THE USE OF GIS AND REMOTELY SENSED DATA IN PREDICTING THE OCCURRENCE OF TWO ENDANGERED AVIAN SPECIES IN CENTRAL TEXAS

A Thesis

by

TIFFANY CUMMINS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee, R. Neal Wilkins
Committee Members, R. Douglas Slack
Fred Smeins
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ABSTRACT

The Use of GIS and Remotely Sensed Data in Predicting the Occurrence of Two
Endangered Avian Species in Central Texas. (May 2006)
Tiffany Cummins, B.S., Western Kentucky University
Chair of Advisory Committee: Dr. R. Neal Wilkins

Over the last 50 to 150 years there has been widespread conversion of grassland to shrubland throughout the western United States. A major management concern on the Edwards Plateau is the encroachment of Ashe Juniper (*Juniperus ashei*). To facilitate brush management programs, I investigated relationships of two endangered species, the black-capped vireo (*Vireo atricapillus*) and the golden-cheeked warbler (*Dendroica chrysoparia*), with their habitats at the landscape level. GIS (Geographic Information Systems) and remotely sensed data, such as Landsat imagery, DEMs (Digital Elevation Maps), and DOQQs (Digital Ortho Quarter Quads) were used to evaluate vegetative and geomorphic features within both 100m- and 400m-radius areas surrounding occupied and (assumed) unoccupied sites. Stepwise-logistic regression was used to develop probability models for each species within a catchment and was then applied to the entire Leon River Watershed and evaluated for accuracy. Golden-cheeked warblers were identified in areas with mean juniper cover greater than 70%, mean departure from North (aspect), and maximum slope. For black-capped vireos, mean shrub cover, mean departure from North, and mean slope were important in habitat selection. Variables at the 400m spatial scale best identified areas of probable occurrence for both species, indicating that features of landscape surrounding a territory may play an important role in habitat selection.

DEDICATION

To Dr. Michael Stokes, for all the support and guidance that you have provided me.

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INTRODUCTION

Woody Species Encroachment on the Edwards Plateau, Texas

Over the last 50 to 150 years, there has been widespread conversion of grassland to shrubland throughout the western United States (Wilcox 2002, Rollins 2000, Diamond et al. 1995, Smeins et al. 1997, Archer 1989, Archer et al. 1988). According to Smeins et al. (1997) the primary mechanisms behind this shift are the decrease in fire frequency due to climate change, fire suppression, and an increase in herbivory by livestock, both in numbers and in intensity of use. In central Texas, Ashe juniper (*Juniperus ashei*), redberry juniper (*Juniperus pinchotii*), and mesquite (*Prosopis glandulosa*) have been the primary source of increased shrub cover (Archer et al. 1988, McPherson et al. 1988, Fowler and Dunlap 1986, Burkhardt et al. 1976).

Historically, the Edwards Plateau of Central Texas was a fire-maintained savanna with live oak (*Quercus virginiana*) as the primary woody species (Fowler and Dunlap 1986, Gould 1962). As settlement occurred, fire suppression and intensive grazing increased, providing favorable conditions for invasion of woody species in the region, particularly *J. ashei* (Fuhlendorf, et al. 1997, Fowler and Dunlap 1986). A 1993 US Department of Agriculture report estimated that 8.6 million acres of land in Texas was dominated by *J. ashei* (Sullivan 1993). Although there appears to be an increase in the volume of juniper as a whole, Van Auken (1993) notes that mature juniper is lacking and suggests past cutting and fire as possible causes. Smeins et al. (1997) explain that between the 1880's and 1950's, following the settlement of Texas, mature juniper stands were removed in large quantities for development. When it grew back, it returned as second and third growth juniper whose bushy multi-stem structure differs

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This thesis follows the style of The American Naturalist.

greatly from the tall, single stem, more open bottom structure of mature primary growth juniper. This translates to a landscape with dense stands of shrubby, clumped immature and second growth juniper. This poses a problem as such stands of juniper provide little to no benefit for many species of important wildlife or livestock (Hamilton 2000, Lyons et al. 1998, Rollins and Armstrong 1997, Sullivan 1993) and decreases herbaceous and woody species diversity (Yager and Smeins 1999, Lyons et al. 1998, Fuhlendorf et al. 1997) . Instead, most species prefer landscapes comprised of a mosaic of woody cover and open areas (Juarez 2005, Hamilton 2000, Rollins and Armstrong 1997, Sullivan 1993).

Ashe juniper is a fire sensitive, phreatophytic species which due to its drought tolerance has a competitive advantage on dry, eroded, and nutrient poor sites (Sullivan 1993). In the Edwards Aquifer recharge area of Texas and many other locations throughout the southwestern United States spreading juniper communities may be contributing to reduced groundwater recharge and springflow (Wilcox 2002, Wu et al. 2001, Thurow 2000). Juniper’s high capacity for interception of moisture and the fact that the deep rooted junipers are often found in regions with shallow soil and permeable parent material supports this concern (Blomquist 1990, Wilcox 2002, Wu et al. 2001). It is believed that juniper eradication in areas where the soil is deeper and forage higher have less effect on stream flow than areas with more shallow soil, like the Edwards Plateau (Wu et al. 2001). They found that brush management on areas with shallow soil and high water yield resulted in twice the increased water yield than sites with deeper soil and higher forge density.

The Edwards Plateau is described by Gould (1962) as “well drained”, with shallow soils underlain by limestone, caliche, or granite and is situated above the

Edwards Aquifer which is the primary water source for both San Antonio and Austin, TX (Wilcox 2002, Smeins et al. 1997). San Antonio is the tenth largest city in the US and the only major city that gets its entire water supply from a single source. As such, brush management programs are currently being implemented to manage this important water resource. These brush management programs are aimed at increased water yield. Such management could be beneficial to livestock, forage production, and the enhancement of wildlife habitat (Hamilton 2000). Species likely to benefit from this management include game species such as the white-tailed deer (*Odocoileus virginianus*) (Hamilton 2000, Rollins 2000), northern bobwhite quail (*Colinus virginianus*), and the wild turkey (*Meleagris gallopavo*) (Rollins 2000) as well as non-game species including both the black-capped vireo (*Vireo atricapillus*) (Grzybowski et al. 1994) and the golden-cheeked warbler (*Dendroica chrysoparia*) (Rollins and Armstrong 1997).

Avifauna

Many Neotropical bird species have attracted attention recently due to population decreases throughout their ranges (Holmes and Sherry 2001, Dowling 1996). A Neotropical migrant bird, as defined by Partners in Flight (PIF), is a species that breeds primarily in the United States or Canada’s temperate zone and winters primarily in the tropics (Faaborg 2002). Such avifaunal declines have been documented in both fragmented (Faaborg 2002, Dowling 1996, Donovan et al. 1995) and unfragmented habitats (Faaborg 2002, Holmes and Sherry 2001) since 1966 (Partners in Flight 2001*b*, Donovan et al. 1995).

Within the Edwards Plateau and Oaks and Prairies Physiographic regions of central Texas there are several high priority Neotropical species including the golden-cheeked warbler (GCWA), black-capped vireo (BCVI), Bell's vireo (*Vireo bellii*), and the painted bunting (*Passerina ciris*) (Partners in Flight 2001a). All four of these species as well as the northern bobwhite, which is a permanent resident, are classified by PIF as possessing a level 5 population trend (PT) with breeding habitat threats ranking from moderate to severe. A level 5 PT is defined as a population that has exhibited a decrease of at least 50% in the last 30 years (Partners in Flight 2001b). Multiple sources have been cited as possible factors in the population declines of these four species. Possible factors include loss of habitat due to fragmentation in both their breeding and wintering grounds as a result of agriculture and urban spread, increased brood parasitism (particularly by the brown-headed cowbird, *Molothrus ater*), decreased pairing success (Faaborg 2002, Holmes and Sherry 2001, Penhollow and Stauffer 2000, Brennan 1999, Lowther et al. 1999, Hopp et al. 1995, and Brown 1993) and loss of grasslands resulting from woody encroachment (Partners in Flight 2001a).

Brown-headed cowbirds pose a threat for over 200 avian species (Barber and Martin 1997, Lowther 1993) of which 144 species have been recorded as raising cowbird young oftentimes in place of their own. Many of these parasitized species are Neotropical migrants (Robinson et al. 1993). The Bell's vireo was ranked the 15th most parasitized species by the brown-headed cowbird (Lowther 1993) and is recorded by Brown (1993) in a California study to have had between one third and one half its nests parasitized. Cowbirds are also known threats for the black-capped vireo and the golden-cheeked warbler. Hayden et al. (2000) report that parasitism rates of black-capped vireo on Fort Hood, Texas, were at 90.9% before the brown-headed cowbird removal program was implemented in 1988 and have since dropped to 12.6%. A study done at Fort Hood between 1991and 1997 estimated the parasitism rate at 29.9%

(Barber and Martin 1997). During this same period, 1991-1997, Jetté et al. 1998 found 8.6% of the golden-cheeked warbler nests were parasitized, and cowbirds are the only known species to parasitize golden-cheeked warbler nests (Ladd and Gass 1999). Two other studies, one in Kendall Co. (1962-1964) and the other in Travis Co. (1993-1995) found parasitism rates at 68% and 14%, respectively (Ladd and Gass 1999).

Two Neotropical migrant species, the golden-cheeked warbler and the black-capped vireo have been designated by the U.S. Fish and Wildlife Service as Endangered (U.S. Fish and Wildlife Service 1987, 1990). Both are species that breed primarily throughout central Texas (Campbell 1995) and have recovery plans that include the implementation of land management strategies aimed at reducing habitat loss and increasing suitable habitat availability on both public and private lands (U. S. Fish and Wildlife Service 1991, 1992). These management methods included controlled burns, application of chemical poisons, grazing management, as well as mechanical removal of encroaching juniper. In order to judge which management method should be applied to an area, it is necessary to identify and understand habitat features that are important for effective management of endangered species (Grzybowski et al. 1994). This is particularly true when the species are subject to rapid changes of their habitat, as are both the golden-cheeked warbler and the black-capped vireo. For both species, a rapid decrease in suitable nesting habitat will result in a decrease in successful nesting and fledging of young (Grzybowski et al. 1994). With an average lifespan of five years (Campbell 1995), a decrease in successful nesting and fledging will result in a rapid decrease in population numbers.

Historically, the black-capped vireo bred from north central Mexico through central Kansas (Graber 1961). Presently, this species is known to breed only from the

SW Tamaulipas in Mexico through central Texas, particularly the Edwards Plateau, and into 2 counties in central Oklahoma (Farquhar and González 2005, Campbell 1995). The Texas population is distributed through the oak (*Quercus spp.*)-cedar (*Juniperus spp.*) woodlands of the Hill Country and Balcones Escarpment of the Edwards Plateau (Graber 1961). In Eastern Edwards Plateau, breeding habitat is patchy, deciduous woody cover subject to periodic fire, and mixed with little to no juniper (Grzybowski et al. 1994). It is also important that the vegetation cover reach the ground as the birds nest only 1-6 feet above the ground (Campbell 1995). Overgrazing, drought, and fire suppression in these areas result in reduced black-capped vireo habitat (Campbell 1995, Graber 1961). Brown-headed cowbird parasitism is a factor thought to influence population declines. Unlike many other bird species, black-capped vireos abandon parasitized nests instead of just removing the cowbirds eggs.

Of the 613 bird species reported in Texas, the golden-cheeked warbler is the only endemic nesting bird (Ladd and Gass 1999) and it breeds exclusively in the cedar breaks of the Edwards Plateau (Campbell 1995, Vidal et al. 1994, Kroll 1980). The large contiguous blocks of mature juniper-oak woodlands that served as breeding habitat in the past have declined. Kroll (1980) explains that they are dependent upon mature juniper trees (generally greater than 40 years old) for nesting and as well as on oaks for forage. The decline of the golden-cheeked warbler populations is believed to be, in part, the result of habitat reduction and fragmentation of golden-cheeked warbler nesting habitat (U. S. Fish and Wildlife Service 1992, Campbell 1995, Beardmore 1994). Overbrowsing by white-tailed deer, goats, and exotic wildlife species, on seedling oaks and other deciduous trees which are important to warbler habitat (Campbell 1995) as well as clearing of mature juniper trees (Ladd and Gass 1999) are contributing to the decrease in both current and future suitable habitat. Another possible factor is brood parasitism by the brown-headed cowbird (Jetté et al. 1998).

Habitat Modeling

Ecosystems are three-dimensional segments of the earth where life forms and environment meet (Cleland et al. 1997). A primary ecological question is: why does a species occur in one place but not another (Caughley and Sinclair 1994)? The study of relationships between a species and its environment is a common theme of much ecological research; however, today it is moving to the forefront of conservation and planning (Seoane et al 2004). A common approach to understanding a bird's relationship to its habitat is to examine the local vegetation found in the patches surrounding individuals of that species (Penhollow and Stauffer 2000). However, evidence suggests that birds are also impacted by the landscape surrounding their own patch (Dearborn and Sanchez 2001, Penhollow and Stauffer 2000, Rolstad et al 2000).

The wildlife-habitat relationship system and the habitat suitability index developed by the United States Fish and Wildlife Service were among the first habitat models used to predict wildlife presence. However, these models were based on literature reviews and did not pertain to well-defined populations (Dettmers and Bart 1999). They were not based on statistical models, and many were not field-tested, or they performed poorly when tested.

The use of Geographic Information Systems (GIS) and remote sensing technologies in the field of wildlife management has grown in the last decade (Allen 1994). Models developed using GIS and data derived by remote sensing can be effective tools for conservation planning and management, as well as reducing land use conflicts and development costs (Wu and Smeins 2000). The use of GIS in field ornithology is encouraged by Shaw and Atkinson (1990) to reduce labor.

Studies such as that by Debinski et al. (1999), which use habitat categories from GIS and remotely sensed data to relate various habitats to species distributions and Dettmers and Bart (1999) which developed a model based on presence data for nine songbirds and used it to predict the amount of good habitat and its spatial distribution., demonstrate the versatility of such data. Another study by Mitchell et al. (2001), predicted the distribution of birds based on combined micro-habitat and landscape models. They found that “coarse landscape (large scale) characteristics are most important to migratory bird species that are limited in the number of habitats that they can use for breeding”. These studies and our knowledge of black-capped vireo and golden-cheeked warbler declining breeding habitats suggests that both species make good candidates for a GIS habitat assessment model developed.

The use of remote sensing data and the growing need to assess vegetation spatial patterns and predict response to restoration or sustainable management has also become more important in recent years (Dymond and Johnson 2002). Remotely sensed data provide some advantages over data collected in the field, as it is often lower cost for a larger area, can be imported directly into a GIS system for analysis, and can easily be used to monitor change in an area over time (Mack et al. 1997). The various forms of available remotely sensed data provide information that is multidimensional. Horizontal, vertical, multi-spectral, and in some cases multi-temporal data can be derived from remotely sensed data (Innes and Koch 1998). Edwards et al. (1996) state that “as conservation efforts begin placing greater emphasis on landscape scales, there is a need to make better use of site- and species-specific habitat relation models in predicting broad-scale spatial distributions", the scale dimensionality provided by remote sensing provides a means to better reach that goal.

Remote sensing data does have its limitations and drawbacks; for example, the spatial and temporal scales of interest may not be easily resolved from available data but many species distribution models have been successfully derived using this type of data (Mack et al. 1997). Franklin and Steadman (1991) used GIS and remote sensing data to map habitat for Polynesian birds on Cook Islands. In addition, Knick and Rotenberry (1995) used Landsat data to evaluate landscape characteristics of fragmented shrub steppe on passerine birds. Further, Thompson and Klassen (1980) used Landsat to map caribou habitat in Canada, while Edwards et al. (1996) used Landsat to evaluate habitat relation models for terrestrial vertebrates. The lowest omission and commission errors, thus highest accuracy, were exhibited by the bird (1.86%, 7.51%, 90.63%) and mammal (4.92%, 11.50%, 83.58%) habitat relation models (Edwards et al. 1996).

Various species respond differently, and to varying degrees, to habitat disturbances due to differences in habitat requirements (Riitters et al. 1997). As Dearborn and Sanchez (2001) stated, "proper management of endangered species requires an understanding of habitat use at a variety of spatial scales". They further claimed that defining "suitable habitat" for birds requires recognition of habitat selection at a hierarchical scale which was supported by Penhollow and Stauffer (2000). Rolstad et al. (2000) used this approach to evaluate habitat selection as a hierarchical spatial process for the green woodpecker (*Picus viridis*). Thus, when investigating avian-habitat relationships and building habitat suitability maps it has been shown to be important to consider multiple spatial scales.

Scale is defined by Maurer (2002: 125-126) as “the resolution at which patterns are measured, perceived, or represented”. Species distribution results from “decisions” by an animal on a hierarchical series at varying spatial scales (Penhollow and Stauffer 2000). Thus it is important when managing a species to understand habitat use at varying spatial scales, particularly when working with endangered species (Dearborn and Sanchez 2001). Scale can be both fine and coarse, either spatial or temporal and the importance of a variable can vary in influence depending on scale (Gillespie and Walter 2001). Therefore it is important to use data that are relevant to the time and place you are researching and understand the limitations of each data set (Wiens 2002: 746-747). Landscape ecology emphasizes broad scale temporal and spatial arrangements within ecosystems (Saveraid et at. 2001). At all scales it is important to remember the roles of both biotic and abiotic factors and their interactions that can potentially impact habitat selection (Heglund 2002, Turner et al. 2001).

Habitat models have been used to determine habitat suitability, distribution, and abundance (Aspinall and Veitor 1993). These models, built using biotic and abiotic variables, have been useful tools for land managers, allowing them to test the effects of a treatment on a population when the pre-treatment population structure is determined (Wu and Smeins 2000).

Biotic factors such as vegetation have been used as a source of potential predictors because they generally provide a more direct link with reproductive success; however, topographic and climatic maps are easier to obtain, in some cases are easier to work with, and do not need to be updated as frequently (Seoane et al 2004). Abiotic factors include climate, elevation, aspect, slope, and the curvature of the land - i.e.

slope shape, concave or convex (Seoane et al. 2004, Turner et al. 2001, Butler and Goetz 1986).

