tree reasonably small (De'ath and Fabricius 2000). The tree is shown graphically in Figure 3 and consists of three parts: the root node, branches, and leaves. The root node represents the undivided data at the top, the branches and leaves each represent one of the final groups beneath. To keep the trees as accurate as possible, cross validation is a widely used technique to look at the independent variables from the tree and calculate the amount of error produced by iteratively combining the independent variables. It starts with one variable, then adds another, and keeps adding independent variables until all independent variables have been included. The result of the cross validation is plotted with the x-axis as the number of terminal nodes and the y-axis as the misclassification error. The best model chosen is the one with the greatest number of terminal nodes with the least amount of misclassification error. The original tree was then pruned to the best model chosen from the cross validation results.

S-PLUS© statistical software was used to fit the classification tree to the Spatial Information Databases for each model (TREE, S-PLUS©, Statistical Sciences 2000). Twenty-two independent variable grid themes and 25 field data categories were used to construct the classification tree to describe the GCW nesting sites in Fort Hood. The independent variable grid themes consisted of each of the seven bands exported as grid themes from Landsat 5 TM and each of the four bands exported as grid themes from SPOT 5. The remaining 11 variables included slope, elevation, aspect, soils, distance to roads, road density, distance to streams, streams density, distance to lake, forest savanna, and landform. ERDAS Imagine Software Grid Export function was used to create the individual grid themes from each band in the imagery (ERDAS Inc. ERDAS Imagine V8.5. 2001, Atlanta, GA). The classification trees were run comparing the nesting site data with the data from GCW habitat with no oak wilt present (GCW/non-OW). The comparison was run with both the grid-theme data and

Table 1—Diagnostic results for a sample of tree mortality locations randomly selected from photointerpretation of satellite imagery of Fort Hood, Texas

Cause of mortality	No. of centers	Total
		Percent
Oak wilt	82	69
Military ops	1	0.8
Unknown	8	6.7
Brush piles	23	19.3
Blow down	1	0.8
Fire	4	3.3

field-collected data (total data), grid-theme data only (independent data), and field-collected data only (field data).

Results

2001–Survey

There were 1,164 polygons delineated as dying oak trees on the IKONOS satellite imagery. A sample of 119 polygons, or 10 percent of the total, was randomly selected for ground truthing (Table 1). Oak wilt was found to be the cause of mortality in 82 (69 percent) of the centers. The major factor, other than oak wilt, delineated as dying or dead trees on the imagery, was brush-clearing operations (19.3 percent), where piles of dead trees resemble the crowns of dead, standing live oaks. With two exceptions, all of the brush piles consisted of Ashe juniper cut and stacked during land-clearing operations. Relatively few other causes of mortality were found, including fire, wind damage, and damage to trees caused by military operations. At eight of the sites, trees identified as oaks were actually some other species, or causes of mortality were not readily identified.

Of the 1,164 polygons, 821 fell within the perimeter of Fort Hood. Of those 821 polygons, 144 or 18 percent were located in designated GCW habitat. Of the total 82 oak wilt centers identified in the survey (including the 1-mi buffer), 60 were located within the post perimeter. Only 7, or 12 percent of the oak wilt centers found within the Fort Hood perimeter, were located in designated GCW habitat.

Table 2—Species composition and average diameters of trees located in sample cluster plots for the 2003—04 survey

Habitat[a]	Total no. plots	Trees / ha	Tree type[b]	Total no. trees	Proportion of total	Ave. d.b.h.[c]
						Inches
GCW/non-OW	28	886	DH	115	0.12	3.8
			LO	38	0.04	6.6
			RO	58	0.06	5.5
			SO/WO	20	0.02	3
			J	762	0.78	6.9
GCW/OW	21	639	DH	55	0.11	5.3
			LO	103	0.21	10.6
			RO	72	0.15	6.6
			SO/WO	6	0.01	2.3
			J	301	0.62	5.6
non-GCW/OW	32	570	DH	190	0.26	5
			LO	260	0.33	11.5
			RO	165	0.23	8.1
			SO/WO	10	0.01	3.3
			J	105	0.13	5.1
non-GCW/non-OW	32	90	DH	42	0.37	4.4
			LO	8	0.07	9.0
			RO	13	0.11	4.5
			SO/WO	0	0	0
			J	52	0.45	6.1
GCW/NS	24	1,298	DH	185	0.15	5.36
			LO	34	0.02	6.76
			RO	122	0.1	7.7
			SO/WO	99	0.08	3.53
			J	806	0.65	6.98

[a] GCW/non-OW = golden cheeked warbler habitat, no oak wilt; GCW/OW = golden cheeked warbler habitat with oak wilt present; non-GCW/OW = non-habitat, oak wilt present; GCW/NS = habitat with nesting site present.
[b] DH = deciduous hardwood, LO = live oak, RO = red oak, SO/WO = shin oak or other white oak.
[c] d.b.h. = diameter at breast height.