Butler and Goetz (1986) discussed the impact that abiotic factors can have on vegetation, soil temperature, and air movement. Slope gradient influences infiltration rates, runoff, nutrients, and sedimentation processes which can impact vegetation development. Concave landscapes are moister and yield higher biomass than convex landscapes which tend to have sparser vegetation cover. Turner et al. (2001) discussed how (in the northern hemisphere) south-facing slopes receive more radiation than north-facing slopes. They also discussed how the shape of the landscape can influence the movement of wind and water, i.e. dispersal pathways, for wind blown seeds and in some cases even animals. Landform can also influence the frequency and spatial pattern of natural disturbances such as fire. Some examples of how topographic features such as aspect or slope can influence a species can be seen in a study done by Weiss et al. (1988) that found that “topographic diversity on several scales is a prime indicator of habitat quality for this butterfly (*Euphydryas editha*)”. They found that larvae developed into pupae earlier on warmer slopes and the availability of direct sunlight can be limiting to their survival. Seoane et al. (2004) found that although the predictive ability of the topo-climatic models was not as high as the vegetation models or the vegetation /topo-climatic models, they could be used to build a predictive avian habitat model. The lack of predictive power was found to be related to the higher number of potential predictors available for the vegetation and vegetation /topo-climatic models.

Remote Sensing

Remotely sensed data, such as LandSat and Light Dectection and Ranging data (LiDar), can be used to derive some of the biotic and abiotic factors used in habitat modeling. Remotely sensed data can be classified using either traditional or sub-pixel classifications. The primary difference between traditional classifications and sub-pixel classifications is the process that is used to develop a signature. Traditional classifications develop a signature by averaging the spectra of all pixels within a training set. The resulting signatures contain contributions to the signature from all materials present within all training pixels. They do not account for the “strength” of a pixel. In contrast, sub-pixel classification derives its signature from a component that is common throughout the training pixels. It produces a more “pure” material of interest (MOI) signature (Applied Analysis Incorporated 2003). Also, the sub-pixel classification allows the user to develop a signature for a MOI that is transferable between scenes.

All land cover types absorb specific portions of the electromagnetic spectrum giving it a distinguishable “signature” of electromagnetic radiation. The sub-pixel classification allows for the variability between like objects within the signature developed for each MOI. Some variability can also be caused by other materials present that may also be common therefore it is important to validate a subset of the predictions from the first signature development run. Pixels are predicted as accurate, over predicting percent cover, predicting the MOI cover were none was present, or not predicting occurrence were the MOI was present. This knowledge allows users to return to the input parameters and create a “tighter” signature for an MOI through identifying and eliminating variability within the signature introduced by non-target materials and false predictions (Applied Analysis Incorporated 2003).

Objectives

My primary goal was to determine factors related to GCWA (golden-cheeked warbler) and BCVI (black-capped vireo) occurrence during the breeding season; and then to develop some preliminary models for predicting site occupancy. The specific objectives were to (1) determine the predictive ability of remotely sensed topographic and vegetative variables in identifying habitats occupied by GCWA and BCVI at multiple spatial scales, (2) develop a series of alternative models to serve as candidates for predicting species occurrence across an area larger than that from which the original models were derived, (3) identify a “best model” by estimating the accuracy rates of all candidate models.

STUDY AREA

The broad geographic area of interest was the Leon River watershed as it traverses Coryell and Hamilton Counties in central Texas (Figure 1). This area includes 3 natural ecological regions: Lampasas Cut Plains, Grand Prairie and Western Crosstimbers (Texas Parks and Wildlife 2001). Elevation ranges from 183 to 549m (The Texas State Historical Association 2001). Ecological sites include steep adobe, low stoney hill, loamy bottomland, and clay loam (National Cartography and Geospatial Center 2002). The most intensive field work for this project occurred in the Coryell Creek sub-watershed which encompasses 22,027 ha of Coryell County and ranges from 183 to 455m in elevation (Coryell County Profile 2005).

The average maximum temperatures in July, 2004 for Hamilton and Coryell Counties were, 33.1°C and 32.2°C with the average minimum temperature in February, 2004 at -0.33°C and 1.55°C respectively (National Oceanic and Atmospheric Administration 2004). Average annual rainfall for this area ranges from 75cm to 81cm (The Texas State Historical Association 2001). Precipitation during the 2 years of this work was 139cm and 123 cm in 2004; and 67cm and 80cm in 2003 in Coryell and Hamilton Counties, respectively (National Oceanic and Atmospheric Administration 2004).

Woody vegetation includes live oak, Ashe juniper (Fowler and Dunlap 1986), red oak (*Quercus rubra*), pecan (*Carya illinoensis*), shin oak (*Quercus sinuata*), spanish oak (*Quercus texana*), post oak (*Quercus stellata*), and mesquite (*Prosopis glandulosa*), Texas persimmon (*Diospyros texana*) (The Texas State Historical Association 2001).

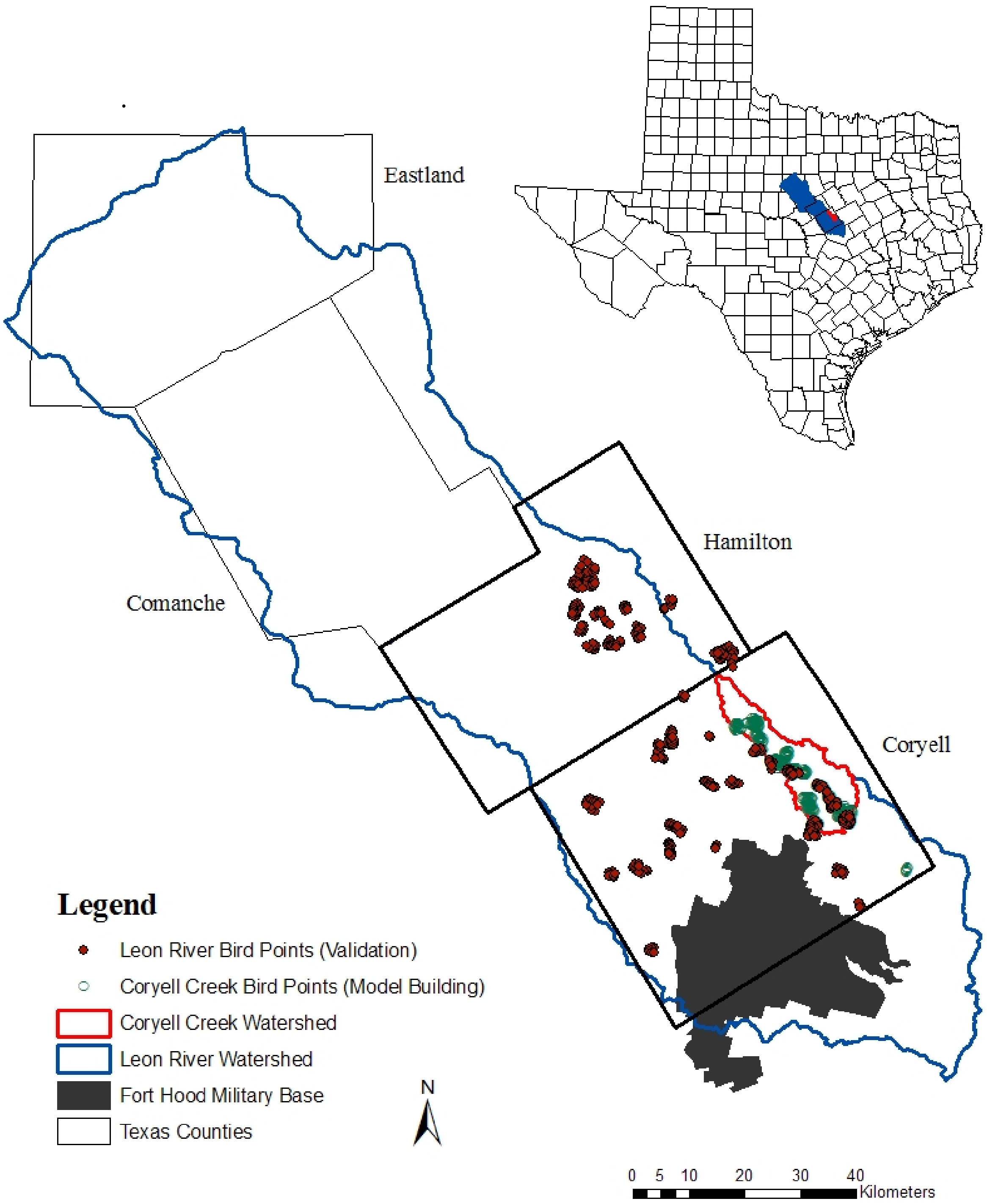

Figure 1. Study area and the Coryell Creek sub-watershed catchment within the Leon River Watershed. Hamilton and Coryell County are boldly outlined. Shown are both survey sites used for model building and model validation.

METHODS

Sample Site Selection

The area of interest for collecting bird site-occupancy data is the Coryell Creek sub-watershed. Most of the area is private farm and ranch land; survey locations were somewhat constrained by access to private lands. County appraisal records were used to construct a list of landowner contacts in the area. Using aerial photography, and on-the-ground validation, I reduced the pool of candidate properties by eliminating consideration of those not dominated by native rangelands. Sites were distributed among the remaining properties depending upon a combination of access rights and approximate spatial distribution across the area of interest. Once properties were selected and access confirmed, survey points were established across the property. Beginning at an arbitrary point, survey sites were systematically spaced. The goal was to sample sites representing the full range of available habitats.

Two independent datasets of survey points were collected for this study, one throughout the Leon River Watershed, and one within the Coryell Creek sub-watershed. The purpose of this was twofold. First, this was done to provide both a model building dataset and a model testing dataset. Second, we wanted to test the accuracy of a model whose data were collected within a subset of the study area when applied across the larger study area. A total of 400 survey points was placed throughout the Coryell Creek sub-watershed spaced at a minimum distance of 200m (Figure 2). Three-hundred and seventy-six survey points were collected within the Leon River Watershed, spaced at a minimum distance of 400m. The larger spacing within the Leon River Watershed was chosen to allow the model to be tested across the larger study area.

Survey Protocol

Species selected for survey included two focal species, the golden-cheeked warbler (GCWA) and the black-capped vireo (BCVI). Also included were northern bobwhites, brown-headed cowbirds, white-eyed vireos, bells vireos, and painted buntings. Surveys were conducted from mid-March until the end of May. Surveys started 15 minutes before sunrise and concluded by 1100 hours due to Bolisinger's (2000) observations that golden-cheeked warblers start singing 20 minutes before sunrise and do most of their singing during dawn hours. To reduce variability due to weather, surveys were not conducted under rainy or high-wind conditions. A fixed-radius (100 m radius) point count, following Hutto et al. (1986), was conducted at each site. Each site was surveyed for 12 minutes (hereafter referred to as a survey period).

Survey periods were broken up into 3 segments: the first segment consisted of a 6 minute auditory survey, the second segment was comprised of a 1 minute golden-cheeked warbler playback followed by a 2 minute auditory survey and the third segment was comprised of a 1 minute black-capped vireo playback followed by another 2 minute auditory survey. Playbacks were played on MP3 players attached to portable speakers. Individual birds heard or seen within a 100m radius were recorded and distance from the observer to the bird estimated. Each site was visited three times, once early in the breeding season, the mid-season, and late season. A site was classified as occupied if the bird was detected during any survey visit (Siegel et al. 2001). Presence or (assumed) absence data for all surveyed species were placed in a table containing the geographic coordinates for each point.

Survey data collected in 2003 using the same techniques described above were used to validate model reliability for use across a broader landscape. These data consist of 376 survey points spread throughout Hamilton and Coryell Counties at a minimum distance of 400m (Figure 3). This is hereafter referred to as the Leon River Watershed data.

Vegetation Surveys

Vegetation surveys were conducted at 161 sites throughout the Coryell Creek sub-watershed. Each site was broken into 4 quadrants using 4 cardinal directions as the X and Y-axis for 15m in each direction. Percent cover by category within each quadrant was visually estimated and placed into 6 categories that correspond with Landsat data output, and 2 categories of woody less than 1.5m. These are juniper, live oak, post oak, spanish oak, deciduous and shrub, juniper less than 1.5m and non-juniper woody cover less than 1.5m, and dead growth. Percent cover was first recorded as proportion occupied by woody cover versus open ground, then subsequently broken down into the 8 categories. Within each quadrant, ground cover was also estimated. Ground cover categories consist of prickly pear, herbaceous, bare, and rock. Average percent cover type at each point was calculated by averaging the values each category from all 4 quadrants (Appendix A).

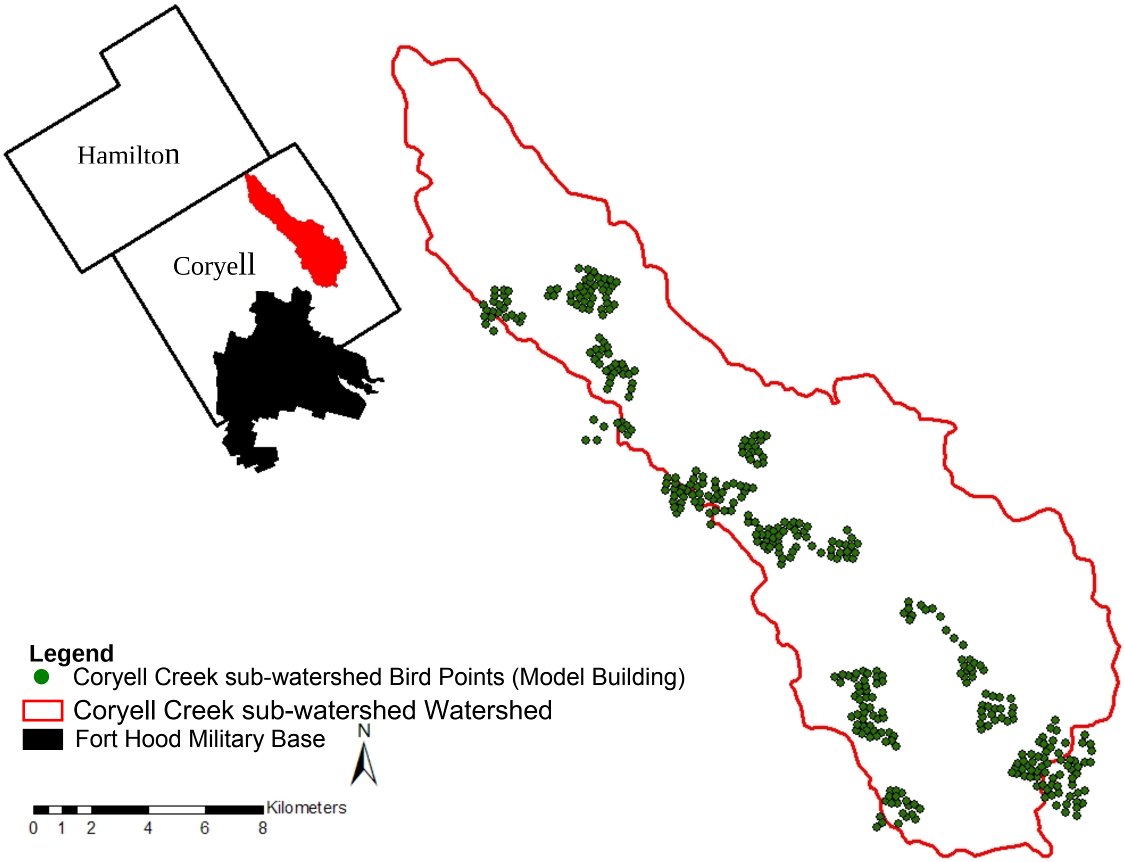

Figure 2. Locations of avian survey sites throughout the Coryell Creek sub-watershed.

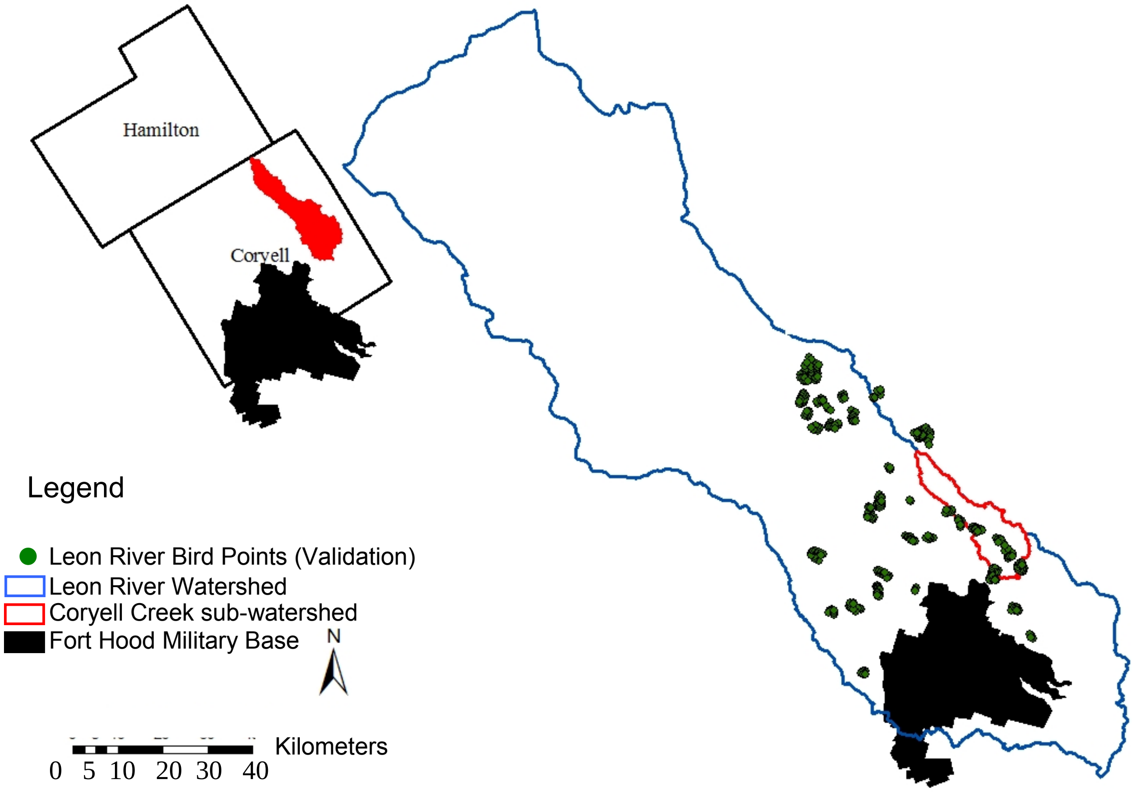

Figure 3. Locations of avian survey sites throughout the Leon River Watershed.

Image Classification

ERDAS Imagine ® software is a program used to analyze remotely sensed data. It was developed by Leica Geosystems specifically to analyze imagery. ERDAS Imagine software was used to perform a sub-pixel analysis of the Landsat TM imagery used in the development of the predictive occupancy models. The selected image was acquired on July 19, 2003 (Center for Space Research, 2003).

Imagery was collected on a clear day with minimal cloud coverage during the leaf-on phase of plant growth. Imagery from four possible dates was analyzed post classification to determine which image provided the most accurate data based upon ground validation.

The sub-pixel classifier within ERDAS Imagine performs a supervised, non-parametric spectral detection and quantification for a specific material of interest (MOI) at a sub-pixel, or 30m x 30m, level. This allows the user to determine the percentage of the MOI within a pixel, from 20% to 100% using a spectral signature (Applied Analysis Incorporated 2003). This process allows the user to discriminate between multiple MOIs within a mixed pixel (a pixel that contains more than one signature).

The sub-pixel analysis was used in place of the traditional supervised classification or unsupervised classification due to its ability to break down a mixed pixel into components and its transferable signature (Appendix B). A non-rectified image (one that has had objects within the 2-D image adjusted so that the relative distance between them is equal to the real distance on the 3-D curvature of the earth’s surface) was used for the classification to avoid “warping” pixels prior to analysis. The image was classified separately for each individual MOI (material of interest); these were juniper, live oak, spanish oak, post oak, deciduous, and shrub. The categories were selected to best approximate the majority of wooody vegetation found on the ground.

To develop a signature for each MOI, the following steps were taken. First, an area of interest was developed using pixels that are known to contain the target MOI, these are referred to as training pixels. The Global Positioning System (GPS) was used to locate specific areas to determine the approximate percent coverage for each target MOI thus allowing us to develop a spectral classification separate of the wildlife data (Aspinall and Veitor 1993). The corresponding pixels for these areas were located and used to develop training pixels. Automatic signature derivation, which takes all training pixels for a specific MOI and evaluates them for a common composition of spectral measurements (i.e. absorption and reflectance values), was used to produce the initial MOI signatures. Fifty new locations were selected, downloaded to GPS, and field validated to account for variability within the signature. This yielded a signature useful for the final analyses of the Landsat imagery for each MOI.

Multiple classifications were run for each MOI on the selected image by varying spectral criteria, i.e. acceptable standard error. All classification runs were compared to ground data and evaluated using linear regression. The strongest (most accurate) run for each MOI was then selected and used for all further data analyses requiring vegetation variables.

Once image classification was complete and classification runs selected, all vegetation layers were exported to ArcMap 8.0. Spatial Analyst rastor calculator was used to develop masks (a layer showing presence/absence at each pixel) for all vegetation layers. The resulting layers were areas of >20%, >50%, >70%, and >90% cover by each MOI at both the 100m and 400m radius.

GIS Database

Various GIS layers (described below) were used in the development of models[1]. ArcMap 8.0 was used for analysis except for when required extensions were only available for ArcView 3.3. Digital elevation models (DEMs) were downloaded from the TNRIS website (U.S Geological Survey, 2004). All DEMs were at a 30m x 30m resolution. ArcToolbox 8.3 was used to project them and convert them into ESRI grids. The 3-D Spatial Analyst extension, surface analyst option was used to generate percent slopes with a Z-factor of 1 and a 30 cell output. The Spatial Analyst rastor calculator was then used to convert the each grid output to a shapefile. Once shapefiles were completed for all necessary DEM quadrats, the new shapefiles were imported into ArcToolbox projection wizards and put in the proper projection. Finally, all DEM shapefiles were merged using the Geoprocessing wizard.

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[1] All GIS data was projected into WGS Nad 83 zone 14.

The DEMs and the 3-D Spatial Analyst extension, surface analyst option were then used to develop an aspect layer for the area. Northings and Eastings were then calculated from the aspect layer using the Spatial Analyst rastor calculator and the following formulas:

Northings 1: CON ([aspect] <= 180, [aspect], 0)

Northings 2: CON ([aspect] >180, 360 - [aspect], 0)

Northings: SUM (Northings1 + Northings2)

Eastings1: CON ([aspect] = -1, [aspect], 0)

Eastings2: CON ([aspect] >= 0 & [aspect] <= 90, 90 - [aspect], 0)

Eastings3: CON ([aspect] > 90 & [aspect] <= 180, [aspect] – 90, 0)

Eastings4: CON ([aspect] >180 & [aspect] <= 270, [aspect] – 90, 0)

Eastings5: CON ([aspect] >270 & [aspect] <= 360, 360 - [aspect] + 90, 0)

Eastings: SUM (Eastings1 + Eastings2 + Eastings3 +Eastings4+ Eastings5)

The DEMs were then imported into Surfer 8.0 to develop both plan curvature and profile curvature maps using the Grid Calculator. These maps were then converted into an ArcView grid using the surfer extension 2.8.

Finally, The ecological site shapefile was acquired from the Soil Survey Geographic database (SSURGO) hosted by the Natural Resource Conservation Service (NRCS) of the US Department of Agriculture (National Cartography and Geospatial Center 2002). These data were used since they contain the highest level of detail published by the National Cooperative Soil Survey. The file was published in Fort Worth, Texas, by the NRCS and was last updated on January 31, 2002. The map is in a 7.5 minute quadrangle format and includes detailed, field verified data.

Once all layers were completed they were imported into ArcMap along with both the Coryell Creek data and the Leon River data. Zonal statistics were then performed upon each data set respectively using both a 100m and a 400m radius buffer. These distances were used to address the findings of Magness et al (2005), which suggested that golden-cheeked warbler occurrence is more reliably predicted at a larger (400m radius) landscape scale when compared to fine scale 100m radius findings by Juarez (2005). The soils data at each landscape scale were converted into percent cover. The 7 most frequent ecological sites were used in this study.

Model Development and Verification

Mann-Whitney-U tests were used to test for differences in habitat variables according to known occupancy. Variables, for both the 100m and 400m spatial scales, were individually evaluated at the species level using univariate logistic regression (LR). Stepwise logistic regression was then used to screen variables, and multiple logistic regression applied to relate independent variables to known occupancy and develop a series of alternative models for predicting occupancy. Models were developed using the Coryell Creek data and then tested for reliability across the Leon River Watershed using a separate dataset.

Variables with a p-value >0.15 were eliminated. At each spatial scale, remaining variables ($p < 0.15$) were then evaluated using the Spearman's rank correlation coefficient (r_s) where $|r_s| > 0.15$ was considered significant. All possible variable combinations for both spatial scales were then evaluated using backwards-stepwise LR. Likelihood ratio statistic (Field 2000) was used to determine the removal of variables with the p-value set at 0.10 for removal and 0.05 for entry. Models were then evaluated using ROC (Receiver Operating Characteristic curve) and McFadden's Rho-square values, with the top five models for both species at each landscape scale selected for validation (Hosemer and Lameshow 2000). When possible, similar models were used at both landscape scales. Model intercept and variable coefficients were recorded.

The top five models for each species were then applied to the Leon River Watershed data to assess predictive capabilities using the following equation:

$$P = \frac{e^{[\text{Intercept} + (\text{coefficient } \alpha * \text{variable } \alpha) + (\text{coefficient } \beta * \text{variable } \beta) + \text{etc...}}}{1 + e^{[\text{Intercept} + (\text{coefficient } \alpha * \text{variable } \alpha) + (\text{coefficient } \beta * \text{variable } \beta) + \text{etc...}}}$$

Alternate thresholds for determining “occupancy” were then evaluated in an effort to minimize the proportion of false negative results (Pearce and Ferrier 2005).

RESULTS

Bird Abundance

A total of 2,400 individuals of 7 selected species were detected within Coryell Creek sub-watershed at 372 of the 400 survey sites (Table 1). At the majority of the sites (70.3%), more than one species was detected. The two most abundant observed species were the brown-headed cowbird (n = 1,518) and the painted bunting (n = 487). The least common species were the bell's vireo (n = 2) and the black-capped vireo (n = 35). The most widespread species was the painted bunting which occupied 73.8% of the sites, and the least widespread was the bell's vireo at 0.5% of the sites. Golden-crowned warblers were observed at 130, or 32.5 %, of the sites.

Species Co-occurrence

Analysis of co-occurrence revealed two significant associations between four of the seven species (Table 2). However, both detected associations were relatively inconsistent. Golden-cheeked warblers and northern bobwhites showed a negative association (Cramer's V = -0.124; $p \leq 0.05$); golden-cheeked warblers were 93.0% more likely to occur at a site where northern bobwhites were absent. A positive association was found between the brown-headed cowbird and the northern bobwhite (Cramer's V = 0.105; $p \leq 0.05$).

Ground Vegetation

Ten categories of mean foliage cover were recorded at 161 survey sites within Coryell Creek sub-watershed (Table 3). Cover categories include, Ashe juniper, live oak, spanish oak, post oak, deciduous (non-oak), shrub, hardwoods < 1.5 m, ashe juniper < 1.5 m, dead cover, prickly pear, overall woody cover, and overall open area.

Table 1. Number of individuals detected, number of sites occupied by species, and percent occupancy at 400 survey sites following 3 survey visits, in the Coryell Creek sub-watershed, Texas. A site was considered occupied if a species was found at the location at least one out of three visits.

Species Common Name	Scientific Name	Code[a]	# Indiv.	# Sites Occupied	% Occupied
Northern bobwhite	*Colinus virginianus*	NOBO	68	52	13.0
White-eyed vireo	*Vireo griseus*	WEVI	78	68	17.3
Bell's vireo	*Vireo bellii*	BEVI	2	2	0.5
Black-capped vireo	*Vireo atricapillus*	BCVI	35	27	6.8
Golden-cheeked warbler	*Dendroica chrysoparia*	GCWA	212	130	32.5
Painted bunting	*Passerina ciris*	PABU	487	295	73.8
Brown-headed cowbird	*Molothrus ater*	BHCO	1518	231	57.8

[a] Species codes for birds as found in the North American Bird Banding Manual (Gustafson et al. 1997).

Table 2. Species co-occurrence expressed as percent of sites occupied by species B out of all sites occupied by species A, and Cramer's values (V) of association between (significant only) species pairs, in the Coryell Creek sub-watershed,Texas.

	%, (V)						
	Species B						
Species A	NOBO 13.0[a]	WEVI 17.3	BEVI 0.5	BCVI 6.8	GCWA 32.5	PABU 73.8	BHCO 57.8
Northern bobwhite (NOBO)	—	19.2	1.9	3.8	17.3** (-0.124)	76.9	71.2** (0.105)
White-eyed vireo (WEVI)	14.7	—	0	4.4	33.8	73.8	55.9
Bell's vireo (BEVI)	50.0	0	—	0	50.0	100.0	100.0
Black-capped vireo (BCVI)	7.4	11.1	0	—	40.7	74.1	66.7
Golden-cheeked warbler (GCWA)	15.9** (-0.124)	17.7	0.8	8.5	—	72.3	60.0
Painted bunting (PABU)	13.6	16.9	0.7	6.8	31.9	—	59.7
Brown-headed cowbird (BHCO)	16.0** (0.105)	16.5	0.9	7.8	33.8	76.2	—

[a] Percent occupancy, the expected value, from 378 survey sites (12 minute count only).
[b] Significant at $^{**}P \leq 0.05$ for χ^2 test of association.

Table 3. All vegetation categories used to evaluate avian species preference and Landsat imagery.

Category	**Common Species**	**Scientific Names***
Juniper Cover	ashe juniper	*Juniperus ashei*
Live Oak	texas live oak	*Quercus virginiana*
Spanish Oak	spanish oak (texas oak)	*Quercus texana*
Post Oak	post oak	*Quercus stellata*
Deciduous	pecan, Texas ash, american elm, cedar elm	*Carya illinoiensis, Fraxinus texensis,Ulmus americana, Ulmus crassifoilia*
Shrub	flame-leaf sumac, honey mesquite, eastern redbud	*Rhus copallina, Prosopis glandulosa, Cercis canadensis*
Juniper < 1.5 m	ashe juniper	*Juniperus ashei*
Deciduous < 1.5 m	pecan, Texas ash, american elm, cedar elm	*Carya illinoiensis, Fraxinus texensis,Ulmus americana, Ulmus crassifoilia*
Dead	n/a	n/a
Woody Coverage	All woody species	All woody species
Open	n/a	n/a
Prickly Pear	prickly pear	*Opuntia spp.*
Herbaceous	grasses, forbes, etc.	Poaceae, Ranunculaceae, etc…
Bare	n/a	n/a
Rock	n/a	n/a

* As named in Shinners & Mahler’s Flora of North Central Taxes (Diggs et al. 1999)

At the 161 sites where vegetation measurements were taken, average wooded cover was 65.4% and average open area was 34.6%. The most commonly encountered woody cover >1.5 m was Ashe juniper, with the mean cover value of 35.5%. The next most common woody coverage was deciduous with a mean cover value of 12.0%. Other woody species >1.5 m accounted for 21.2% mean cover at the vegetation survey sites.

Sites occupied by northern bobwhites and white-eyed vireos had significantly more Spanish oak than those where the species was not detected; however, in all cases cover was < 16.0% (Table 4). White-eyed vireos and Bell's vireo both demonstrated a significant association with areas with dead woody vegetation. Sites occupied by painted buntings had significantly less live oak and prickly pear coverage than sites where the species was not detected, but all values were < 7.0%. Black-capped vireos were found at sites with more post oak, while golden-cheeked warblers were found at sites with more Ashe juniper, Spanish oak, post oak, and general overall woody cover (Table 5). However, areas where golden-cheeked warblers were found had less live oak and prickly pear; and were negatively associated with areas containing larger patches of bare ground and open canopy (Table 6).

Table 4. Mean % foliar cover by woody plant group composition for bird species occupancy, from 161 sites in the Coryell Creek sub-watershed, Coryell County, Texas.

	Northern bobwhite				White-eyed vireo				Bell's vireo			
	Occupied (n = 16)		Unoccupied (n = 145)		Occupied (n = 23)		Unoccupied (n = 138)		Occupied (n = 1)		Unoccupied (n = 160)	
Woody group	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	38.0	5.5	35.3	2.2	35.9	6.0	35.5	2.2	31.0	--[b]	35.6	2.1
Live oak	3.1	1.7	4.2	0.7	4.2	1.7	4.1	0.1	2.5	--	4.1	0.7
Spanish oak	14.6	4.1	6.0*[a]	0.9	15.2	4.0	5.4*	0.8	11.1	--	6.8	1.0
Post oak	4.2	1.8	2.9	0.6	2.2	1.2	3.2	0.6	11.1	--	3.0	0.6
Deciduous	10.0	2.5	12.5	1.1	10.1	2.4	12.6	1.1	10.1	--	12.2	1.0
Shrubs	8.2	3.4	7.1	1.0	4.4	1.3	7.7	1.1	37.0	--	7.0	0.9
All hardwood (<1.5m in height)	11.7	1.3	9.9	0.3	9.2	0.5	10.2	0.4	13.6	--	10.0	0.3
Ashe juniper (<1.5m in height)	9.8	0.7	8.8	0.4	8.0	0.8	9.1	0.4	7.5	--	9.0	0.3
Overall woody cover	69.7	6.4	64.9	2.2	67.2	6.2	65.1	2.2	55.0	--	65.5	2.1
Overall open area	30.2	6.4	35.1	2.2	32.8	6.2	34.8	2.2	45.0	--	34.5	2.1
Dead cover	7.5	3.3	5.3	0.7	10.0	2.7	4.8**	0.6	28.4	--	5.4*	0.7
Prickly pear cover	6.6	2.4	4.7	0.7	4.2	1.8	5.0	0.7	0	--	4.9	0.7

[a] Significant at * $P \leq 0.01$ when comparing occupied versus unoccupied sites (Mann-Whitney tests).
[b] Sample size too small for SE calculation

Table 4. (continued)

Woody group	Painted Bunting				Brown-headed Cowbird			
	Occupied (n = 108)		Unoccupied (n = 53)		Occupied (n = 96)		Unoccupied (n = 65)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	37.7	2.5	31.1	3.6	35.5	2.7	35.6	3.2
Live oak	2.9	0.6	6.5***[a]	1.5	4.1	0.8	4.1	1.0
Spanish oak	7.9	1.3	4.7	1.1	7.2	1.4	6.3	1.3
Post oak	3.1	0.7	2.9	0.9	2.4	0.6	4.0	1.1
Deciduous	11.0	1.1	14.7	2.1	11.8	1.2	12.8	1.8
Shrubs	7.13	1.2	7.38	1.7	8.1	1.4	6.0	1.2
All hardwoods (<1.5 m in height)	9.9	0.4	10.3	0.5	10.3	0.4	9.7	0.4
Ashe juniper (<1.5 m in height)	9.4	0.4	8.0	0.5	9.2	0.5	8.5	0.4
Overall woody cover	64.4	2.5	67.4	3.8	64.8	2.7	66.3	3.4
Overall open area	35.6	2.5	32.4	3.8	35.3	2.7	33.5	3.4
Dead cover	6.2	0.9	4.2	10.0	5.4	0.9	5.7	1.1
Prickly pear cover	5.7	0.9	3.1**	10.0	4.5	0.8	5.3	1.1

[a] Significant at $^{*}P \leq 0.10$, $^{**}P \leq 0.05$, or $^{***}P \leq 0.01$ when comparing occupied versus unoccupied sites (Mann-Whitney tests).

Table 5. Mean % foliar cover by woody plant group composition for black-capped vireo and golden-cheeked warbler occupancy, from 400 sites in the Coryell Creek sub-watershed, Coryell County, Texas.

	Black-capped Vireo				Golden-cheeked warbler			
	Occupied (n =14)		Unoccupied (n = 147)		Occupied (n = 58)		Unoccupied (n = 103)	
Woody group	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ashe juniper	31.5	8.2	35.9	2.1	41.3	3.3	32.2**	2.5
Live oak	2.3	1.2	4.3	0.7	2.7	0.9	4.9*	0.9
Spanish oak	5.9	2.7	6.9	1.0	9.8	1.9	5.2***	1.0
Post oak	7.0	3.4	2.6**[a]	0.5	3.6	0.9	2.7***	0.7
Deciduous	10.0	3.1	12.4	1.1	13.5	1.7	11.5	1.2
Shrubs	12.0	4.3	6.8*	1.0	6.8	1.5	7.4	1.2
All hardwoods (<1.5m in height)	10.7	0.8	10.0	3.3	10.8	0.5	9.6	0.4
Ashe juniper (<1.5m in height)	9.5	0.3	8.9	0.4	9.6	0.5	8.6*	0.4
Overall woody cover	62.2	8.2	65.7	2.2	74.8	3.2	60.1***	2.6
Overall open area	37.9	8.2	34.3	2.2	25.3	3.2	39.8***	2.6
Dead cover	3.2	1.6	5.7	0.7	5.9	1.1	5.3	0.8
Prickly pear cover	4.9	1.7	4.8	0.7	2.8	0.8	6.0**	0.9

[a] Significant at *P ≤ 0.10, **P ≤ 0.05, or ***P ≤ 0.01 when comparing occupied versus unoccupied sites (Mann-Whitney tests).

Table 6. Mean % ground cover for the black-capped vireo and golden-cheeked warbler for 131 occupied sites and unoccupied sites in the Coryell Creek sub-watershed, Coryell County, Texas.