2003–04 Survey

The highest stand densities, 1,298 trees/ha, were found at the nesting sites within GCW habitat (GCW/NS) (Table 2). Stand densities were

Table 3—Juniper to oak ratios for each of the four sampling categories at Fort Hood, Texas

Habitat[a]	J:O ratio
GCW/non-OW	6.57:1
GCW/OW	1.66:1
non-GCW/OW	0.24:1
non-GCW/non-OW	2.48:1
GCW/NS	3.16:1

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

also relatively high in habitat where there was no oak wilt (GCW/non-OW = 886 trees/ha). At oak wilt locations both within and outside of habitat, the stand densities were relatively lower. There were also notable trends in the species among the various categories. The proportion of juniper was far lower outside GCW habitat where oak wilt was present (13 percent) than in the plots located within GCW habitat (62 percent) (Table 2). Live oak density was greater in oak wilt locations, whether they were within (21 percent) or outside of habitat (33 percent), than in the uninfected plots within habitat (4 percent) or nesting sites (2 percent).

The juniper to oak ratios (J:O) varied widely among the four sampling categories. The highest J:O ratio was 6.57:1 in the GCW habitat where there was no oak wilt (Table 3). The lowest was 0.24:1 in oak wilt centers outside of GCW habitat.

Classification Tree Model

The classification tree model was developed using the plot survey data from nesting sites (GCW/NS) in 2004 and tested with plot survey data from one of the four habitat categories (GCW/non-OW) collected in 2003 and 2004. The nesting sites were assigned a value of 1, and the plots used to test against were assigned the value of 0. The analysis included the total data (field and independent data) from both the nesting-site plots and from the GCW/non-OW plots. Preliminary analysis indicated that the accuracy of the classification tree could be increased by modeling the soil types separately from the other independent data. The resulting classification tree had an accuracy of 98.2 percent with 8 terminal nodes (Figure 3). Discriminating variables included road density, Landsat band 6, elevation, distance to roads, and Spot band 3. Deviance was calculated for each variable by dividing the total deviance of the model variance by each of the variables produced (Kelly 2002). Road density explained the most variance (62 percent) in nesting site habitat location, followed by Landsat band 6 (43 percent), elevation (30 percent), road density (16 percent), distance to roads (6 percent), and Spot band 3 (3 percent). Plots that had a road density of less than 969.5 m per mi^2 had a higher probability of being in a site for GCW nesting-site habitat. Of all combinations of forest habitat conditions for this test, GCW habitat nesting sites are more likely to occur in areas having low road density (roadense < 969.5 m per mi^2), an elevation greater than 247.5 m, and a distance from roads of less than 91.5 m.

Discussion

Photointerpretation of the satellite imagery for the 2001 survey proved to be fairly accurate in identifying oak wilt. Brush piles resulting from roguing Ashe juniper were the features most often confused with oak wilt. Improved training would probably reduce many of these errors, but may not eliminate them altogether. Juniper clearing is a common practice in the Hill Country, and, in many cases, piles were visually indistinguishable from the crowns of dead live oaks.

Oak wilt was found to be a prominent feature and a major cause of oak mortality throughout Fort Hood. No other cause of mortality came close to the level found for oak wilt. However, the survey was not designed to determine the volume or extent of the other major cause of tree mortality—fire. It was noted that in certain locations, fire was a dominant cause of mortality and probably far exceeded the extent of oak wilt as a disturbance. A detailed analysis of the comparative effects of fire and oak wilt on habitat is warranted and will be considered in future studies.