Ground cover	Black-capped vireo[a]				Golden-cheeked warbler			
	Occupied (n =11)		Unoccupied (n = 120)		Occupied (n = 38)		Unoccupied (n = 93)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Bare ground	48.0	6.5	52.9	2.1	44.2	3.8	55.9***[a]	2.3
Rock	7.5	4.1	14.8	2.1	21.3	4.5	11.2*	2.0
Herbaceous	30.8	5.5	23.0	1.7	21.7	3.1	24.5	1.9

[a] Comparison of occupied sites versus unoccupied sites (Mann-Whitney U-test). Significant at *P ≤ 0.10, **P ≤ 0.05, or ***P ≤ 0.01

Landsat Image Classification

Linear regression was used to identify the best of each Landsat imagery classification for each category. Ground measurements for juniper cover were regressed against imagery measurements for mean juniper cover values at the 100m spatial scale to test predictive accuracy of each run. Juniper run 16 (R^2= 0.40, F-ratio= 102.71, P <0.001) was selected to be used for model building. This method was then applied to evaluate the ability of the imagery to identify shrub[2]. Imagery run SH28 (R^2= 0.04, F-ratio= 6.458, P= 0.01) was selected for determining shrub cover within the models.

Model Development

Summary statistics for all 24 vegetation variables and 22 geomorphic variables within the Coryell Creek sub-watershed were calculated for black-capped vireo (Appendix D, Appendix E) and golden-cheeked warblers (Appendix F, Appendix G) at both spatial scales (100m and 400m). Using univariate LR, 32 golden-cheeked warblers variables (Appendix C) and 16 black-capped vireo variables (Table 7) were found to be significant (p ≤0.15) at the 100m scale. Of the golden-cheeked warblers variables at this scale, 21 (65.6%) were vegetation variables and 11 (34.4%) were geomorphic variables. For black-capped vireos, 10 (62.5%) were vegetation variables and six (37.5) were geomorphic variables.

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[2] Four other vegetation correlations (live oak, spanish oak, post oak, and deciduous) were calculated for other cover types, however, none were used in the final models.

At the 400m spatial scale, 27 golden-cheeked warblers variables (Table 8) and 15 black-capped vireo variables were significant (Table 9). At this scale, 19 (70.4%) of the golden-cheeked warblers variables were vegetation and 8 (29.6%) were geomorphic while 11 (73.3%) of the black-capped vireo variables were vegetation and four (26.7%) were geomorphic.

Once multi-collinearity was tested for all variables at both scales backwards step-wise selection was used upon all combinations of non-correlated variables. These combinations of variables (model) ranged from 2-4 variables. Once completed, the top five models were selected based upon ROC and rho-square values for both species at the 100m (Table 10) and the 400m (Table 11) spatial scales. The ROC scores tell usindicate the probability of accurately discriminating between an occupied site versus an unoccupied site. Nine variables comprised all 10 GCWA models with juniper cover greater than 70%, mean departure from north, and maximum slope found in models at both spatial scales (Figure 4).

Table 7. BCVI significant ($p \leq 0.15$) variables determined using univariate logistic regression at the 100m spatial scale.

Rank	Variable	P-value	Coefficient (B)	Rho-Sq	ROC
1	PROF_MIN	0.01	-179.49	0.03	0.66
2	ASNO_MEAN	0.01	-0.02	0.04	0.65
3	LO70	0.01	0.06	0.04	0.63
4	ASNO_MIN	0.04	-0.02	0.03	0.62
5	SLOPE_MAX	0.12	0.06	0.01	0.62
6	ASNO_MAX	0.02	-0.01	0.03	0.62
7	SHR50	0.03	0.05	0.02	0.61
8	SLOPE_MEAN	0.06	0.12	0.02	0.61
9	SHR20	0.06	0.04	0.02	0.59
10	SHR70	0.09	0.04	0.01	0.59
11	JUN90	0.12	0.02	0.01	0.56
12	LO50	0.08	0.03	0.02	0.56
13	LO20	0.12	0.02	0.01	0.56
14	LO90	0.07	0.17	0.01	0.54
15	SO70	0.12	0.04	0.01	0.54
16	SHR90	0.09	0.09	0.01	0.49

Table 8. GCWA significant ($p \leq 0.15$) variables determined using univariate logistic regression at the 400m spatial scale.

Rank	Variable	P-value	Coefficient (B)	Rho-Sq	ROC
1	JUN90	< 0.001	0.152	0.185	0.78
2	DEC70	< 0.001	0.075	0.150	0.78
3	DEC20	< 0.001	0.071	0.157	0.78
4	DEC50	< 0.001	0.070	0.156	0.78
5	JUN70	< 0.001	0.078	0.169	0.77
6	PO70	< 0.001	0.143	0.139	0.77
7	PO50	< 0.001	0.118	0.118	0.75
8	JUN50	< 0.001	0.064	0.144	0.74
9	PO20	< 0.001	0.102	0.103	0.73
10	JUN20	< 0.001	0.061	0.130	0.73
11	SO50	< 0.001	-0.195	0.112	0.73
12	SO20	< 0.001	-0.153	0.100	0.72
13	LO90	< 0.001	1.375	0.074	0.70
14	SO70	< 0.001	-0.246	0.069	0.69
15	SLOPE_MAX	< 0.001	0.071	0.028	0.62
16	ASNO_MEAN	< 0.001	-0.020	0.030	0.61
17	SLOPE_MEAN	0.010	0.179	0.013	0.61
18	LB	0.003	1.620	0.018	0.61
19	PROF_MIN	0.003	-117.336	0.018	0.59
20	LO50	0.029	-0.048	0.010	0.57
21	LO20	0.045	-0.039	0.008	0.56
22	ASEA_MEAN	0.052	-0.010	0.008	0.56
23	SHR90	0.133	0.157	0.004	0.56
24	PO90	0.037	1.450	0.009	0.55
25	LS	0.139	-0.722	0.004	0.54
26	SHR20	0.078	-0.050	0.006	0.54
27	CL	0.132	-8.509	0.007	0.53

Table 9. BCVI significant ($p \leq 0.15$) variables determined using univariate logistic regression at the 400m spatial scale.

Rank	Variable	P-Value	Coefficient (B)	Rho-Sq	ROC
1	SHR90	0.021	0.420	0.026	0.67
2	ASNO_MEAN	0.006	-0.031	0.044	0.66
3	JUN20	0.005	0.037	0.043	0.65
4	PO20	0.014	0.055	0.029	0.65
5	SLOPE_MEAN	0.033	0.248	0.022	0.64
6	JUN50	0.008	0.034	0.037	0.64
7	PO70	0.007	0.069	0.035	0.634
8	PO50	0.010	0.061	0.032	0.64
9	DEC20	0.015	0.031	0.030	0.63
10	JUN70	0.010	0.036	0.035	0.63
11	JUN90	0.007	0.060	0.035	0.63
12	DEC50	0.015	0.030	0.029	0.62
13	DEC70	0.027	0.029	0.024	0.62
14	SA	0.129	1.279	0.013	0.59
15	PLAN_MEAN	0.133	0.026	0.010	0.58

Table 10: Coryell Creek sub-watershed logistic regression models for predicting avian species in central Texas using 100m radius variables.

		Variables												
		Vegetation					Geomorphic							
Species	ID	JUN 70[a]	JUN 50	SHR 70	SHR 50	SHR 20	Aspect (N)[b]	Slope (Mean)	Slope (Max)	Profile Curvature	Plan Curvature	k*	ROC	Rho-Sq
GCWA	1	+				--	--					3	0.78	0.17
	2	+					--					2	0.77	0.16
	3	+										1	0.75	0.14
	4		+		+							2	0.76	0.14
	5						--		+		+	3	0.64	0.04
BCVI	1				+		--			--		3	0.72	0.09
	2						--					1	0.65	0.04
	3									--		1	0.65	0.03
	4			+				+				2	0.64	0.04
	5				+							1	0.61	0.02

[a] Mean area covered by Juniper with canopy value > 70%.
[b] Mean departure from North (0-180°)
*k represents the number of parameters within each model.
Notes: Negative and positive signs indicate variable coefficient occurrence and value within the model.

Table 11: Coryell Creek sub-watershed logistic regression models for predicting avian species in central Texas using 400m radius variables.

		Variables											
		Vegetation				Geomorphic							
Species	ID	JUN 90[a]	JUN 70	JUN 20	SHR 90	Aspect (N)[b]	Slope (Mean)	Slope (Max)	Profile Curvature	Plan Curvature	k	ROC	Rho-Sq
GCWA	1	+							--		2	0.80	0.20
	2		+			--			--		3	0.78	0.18
	3		+					+			2	0.78	0.18
	4		+								1	0.77	0.16
	5		+			--					2	0.77	0.17
BCVI	1				+		+				2	0.71	0.07
	2				+	--					2	0.75	0.10
	3				+	--	+				3	0.75	0.11
	4				+	--				--	3	0.78	0.11
	5			+		--				--	3	0.72	0.09

[a] Mean area covered by Juniper with canopy value > 90%.

[b] Mean departure from North (0-180°)

Notes: Negative and positive signs indicate variable coefficient occurrence and value within the model. k represents the number of parameters within each model.

The top five 100m and 400m GCWA models are in Figure 6 and Figure 7, respectively. Eight variables comprised all 10 black-capped vireo models with mean slope and mean departure from north used at both scales (Figure 7). For both species at both spatial scales, the ratio of significant vegetation variables to geomorphic variables is approximately 2:1. The top five 100m and 400m black-capped vireo models are in Figure 10 and Figure11, respectively.

All top models were evaluated using independent survey sites (presence/absence) and varied thresholds ranging from 0.50 to 0.25. A lower threshold value allows a site to be predicted as positive at a lower level of probability. This allows for increases in true positives (TP) but resulted in a decrease in the ROC values at both the 100m (Table 12) and the 400m (Table 13) scale (Pearce and Ferrier 2000). For model building at the 100m spatial scale, the highest GCWA values were ROC = 0.78 with a rho-square = 0.171. At this spatial scale, the highest black-capped vireo values were ROC = 0.71 with a rho-squared of 0.094. At the 400m spatial scale, the highest GCWA values were ROC = 0.80 with a rho-square = 0.204 and the highest black-capped vireo were ROC = 0.78 with a rho-square of 0.111. The validated model GCWA 100m ROC values (threshold = 0 .5) range from 0.827 to 0.851 and the black-capped vireo 100m ROC values range from 0.926 to 0.944. At 400m, the validated model GCWA ROC values (threshold =0 .5) range from 0.78 to 0.86 and the black-capped vireo 100m ROC values range from 0.93 to 0.94.

The 400m models consistently had higher ROC values. The top two GCWA models were 400m model 2 and model 3. The top two black-capped vireo models were 400m model 4 and model 2. When the top two ranking models for each species were compared on a pixel by pixel basis, the top two GCWA models demonstrate the most variability. Figure 10 shows a spatial representation of areas with highest probability difference. The difference in probability prediction between GCWA models ranged up to 0.475 while the top two black-capped vireo models differ by a maximum value of 0.028. The top model for golden-cheeked warblers and black-capped vireos, are shown in Figures 13 and 14 respectively.

When model reliability is compared between species, the GCWA models consistently scored higher ROC values than the black-capped vireo model. The top GCWA model (model 2, Figure 13) had an ROC score of 0.80 and McFaddin's Rho-square of 0.204 at the 0.5 threshold while the top black-capped vireo model (model 4, Figure 14) had an ROC score of only 0.71 and McFaddin's Rho-square of 0.066 at the 0.5 threshold.

4a

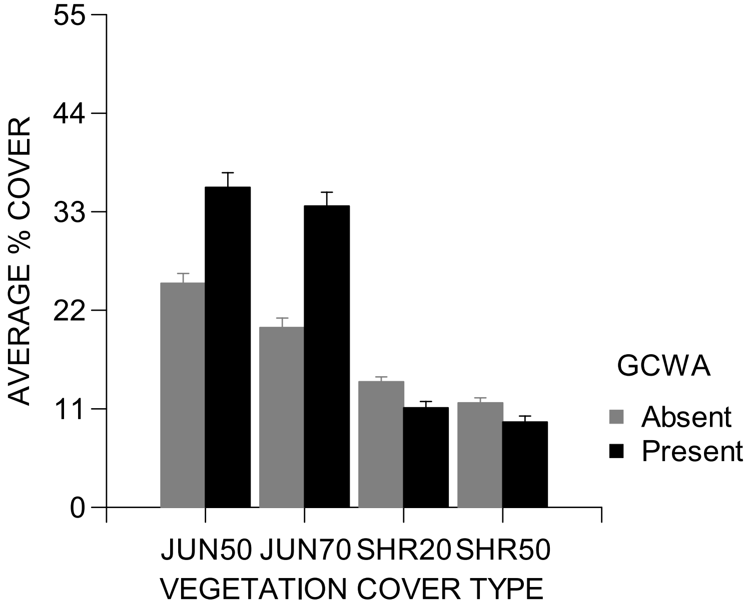

Figure 4a. Comparison of key vegetation types overall average values at the 100m scale for all 400 Coryell Creek sub-watershed points where sites with GCWA present are compared to GCWA absence sites.

4b

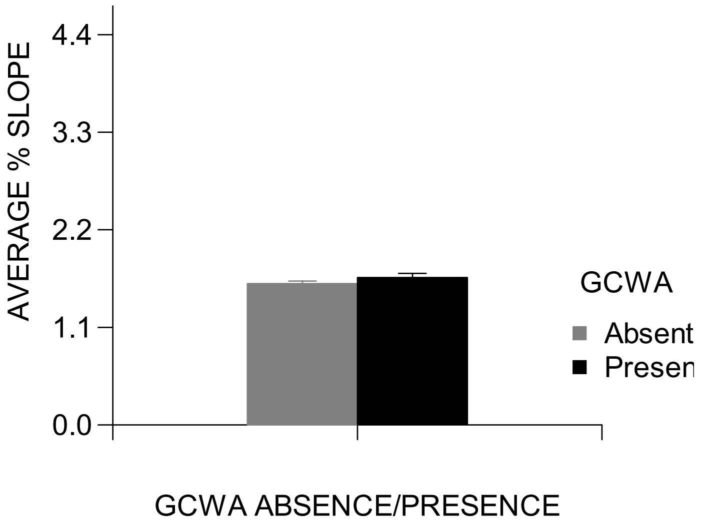

Figure 4b. Comparison of the slope values, GCWA present versus absent, of all 400 Coryell Creek sub-watershed points at the 100m scale.

4c

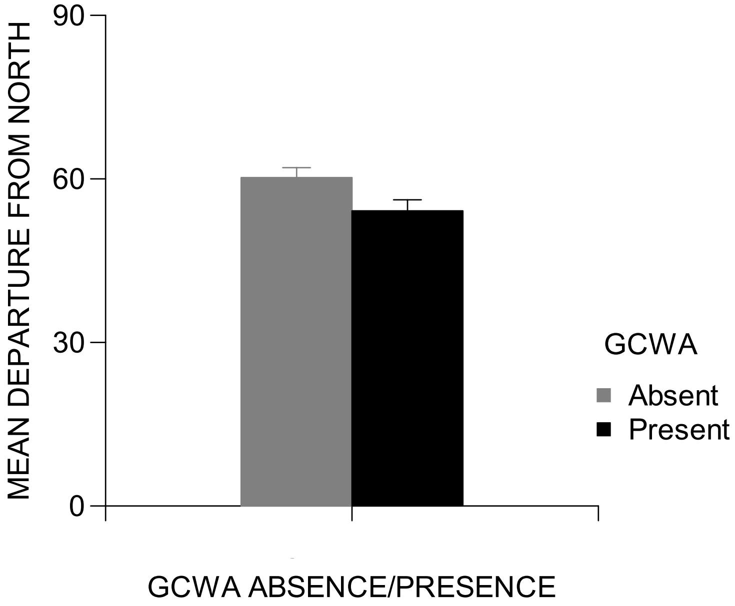

Figure 4c. Comparison of the northing aspect values, GCWA present versus absent, of all 400 Coryell Creek sub-watershed points at the 100m scale.

4d

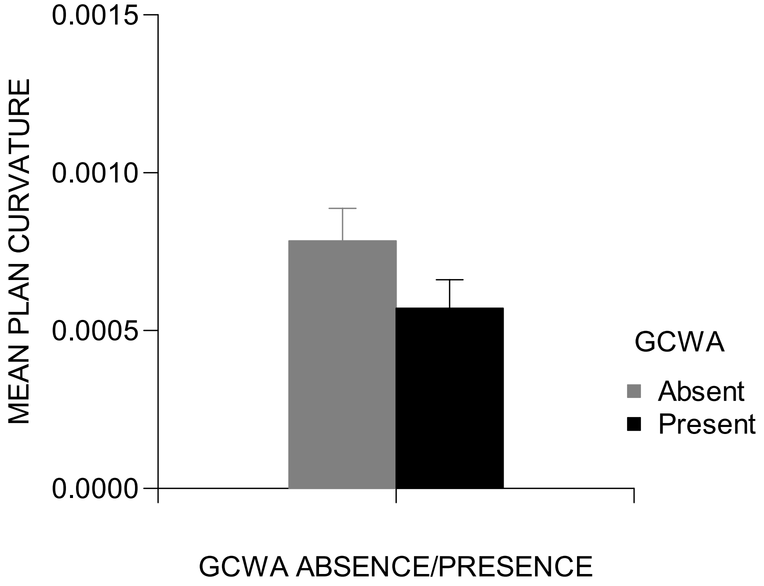

Figure 4d. Comparison of the mean curvature values, GCWA present versus absent, of all 400 Coryell Creek sub-watershed points at the 100m scale.

5a

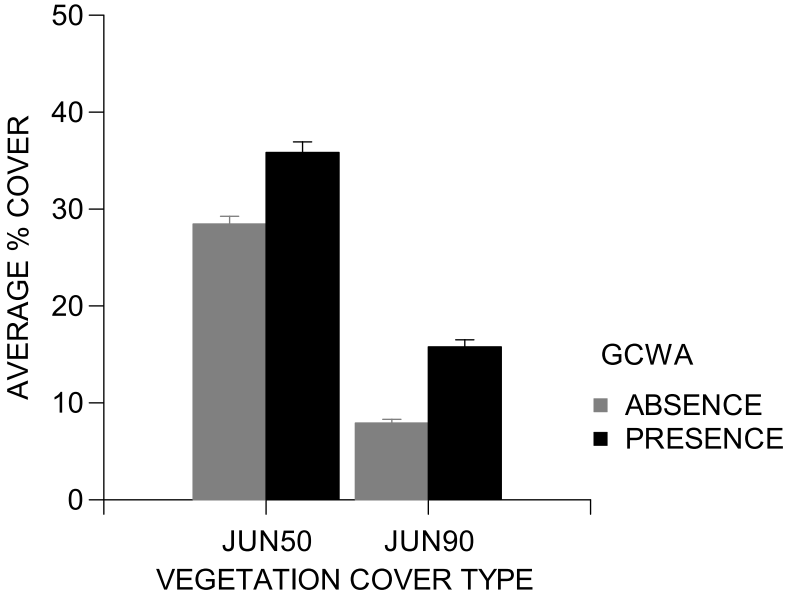

Figure 5a. Comparison of key vegetation types overall average values at the 400m scale for all 400 Coryell Creek sub-watershed points where sites with GCWA present are compared to GCWA absence sites.

5b

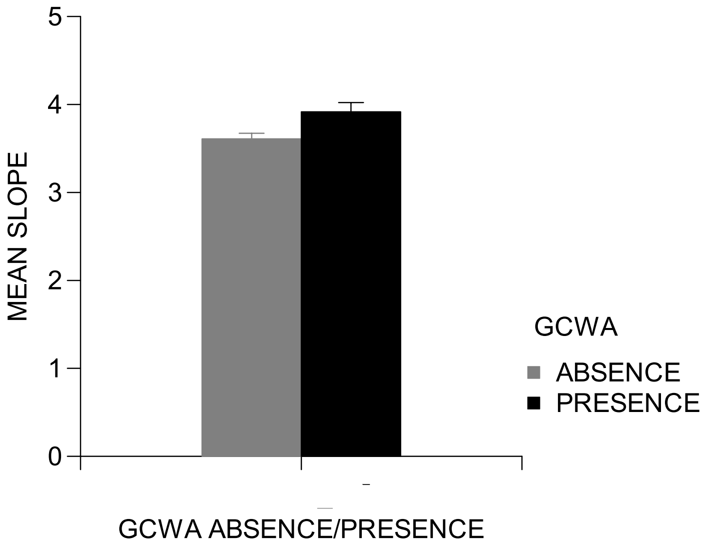

Figure 5b. Comparison of the slope values, GCWA present versus absent, of all 400 Coryell Creek sub-watershed points at the 400m scale.

5c

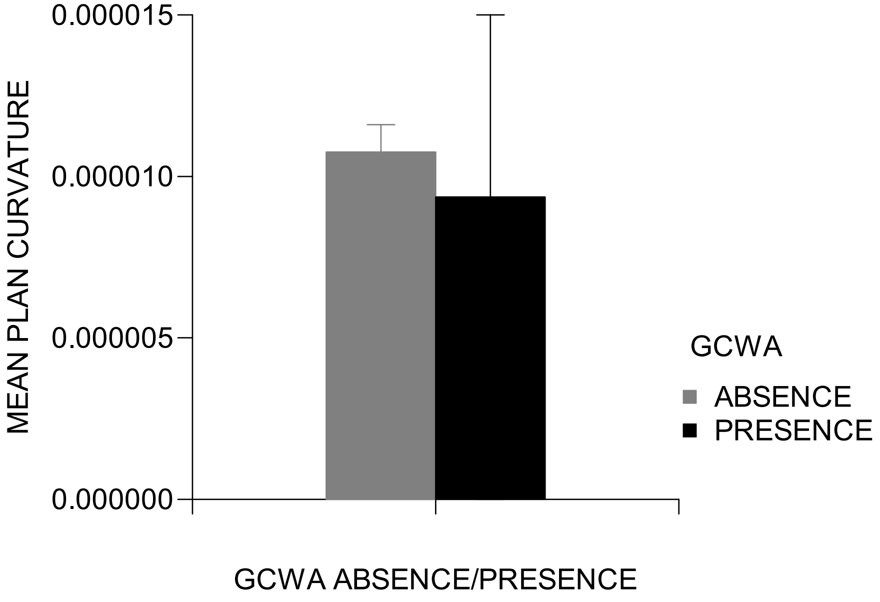

Figure 5c. Comparison of the mean curvature values, GCWA present versus absent, of all 400 Coryell Creek sub-watershed points at the 400m scale.

5d

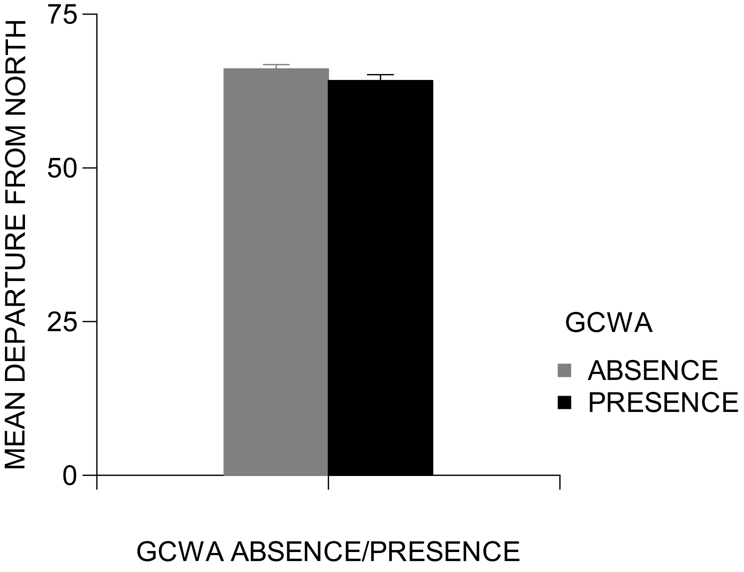

Figure 5d. Comparison of the northing aspect values, GCWA present versus absent, of all 400 Coryell Creek sub-watershed points at the 400m scale.

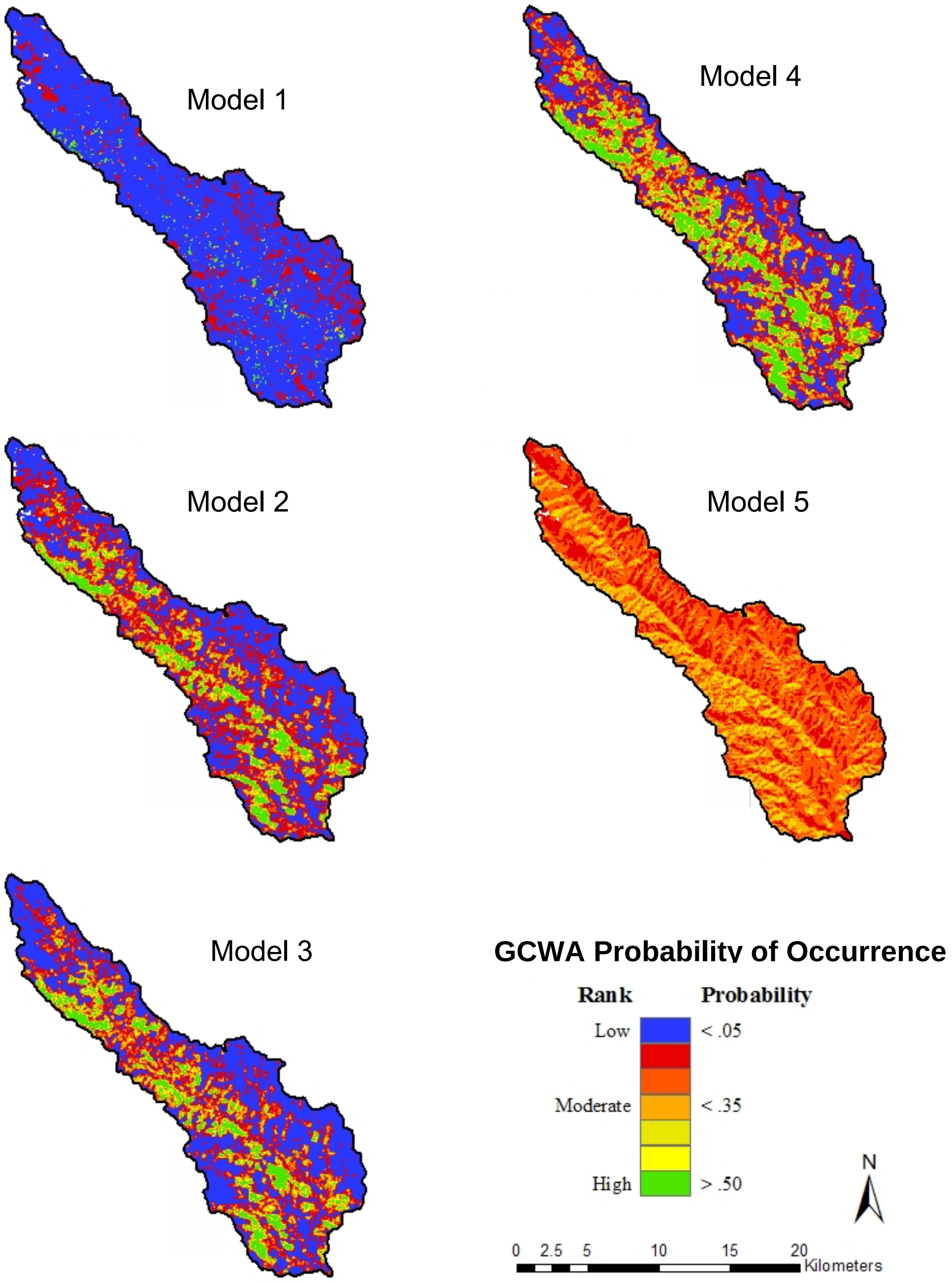

Figure 6. The top five GCWA models at the 100m scale based on ROC and McFaddin's Rho-square values. All models are subset to the Coryell Creek sub-watershed, Coryell County, Texas. Pixel values range from 0 to 100.

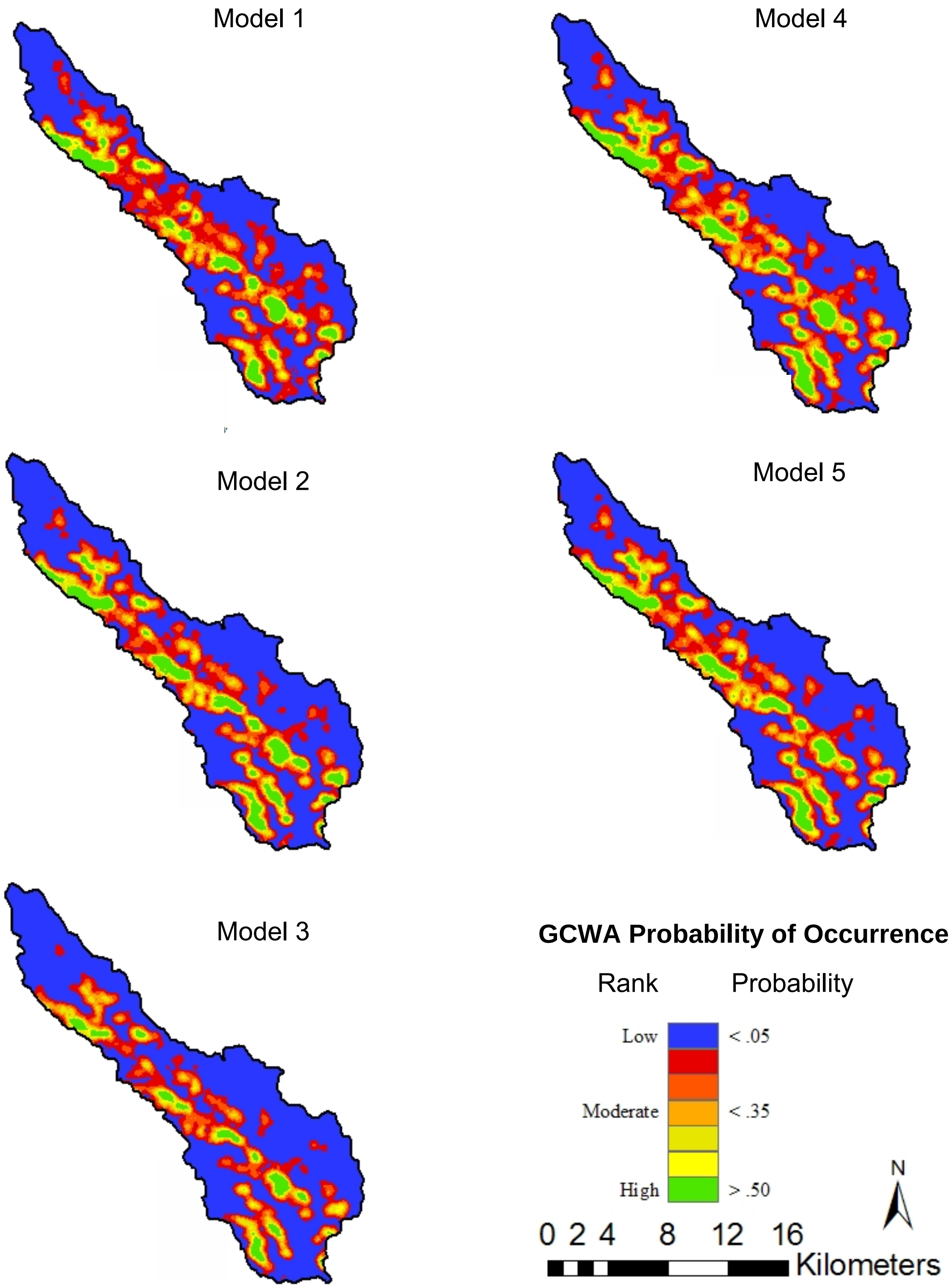

Figure 7. The top five GCWA models at the 400m scale based on ROC and McFaddin's Rho-square values. All models are subset to the Coryell Creek sub-watershed, Coryell County, Texas. Pixel values range from 0 to 100.

8a

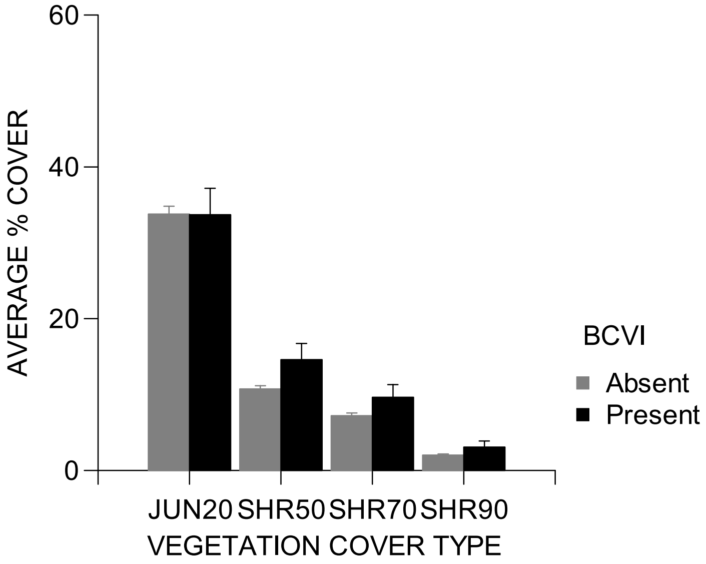

Figure 8a. Comparison of key vegetation types overall average values at the 100m scale for all 400 Coryell Creek sub-watershed points where sites with BCVI present are compared to BCVI absence sites.

8b

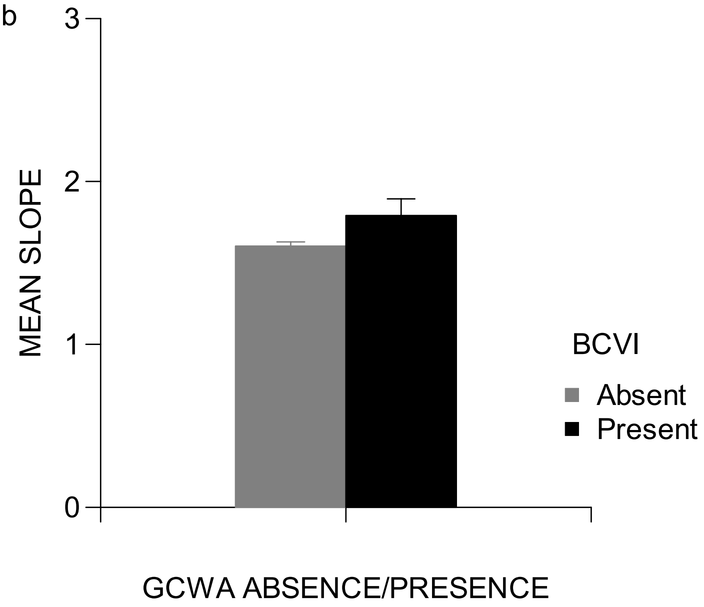

Figure 8b. Comparison of the slope values, BCVI present versus absent, of all 400 Coryell Creek sub-watershed points at the 100m scale.

8c

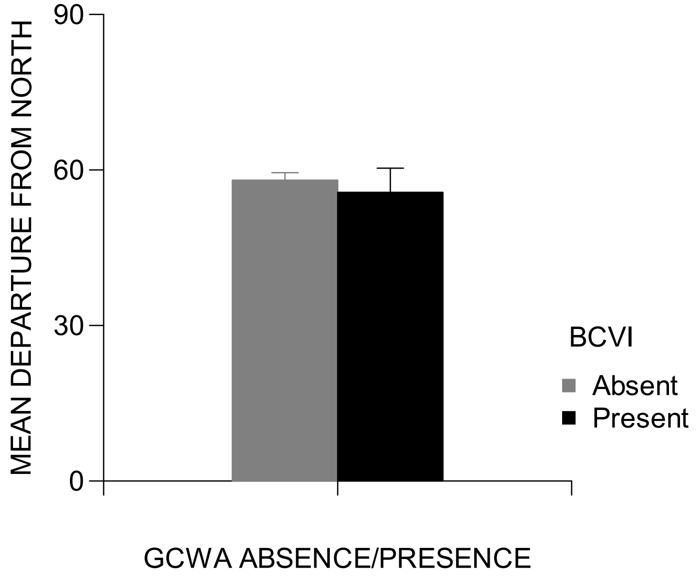

Figure 8c. Comparison of the northing aspect values, BCVI present versus absent, of all 400 Coryell Creek sub-watershed points at the 100m scale.

8d

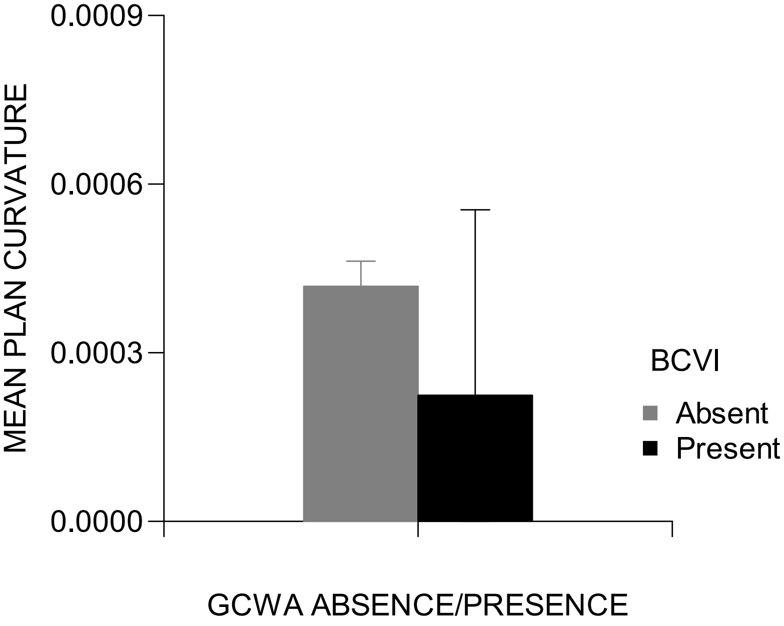

Figure 8d. Comparison of the mean curvature values, BCVI present versus absent, of all 400 Coryell Creek sub-watershed points at the 100m scale.