Habitat requirements and tree species composition associated with GCW populations have been addressed in previous studies (Kroll 1980). The dependency of GCW on Ashe juniper bark as a source of nesting materials is a well-described phenomenon (Kroll 1980, Pulich 1976). There appear to be preferences for the sizes and densities of junipers. Kroll (1980) characterized good habitats as those with juniper-oak ratios of 1.35 to 1, and poor habitats with ratios of 2.27 to 1. We also found trends for the selection of nesting sites at Fort Hood. The juniper-oak ratios ranged from a high of 6.57:1 to a low of 1.66:1 in designated GCW habitat (Table 3). But, our results indicate that preferred nesting sites were in areas with a juniper-oak ratio of 3.16:1. Other variables determined to be characteristic of good habitats by Kroll (1980) were older Ashe junipers at wider spacing and relatively lower densities than those of poor habitats. In a previous study conducted at Fort Hood, Dearborn and Sanchez (2001) made pairwise comparisons of 13 vegetation variables between nest locations and nearby non-use vegetation patches. The only significant variable was canopy closure, which was greater at nesting sites than at the paired nest-free location. A stand density equivalent to 487 stems per ha for junipers and hardwoods combined was found at nesting sites, and junipers dominated hardwoods in all size classes. Nesting sites were characterized as having dense vegetation and nearly complete canopy closure dominated by junipers (Dearborn and Sanchez 2001). The nesting sites in our survey appear to have higher stand densities than those surveyed by Dearborn and Sanchez (2001), but we included smaller diameter stems in the survey protocol. The trends in both surveys are consistent. Of all habitats surveyed, our results confirm that GCWs prefer dense vegetation with high juniper densities.

Live oaks dominated sites where oak wilt occurred outside of GCW habitat. Within GCW habitat, the highest levels of live oaks also occurred in oak wilt centers, with a large decrease of live oak density at nesting sites and randomly selected habitat sites. The average diameters of live oak were larger in oak wilt centers than in healthy plots. A similar trend, although not as pronounced, was observed for the deciduous oaks. Oak wilt appears to be less likely to occur in places where the proportion of oaks is relatively low, such as GCW nesting sites. The incidence of live oak depends, for the most part, on availability of susceptible hosts, availability of inoculum, occurrence of infection courts (fresh wounds), and existence of nitidulid vectors (Appel 2001). Red oak density was fairly consistent among the different plot types, so inoculum availability in the form of fungal mats was potentially the same. The most likely explanation relates to vector behaviors in the live oak–dominated stands, but this suggestion would need to be confirmed with trapping studies. Our results also suggest that the site requirements for oaks may not coincide with sites preferred by GCW. The oak wilt threat to critical habitat may therefore be less than anticipated. A comparison of the GCW classification tree model developed in the present study for nesting sites, with the oak wilt model developed by FHTET, should be useful in determining whether oak wilt is a threat to GCW breeding habits.

Classification tree modeling proved to be a useful technique for establishing the site factors influential in determining the habitat for GCW nesting sites. When the comparison was made between designated habitats classified by The Nature Conservancy and nesting sites, the classification tree revealed that low road density was needed for ideal nesting-site locations. This agrees with other research findings that GCW prefers to have large unfragmented habitat for breeding and territory ranges (Kroll 1980, Ladd 1985, Moses 1996). There are, however, conflicting opinions on the GCW preferences for large blocks of unfragmented habitat or for sites bounded by edges of different vegetative composition (Moses 1996). In one study in Travis County (Texas), the estimated territory required per breeding pair of GCWs was 1.9 to 2.7 ha/pair (Ladd 1985). Kroll (1980) estimated ranges for breeding pairs were 4.49 to 8.48 ha/pair in a Texas state park. These estimates were noted to be larger than those from previous research, which resulted in estimates of territory sizes ranging from 0.81 ha to 2.55 ha per breeding pair (Kroll 1980). One effect of oak wilt is to fragment contiguous tree stands into treeless patches and expanding edges (Appel and others 1989). Dispersal distances for adult males averaged 223 m in a study conducted at Fort Hood during 1991–96, whereas juvenile dispersal distances were greater, averaging 4040 m (Jette and others 1998). These dispersal distances, patch expansion, and the creation of edges by oak wilt requires further research to determine how the disease relates to the GCW beyond the consequences of direct loss of trees.

The effects of oak wilt on the landscape go beyond the destruction of trees. Gaps and edges are created, tree composition is changed, and woodland stand structure is altered. All of these effects may influence GCW populations and will require further analysis to confidently decide whether to manage the disease in the vicinity of GCW nesting sites. Oak wilt control activities need not be disruptive because they can be implemented when the birds are migrating. However, because oak wilt appears to fall in areas where oak densities are greater than those found in preferred GCW habitats, the simple loss of trees may not be sufficient justification to undertake expensive and disruptive oak wilt control methods.

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