9a

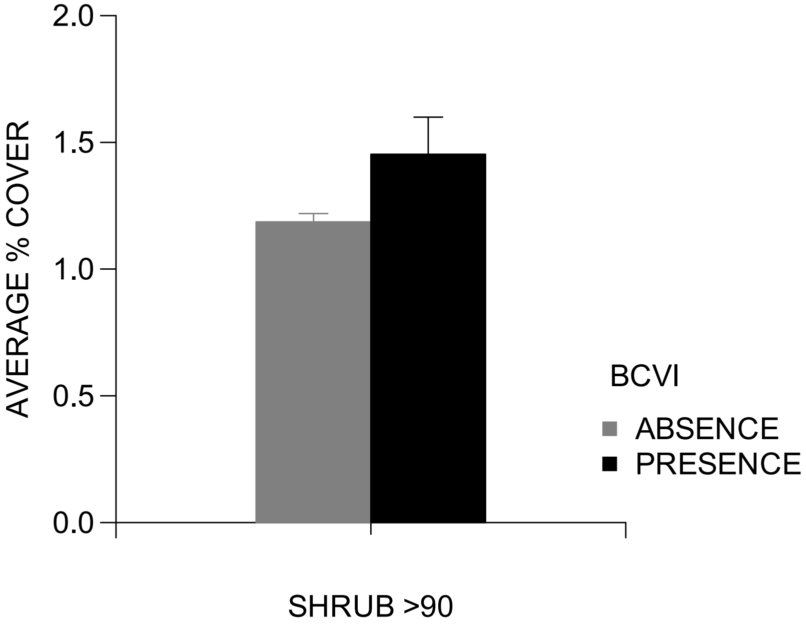

Figure 9a. Comparison of key vegetation types overall average values at the 400m scale for all 400 Coryell Creek sub-watershed points where sites with BCVI present are compared to BCVI absence sites.

9b

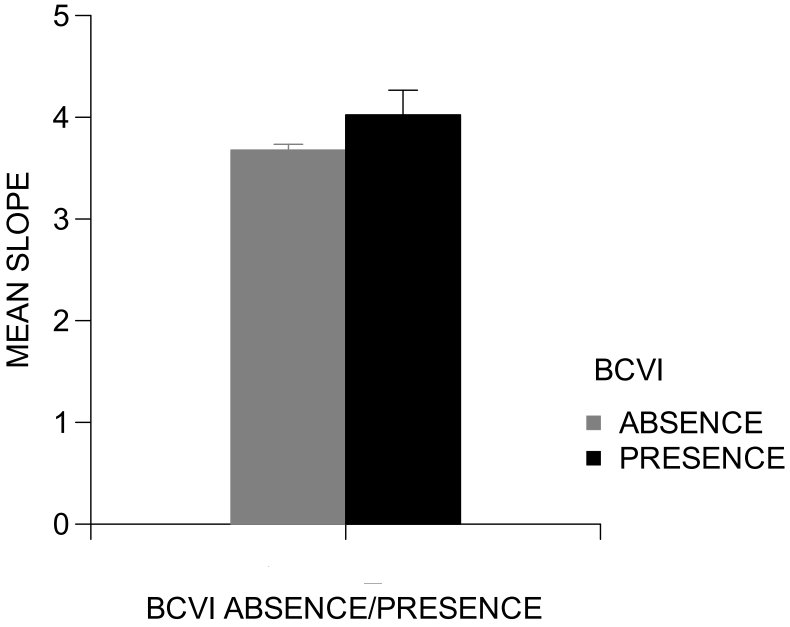

Figure 9b. Comparison of the slope values, BCVI present versus absent, of all 400 Coryell Creek sub-watershed points at the 400m scale.

9c

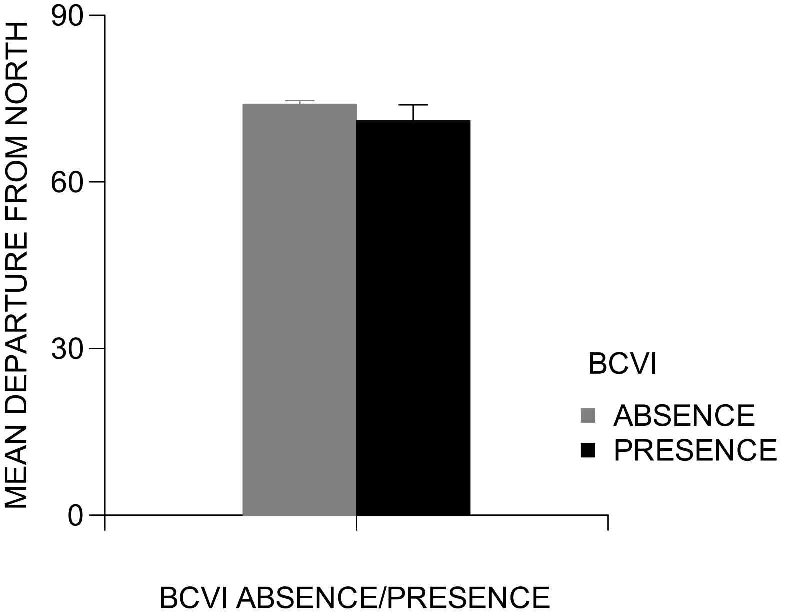

Figure 9c. Comparison of the northing aspect values, BCVI present versus absent, of all 400 Coryell Creek sub-watershed points at the 400m scale.

9d

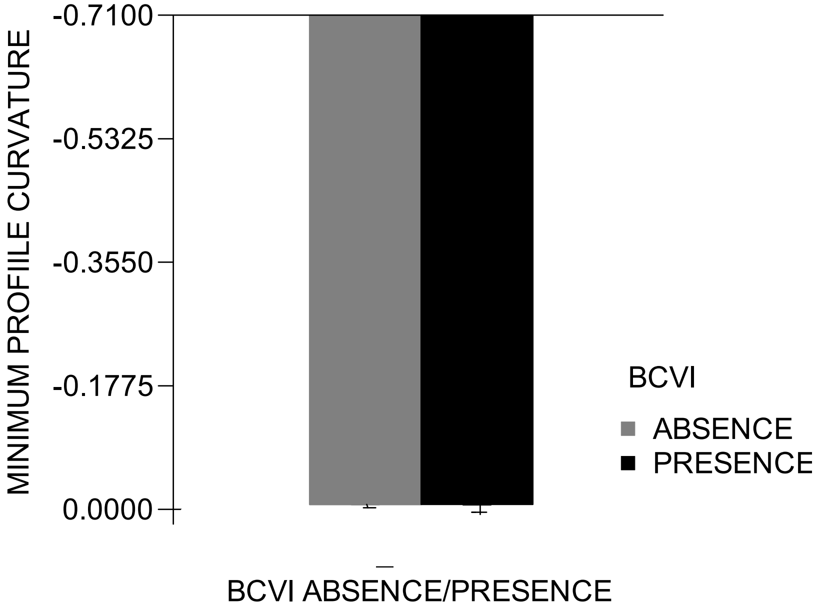

Figure 9d. Comparison of the mean curvature values, BCVI present versus absent, of all 400 Coryell Creek sub-watershed points at the 400m scale.

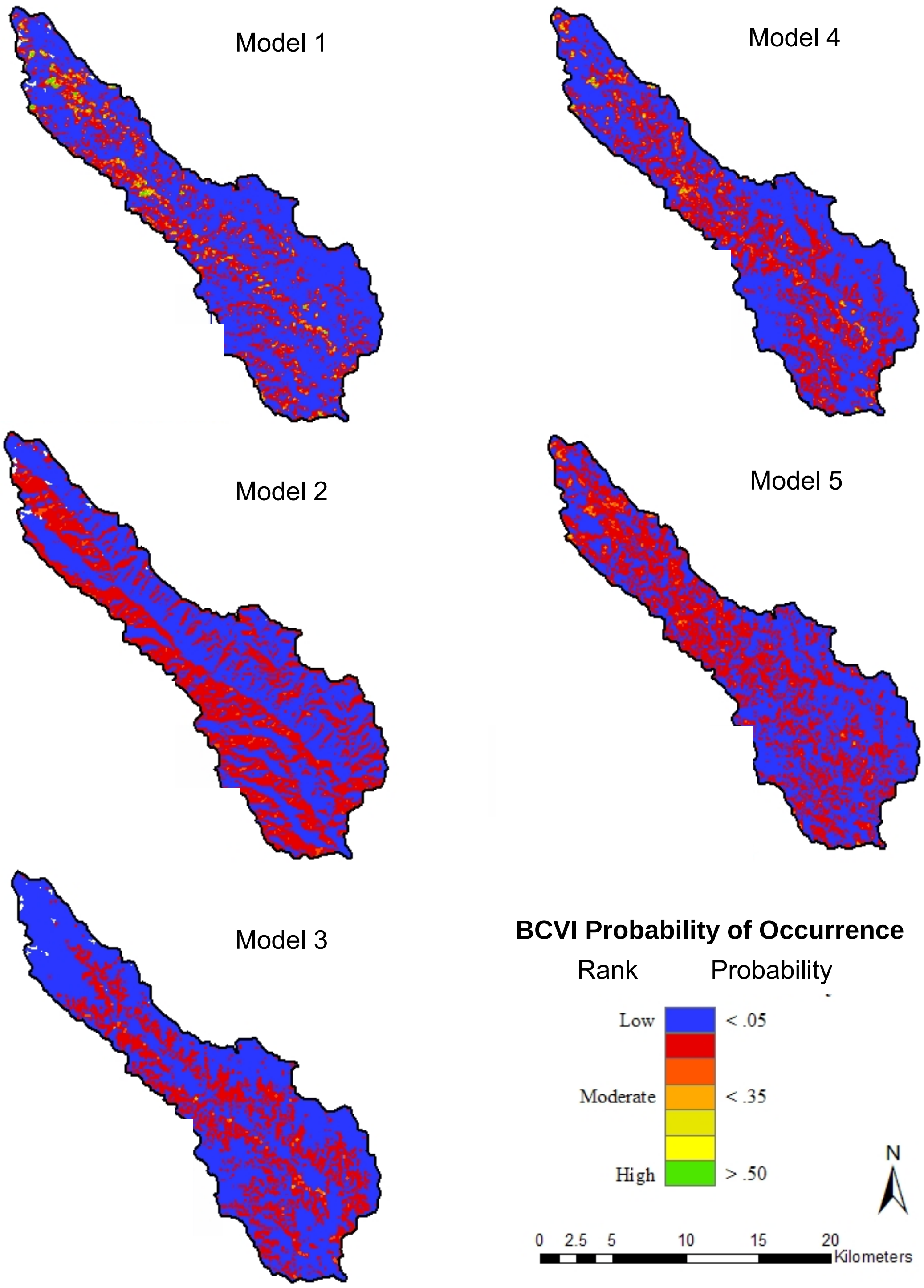

Figure 10. The top five BCVI models at the 100m scale based on ROC and McFaddin's Rho-square values. All models are subset to the Coryell Creek sub-watershed, Coryell County, Texas. Pixel values range from 0 to 100.

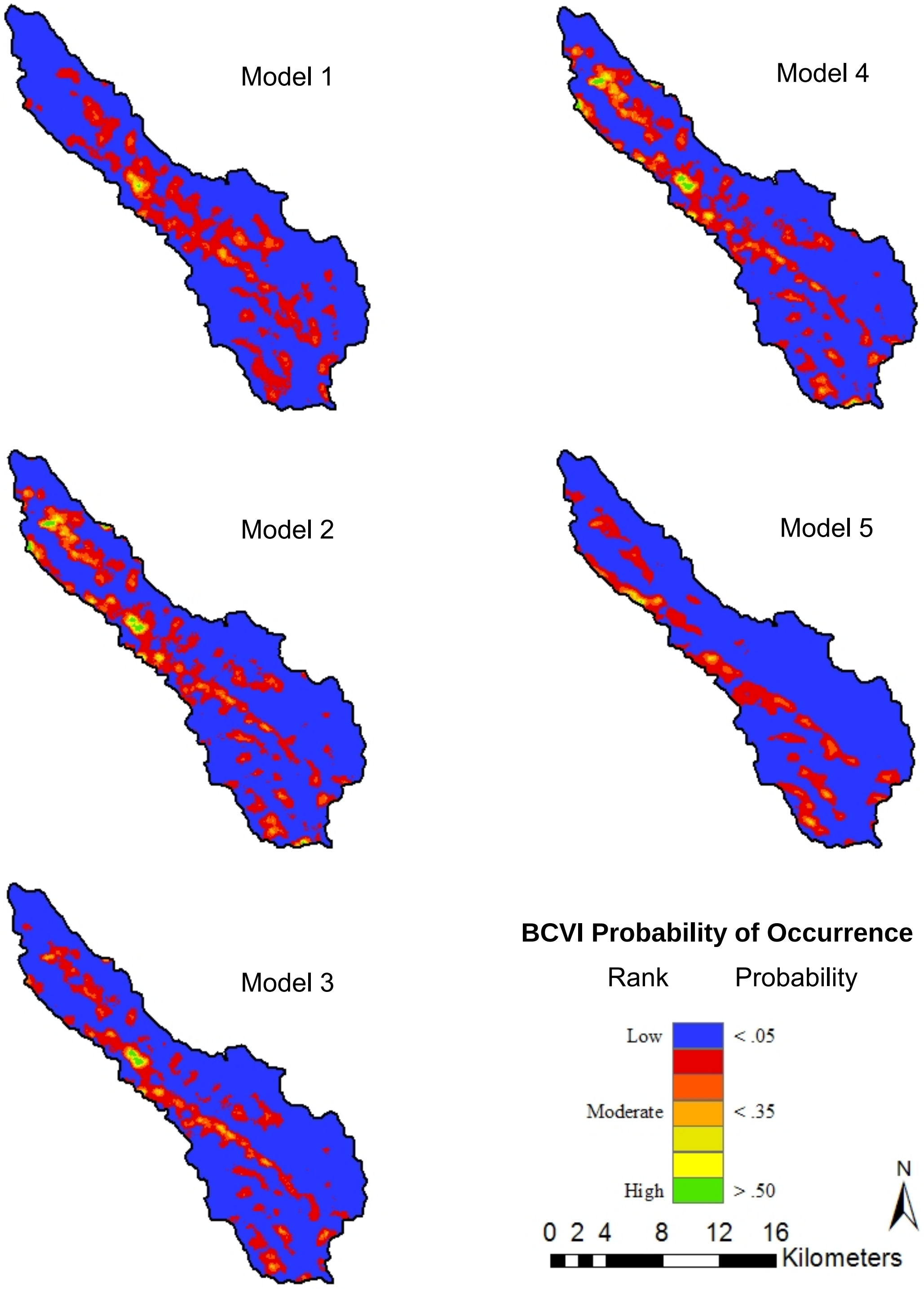

Figure 11. The top five BCVI models at the 400m scale based on ROC and McFaddin's Rho-square values. All models are subset to the Coryell Creek sub-watershed, Coryell County, Texas. Pixel values range from 0 to 100.

Table 12. Results of model validation using a separate set of 376 locations in the Leon River Watershed, Hamilton and Coryell Counties, Texas. True positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) for all habitat models at the 100m scale are shown. Model thresholds represent varying levels of confidence in correctly identifying occupied sites.

BCVI							GCWA						
Threshold	Model	TP	TN	FN	FP	ROC *	Threshold	Model	TP	TN	FN	FP	ROC
0.50	1	0.00	0.99	1.00	0.01	0.94	0.50	1	0.35	0.90	0.65	0.10	0.83
0.45		0.00	0.99	1.00	0.01	0.93	0.45		0.37	0.92	0.63	0.08	0.84
0.40		0.00	0.99	1.00	0.01	0.93	0.40		0.42	0.85	0.58	0.15	0.79
0.35		0.05	0.99	0.95	0.01	0.93	0.35		0.56	0.81	0.44	0.19	0.78
0.30		0.05	0.97	0.95	0.03	0.92	0.30		0.63	0.77	0.37	0.23	0.75
0.25		0.05	0.96	0.95	0.04	0.91	0.25		0.75	0.69	0.25	0.31	0.70
0.50	2	0.00	1.00	1.00	0.00	0.94	0.50	2	0.37	0.93	0.63	0.07	0.85
0.45		0.00	1.00	1.00	0.00	0.94	0.45		0.42	0.91	0.58	0.09	0.85
0.40		0.00	1.00	1.00	0.00	0.94	0.40		0.46	0.84	0.54	0.16	0.79
0.35		0.00	1.00	1.00	0.00	0.94	0.35		0.52	0.80	0.48	0.20	0.76
0.30		0.00	1.00	1.00	0.00	0.94	0.30		0.67	0.74	0.33	0.26	0.73
0.25		0.00	1.00	1.00	0.00	0.94	0.25		0.77	0.67	0.23	0.33	0.68
0.50	3	0.00	1.00	1.00	0.00	0.94	0.50	3	0.35	0.93	0.65	0.07	0.85
0.45		0.00	1.00	1.00	0.00	0.94	0.45		0.44	0.92	0.56	0.08	0.85
0.40		0.00	1.00	1.00	0.00	0.94	0.40		0.52	0.85	0.48	0.15	0.81
0.35		0.00	1.00	1.00	0.00	0.94	0.35		0.56	0.79	0.44	0.21	0.76
0.30		0.00	1.00	1.00	0.00	0.94	0.30		0.63	0.72	0.37	0.28	0.70
0.25		0.00	1.00	1.00	0.00	0.94	0.25		0.77	0.63	0.23	0.37	0.65
0.50	4	0.00	1.00	1.00	0.00	0.94	0.50	4	0.29	0.93	0.71	0.07	0.84
0.45		0.00	1.00	1.00	0.00	0.94	0.45		0.37	0.92	0.63	0.08	0.84
0.40		0.00	1.00	1.00	0.00	0.94	0.40		0.50	0.87	0.50	0.13	0.82
0.35		0.00	0.99	1.00	0.01	0.94	0.35		0.60	0.81	0.40	0.19	0.78
0.30		0.00	0.99	1.00	0.01	0.93	0.30		0.69	0.73	0.31	0.27	0.72
0.25		0.00	0.98	1.00	0.02	0.93	0.25		0.77	0.66	0.23	0.34	0.67
0.50	5	0.00	0.98	1.00	0.02	0.93	0.50	5	0.02	0.97	0.98	0.03	0.84
0.45		0.00	0.97	1.00	0.03	0.92	0.45		0.12	0.92	0.88	0.08	0.81
0.40		0.00	0.96	1.00	0.04	0.90	0.40		0.31	0.81	0.69	0.19	0.74
0.35		0.00	0.95	1.00	0.05	0.89	0.35		0.48	0.67	0.52	0.33	0.64
0.30		0.05	0.92	0.95	0.08	0.87	0.30		0.62	0.45	0.38	0.55	0.47
0.25		0.05	0.90	0.95	0.10	0.85	0.25		0.73	0.27	0.27	0.73	0.34

* BCVI ROC values are inflated by the number of correctly identified absent sites.

Table 13. Results of model validation using a separate set of 376 locations in the Leon River Watershed, Hamilton and Coryell Counties, Texas. True positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) for all habitat models at the 400m scale are shown. Model thresholds represent varying levels of confidence in correctly identifying occupied sites.

BCVI							GCWA						
Model	Threshold	TP	TN	FN	FP	ROC*	Model	Threshold	TP	TN	FN	FP	ROC
1	0.50	0.00	1.00	1.00	0.00	0.94	1	0.50	0.25	0.95	0.75	0.05	0.85
	0.45	0.00	1.00	1.00	0.00	0.94		0.45	0.29	0.93	0.71	0.07	0.84
	0.40	0.00	1.00	1.00	0.00	0.94		0.40	0.33	0.92	0.67	0.08	0.97
	0.35	0.05	1.00	0.95	0.00	0.95		0.35	0.38	0.90	0.62	0.10	0.83
	0.30	0.10	1.00	0.90	0.00	0.95		0.30	0.42	0.87	0.58	0.13	0.81
	0.25	0.14	0.98	0.86	0.02	0.94		0.25	0.54	0.85	0.46	0.15	0.80
2	0.50	0.10	0.99	0.90	0.01	0.94	2	0.50	0.33	0.94	0.67	0.06	0.85
	0.45	0.10	0.99	0.90	0.01	0.94		0.45	0.35	0.92	0.65	0.08	0.84
	0.40	0.14	0.98	0.86	0.02	0.93		0.40	0.38	0.89	0.62	0.11	0.82
	0.35	0.14	0.97	0.86	0.03	0.92		0.35	0.50	0.85	0.50	0.15	0.80
	0.30	0.14	0.96	0.86	0.04	0.91		0.30	0.60	0.80	0.40	0.20	0.77
	0.25	0.19	0.93	0.81	0.07	0.89		0.25	0.67	0.76	0.33	0.24	0.75
3	0.50	0.05	0.99	0.95	0.01	0.94	3	0.50	0.33	0.94	0.67	0.06	0.85
	0.45	0.05	0.99	0.95	0.01	0.93		0.45	0.35	0.92	0.65	0.08	0.84
	0.40	0.05	0.99	0.95	0.01	0.93		0.40	0.38	0.89	0.62	0.11	0.82
	0.35	0.10	0.98	0.90	0.02	0.93		0.35	0.50	0.85	0.50	0.15	0.80
	0.30	0.14	0.97	0.86	0.03	0.92		0.30	0.60	0.80	0.40	0.20	0.77
	0.25	0.14	0.96	0.86	0.04	0.91		0.25	0.67	0.76	0.33	0.24	0.75
4	0.50	0.10	0.99	0.90	0.01	0.94	4	0.50	0.33	0.95	0.67	0.05	0.86
	0.45	0.14	0.99	0.86	0.01	0.94		0.45	0.37	0.93	0.63	0.07	0.85
	0.40	0.14	0.98	0.86	0.02	0.93		0.40	0.46	0.90	0.54	0.10	0.84
	0.35	0.14	0.97	0.86	0.03	0.93		0.35	0.48	0.85	0.52	0.15	0.80
	0.30	0.14	0.95	0.86	0.05	0.91		0.30	0.58	0.80	0.42	0.20	0.77
	0.25	0.19	0.93	0.81	0.07	0.89		0.25	0.65	0.74	0.35	0.26	0.73
5	0.50	0.00	1.00	1.00	0.00	0.93	5	0.50	0.10	0.90	0.90	0.10	0.79
	0.45	0.00	1.00	1.00	0.00	0.93		0.45	0.10	0.87	0.90	0.13	0.76
	0.40	0.00	1.00	1.00	0.00	0.93		0.40	0.13	0.83	0.87	0.17	0.74
	0.35	0.00	1.00	1.00	0.00	0.93		0.35	0.15	0.79	0.85	0.21	0.70
	0.30	0.00	1.00	1.00	0.00	0.93		0.30	0.19	0.73	0.81	0.27	0.66
	0.25	0.00	1.00	1.00	0.00	0.93		0.25	0.29	0.69	0.71	0.31	0.63

* BCVI ROC values are inflated by the number of correctly identified absent sites.

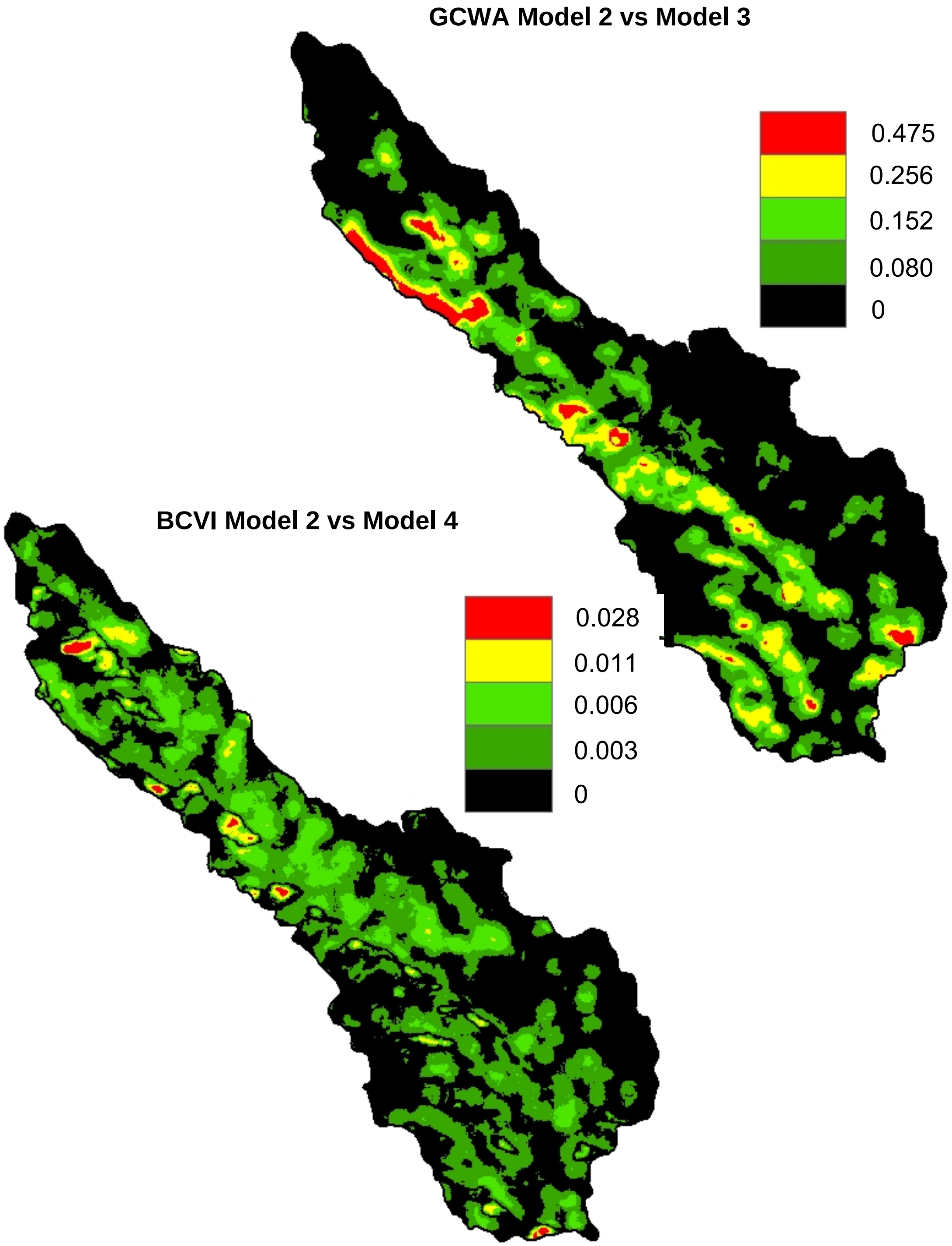

Figure 12. These Coryell Creek sub-watershed maps indicate the difference between the two top post validation models (400m) for both GCWA and BCVI. Color ramp scales indicate degree of difference for each pixel between models. Note the different scales for each maps.

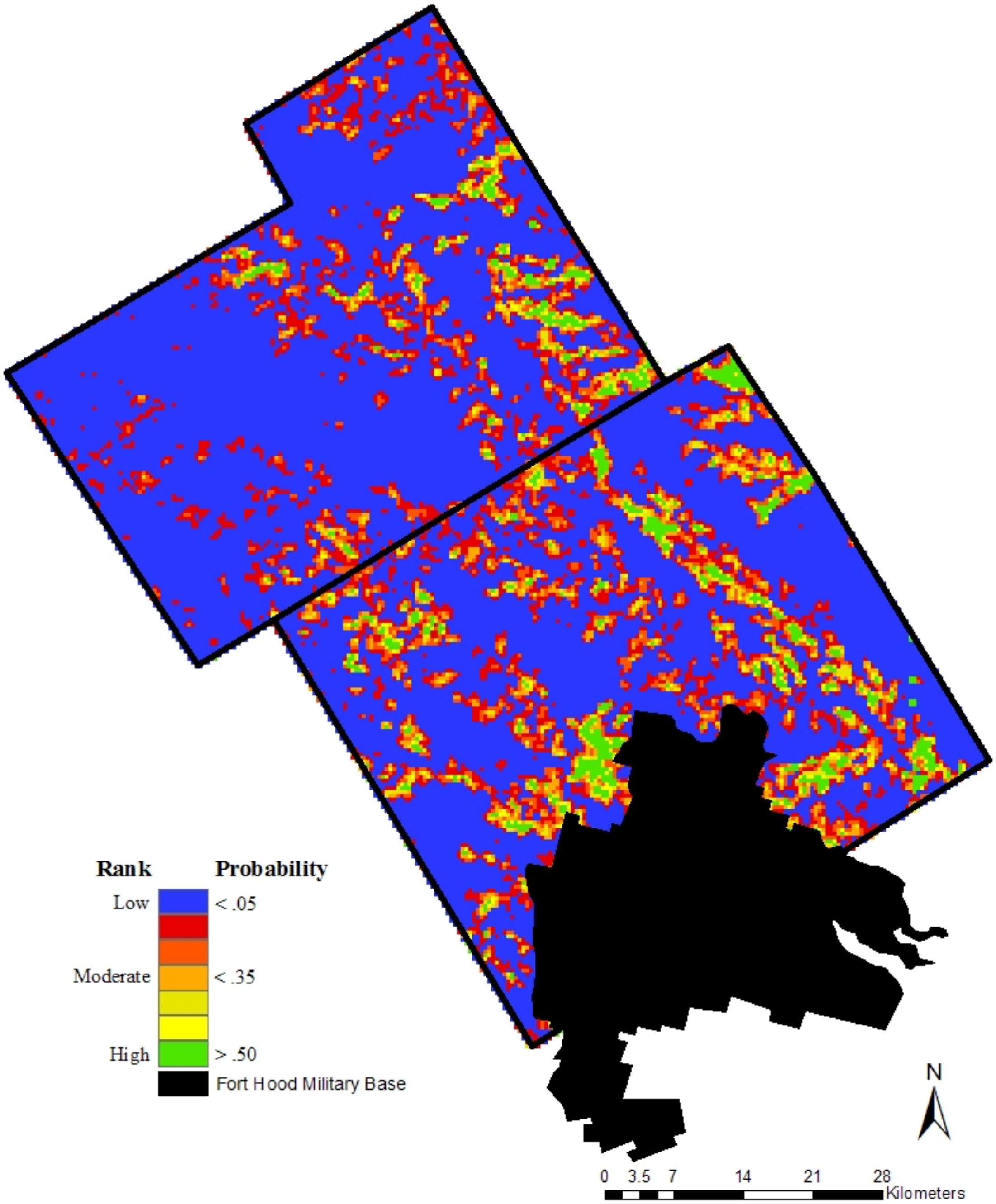

Figure 13. 400m GCWA model 2 showing probability of occurrence throughout Hamilton and Coryell Counties, Texas. Variables include ln mean juniper > 70%, minimum profile curvature, and ln mean departure from north (ROC = 0.795, Rho-

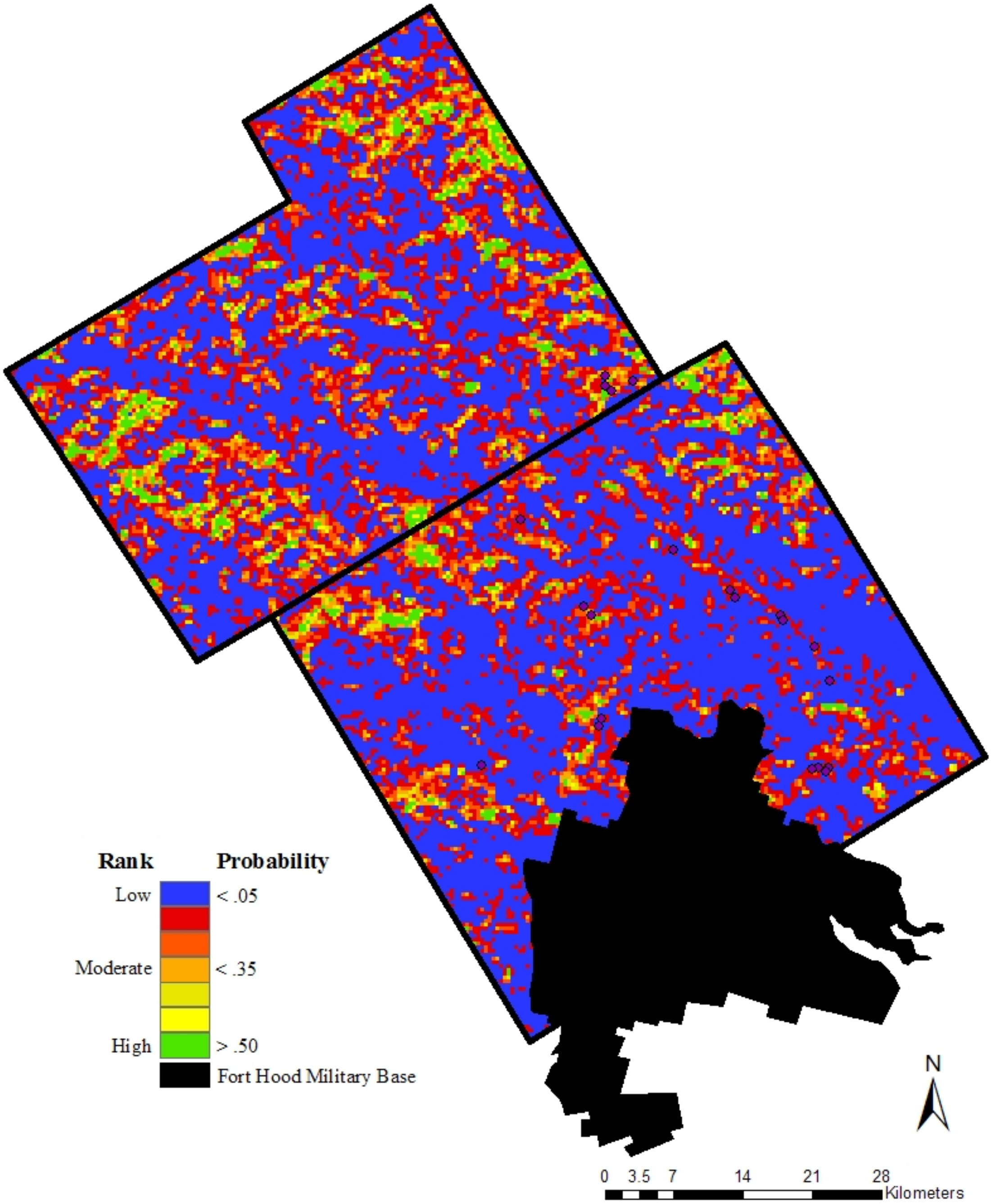

Figure 14. 400m BCVI model 2 showing probability of occurrence throughout Hamilton and Coryell Counties, Texas. Variables include ln mean shrub cover > 90%, SIN plan curvature, and ln mean departure from north (ROC = 0.708, Rho-sq = 0.066).

DISCUSSION

It is important to note that the following discussion focuses on the variables that were identified to be the strongest non-correlated variables and most easily distinguishable at the resolution of my remotely sensed data. The purpose of my study was to indicate if this technology could accurately predict occurrence for these species and to develop several 'best' non-correlated alternative models. I do not discuss in depth all variables that were found to be important in predicting occurrence. Therefore, just because a variable is not mentioned in the context of selected models does not mean that it should be excluded as an important habitat requirement.

Golden-cheeked Warbler

Important Landscape Features **–** These results suggest that golden-cheeked warbler habitat occupancy can be predicted using a combination of factors. Specifically, it is the combination of heavy juniper dominated woodland combined with landform that provides the best predictions of occupancy. At sites occupied by golden-cheeked warblers mean juniper cover is approximately 1.5 times greater at both 100m and 400m spatial scales than at unoccupied sites. This supports Kroll's (1980) and Beardmore's (1994) findings that sites with higher juniper abundance were important in golden-cheeked warbler occurrence. My study provides important confirmation of the requirement of high density mature juniper for this species.

Aspect and slope were also found to be important in predicting occurrence of this species. Average aspect was 15.6° and 8.5° less at occupied sites (100m and 400m scales respectively) than unoccupied sites, showing that this species tends to occur on more northern facing slopes. Maximum slope was also greater on average in occupied sites with16.3% and 59.0% of the sites at the 100m and 400m scale having an average maximum slope greater than 15.0 in contrast with 10.7% and 44.4% in unoccupied sites, demonstrating the trend often mentioned in habitat descriptions for this species (Campbell 1995, and Kroll 1980). Curvature was also important, with plan curvature influencing habitat occupancy at the 100m scale and profile curvature at the 400m scale. Vegetation structure and composition of occupied and unoccupied areas for golden-cheeked warblers have been investigated in depth, but little research has been done to determine the importance of landform features.

Spatial Scale -The strongest models were found to be comprised of 400m (50.2ha) variables. The top model was comprised of variables that were applicable at both scales, heavy juniper cover (juniper cover > 70%), aspect (mean departure from North), and minimum profile curvature. Landscape features up to six times the size of the upper range of their territory (20 acres or 8.1ha) or approximately 30 times the mean territory size of 1.7 ha as described by Campbell (1995) were found to be most significant. These results support Magness' (2005) findings that habitat occupancy by golden-cheeked warblers is impacted by the vegetation surrounding the territory, implying that when managing golden-cheeked warbler habitat it is important to consider the areas surrounding a territory, not just the territory itself.

Model Assessment- A threshold value between 0.35-0.40 appears to offer the highest number of accurate predictions of occurrence while retaining at least an 80% accuracy rate for identifying unoccupied areas. Pearce and Ferrier (2005) reported that alternate thresholds should be used when working with models in order to try and minimize false negatives. Overall ROC value at the 0.50 threshold level for the top five models at each spatial scale when applied to the landscape ranged from 0.79 to 0.86. This meets the requirements of an acceptable model by Hosmer and Lemeshow (2000:162) who consider a ROC score between 0.70 and 0.80 acceptable and anything higher than 0.80 excellent. These results suggest that the level of spectral resolution in Landsat imagery (30mx30m) provides useful information in identifying golden-cheeked warbler habitat at the landscape level.

Black-capped Vireo

Important Landscape Features **–** My results indicate that black-capped vireo occupancy is best identified using a combination of heavy shrub cover combined with landform features. At sites occupied by black-capped vireos, shrub cover >70% is 1.3 times higher in occupied sites than unoccupied (9.7% vs 7.2%) at the 100m scale and 1.1 times greater (7.2% vs 7.0%)at the 400m scale. This indicates that heavy shrub cover is important to black-capped vireos, supporting Grzybowski's (1995) description that heavy shrub cover should be ≥ 35.0% in adult territories. These findings suggest that when managing for this species, it is important to manage for areas with dense shrub cover.

Aspect, slope and curvature were also useful in identifying areas of occupancy by this species. Occupied sites averaged a northern aspect of 71.1 and 79.8 at the 100m and 400m scales respectively while unoccupied sites averaged 90.7 and 91.8. These findings support that black-capped vireos tended to prefer the cooler, water shedding (convex slopes), tops of northern slopes, supporting research by Graber (1961) who found that shrub growth was highest on north and east facing slopes. Graber's findings are important in that they imply that both topology of the land as well as vegetation cover are important factors when managing for this species. Currently little research has been done to investigate the relationship between black-capped vireos and landform features such as curvature.

Spatial Scale - Black-capped vireos appear to be using landscape features up to 7.8 times the size of the upper range of their territory (6.5ha) as described by Campbell (1995) or approximately 33.5 times the mean territory size of 1.5 ha as described in the recovery plan (Graber 1961). The strongest models were found to be comprised of 400m (50.2ha) variables. The top model was comprised of variable types that were applicable at both scales, mean shrub cover greater than 90%, mean departure from North, and mean plan curvature. This is important because while much research has been done for this species at the micro-site scale (Farquhar and Gonzales 2005, Juarez 2005, Grzybowski 1994) little research has been done at the landscape level.

Model Assessment- A threshold value between 0.35-0.40 appears to offer the highest true positives while retaining at least an 80 percent true negative rate. Overall ROC value at the 0.50 threshold level for the top five models at each spatial scale when applied to the landscape ranged from 0.93 to 0.94. Hosmer and Lameshow (2000) state that a model with an ROC value ≥ 0.70 is a successful model; however these values are misleading. Due to the small sample size for this species, the ROC values are inflated by the number of true negatives, not by true positives. Just as a “true negative” might identify a site at which a bird was not located because there was none there, one can not be certain that in truth that location was not an areas at which a bird was not detected even when present (Browning et al. 2005). This hinders the ability to call a model that relies heavily on true negatives for a high predictive value a good model in the case of small sample size.

The overall findings suggest that golden-cheeked warblers are found on steep northerly slopes with heavy deciduous and mature juniper cover while black-capped vireos are found at the top transition areas of these same northerly slopes (Figure 15, Figure 16). This could be due to the fact that in the northern hemisphere, north facing slopes tend to be cooler and more moist. This could potentially affect the vegetation type, vegetation density, as well as overall temperature. This relationship is another area that needs further investigation.

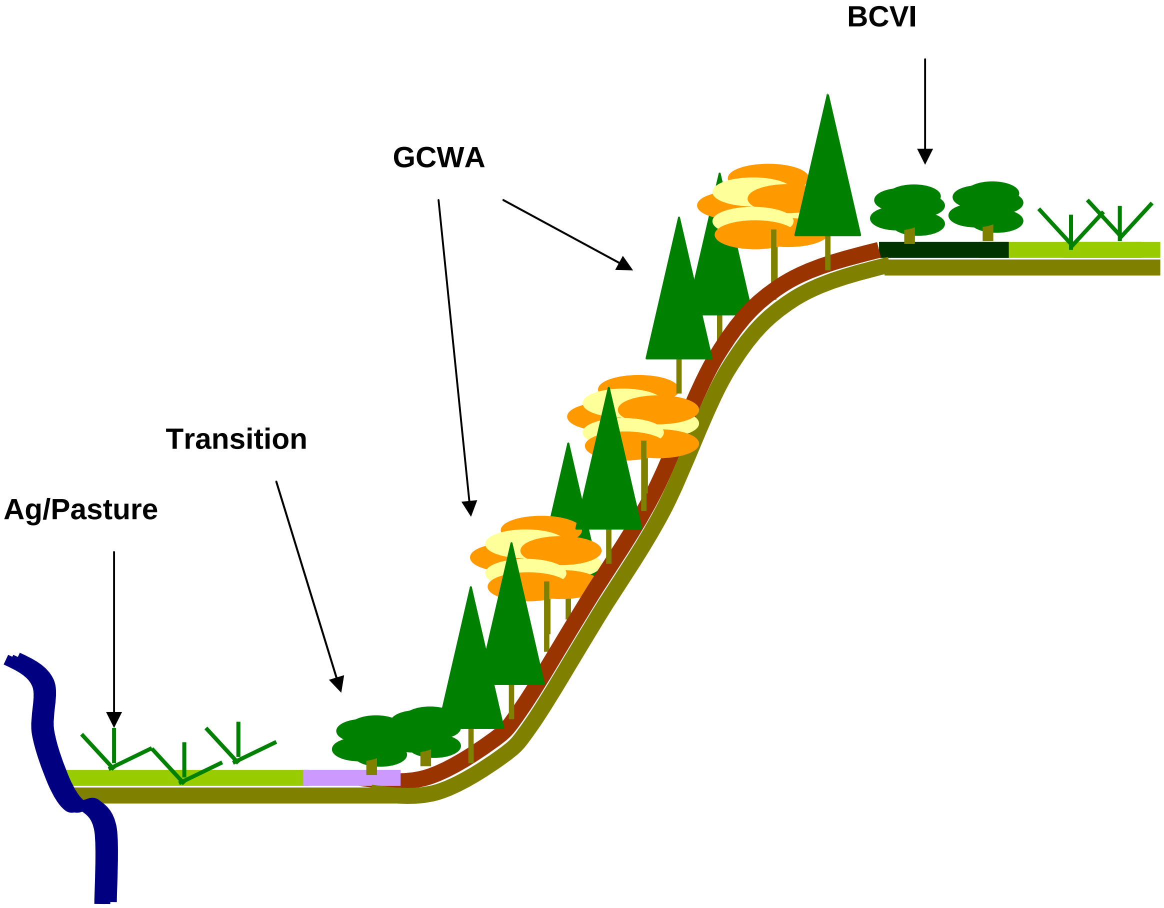

Figure 15. Profile curvature representation of findings from this study, indicating areas where golden-cheeked warblers and black-capped vireos are most likely to occupy.

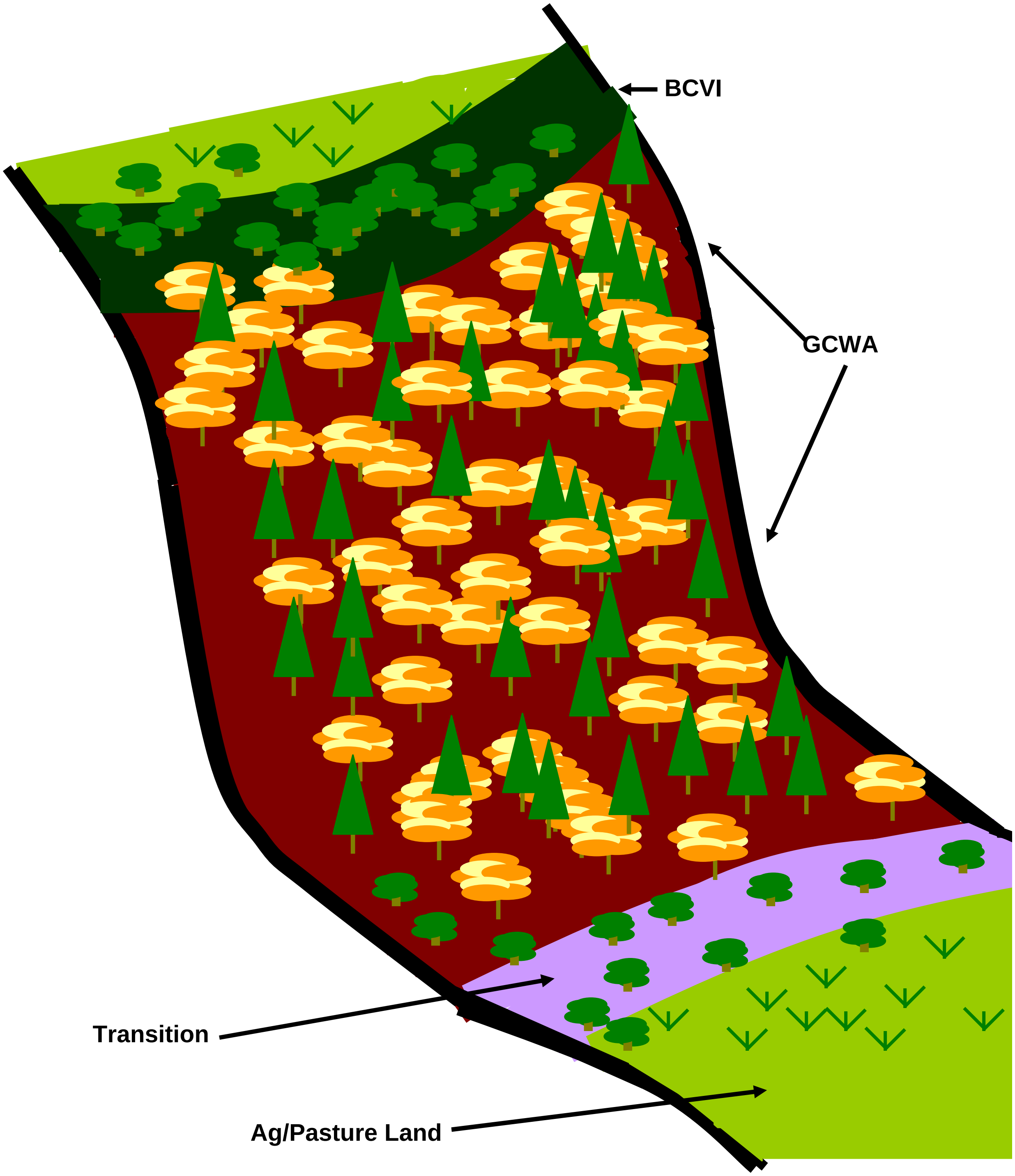

Figure 16. Plan curvature representation of findings from this study, indicating areas where golden-cheeked warblers and black-capped vireos are most likely to occupy.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Models developed using GIS and relationships derived from remotely sensed data can be effective tools for conservation planning and management, as well as reducing land use conflicts and development costs (Wu and Smeins 2000). Models proposed by this research are preliminary models to be used for management purposes, but also to be improved upon with consideration of additional data. As such, the models developed and the methods described in this research may yield applications beneficial to wildlife ecology and management.

By using sub-pixel analysis to derive the spectral signatures and incorporating GIS variables from data readily accessible to the general public, the models developed within this study can be applied across species ranges that are comprised of similar vegetation and topographical features. However, when using these models outside of their intended area, caution is suggested. When using them in another area, these models should be used only as a preliminary starting point. These models may also be compared to models developed in other areas of the range that differ in habitat availability with the end result of determining the variability of minimum habitat requirements across a species range. Finally, such models can enhance wildlife management efforts by identifying habitats likely to support a species, thus enabling a manager to effectively identify areas either timber removal or habitat management.

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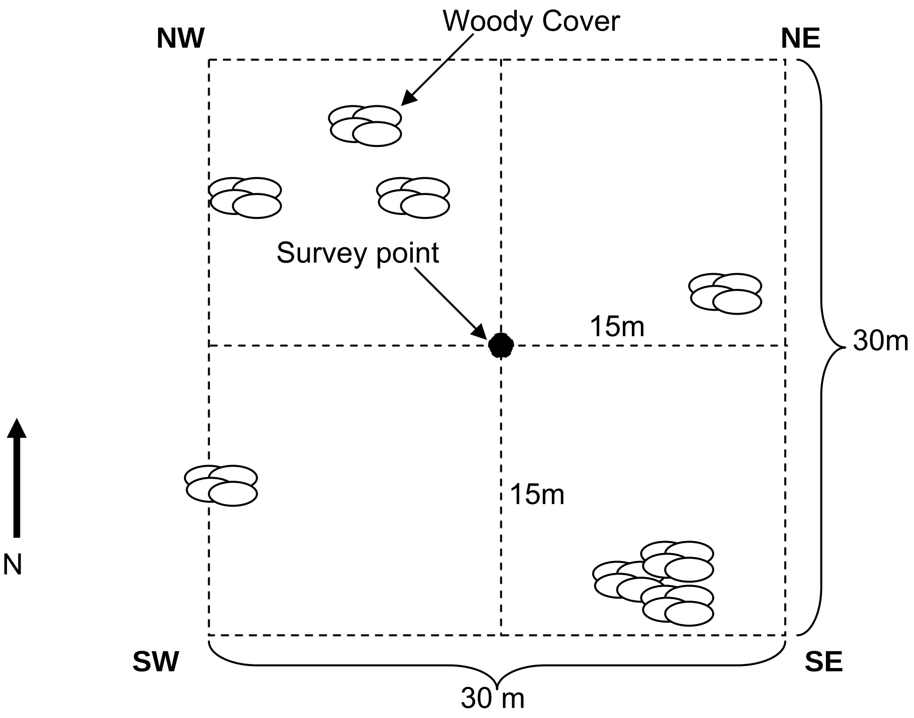
APPENDIX A

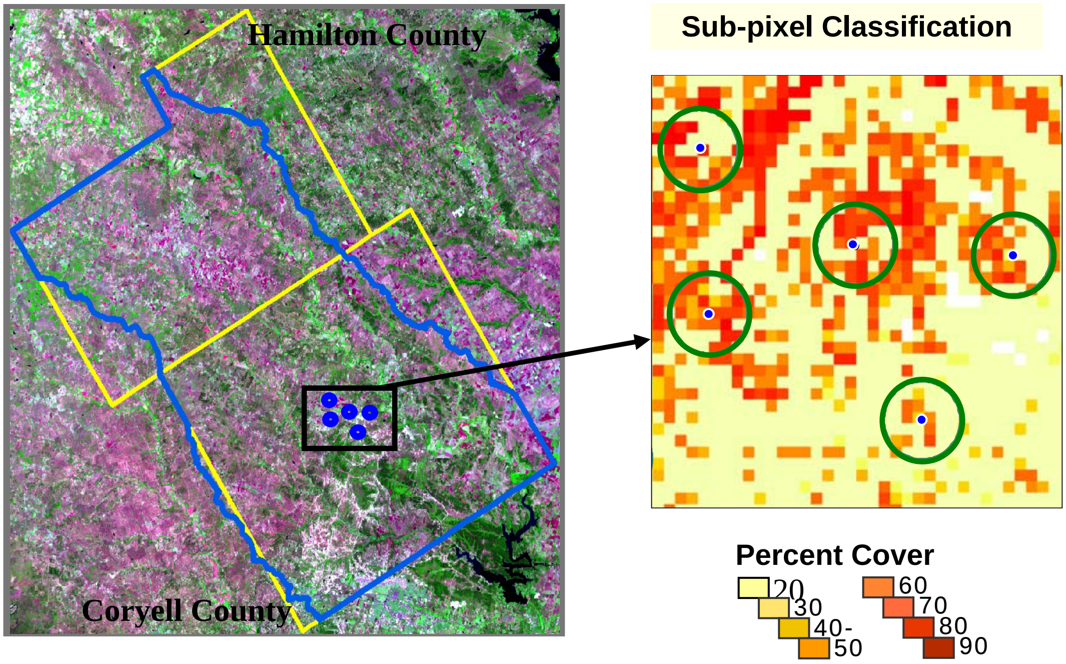
Diagram of the vegetation surveys at each point.



[(NW + NE + SW + SE) / 4] = Average woody cover at each point

APPENDIX B

Visual representation of a sub-pixel classification.



APPENDIX C

GCWA significant ($p \leq 0.15$) variables determined using univariate logistic regression at the 100m spatial scale.

Rank	Variable	P-value	Coefficient (B)	Rho-Sq	ROC
1	JUN90	< 0.001	0.073	0.138	0.76
2	JUN70	< 0.001	0.042	0.138	0.75
3	DEC70	< 0.001	0.038	0.109	0.74
4	DEC50	< 0.001	0.034	0.106	0.73
5	JUN50	< 0.001	0.035	0.120	0.73
6	DEC20	< 0.001	0.034	0.103	0.73
7	JUN20	< 0.001	0.033	0.102	0.71
8	SO50	< 0.001	-0.083	0.074	0.71
9	SO20	< 0.001	-0.071	0.070	0.70
10	PO70	< 0.001	0.054	0.069	0.69
11	S070	< 0.001	-0.102	0.051	0.67
12	PO50	< 0.001	0.044	0.054	0.66
13	PO20	< 0.001	0.037	0.042	0.64
14	LO50	< 0.001	-0.040	0.032	0.63
15	LO20	< 0.001	-0.036	0.031	0.62
16	ASNO_MEAN	< 0.001	-0.011	0.029	0.62
17	ASNO_MIN	< 0.001	-0.011	0.028	0.60
18	SA	0.005	0.008	0.016	0.60
19	SHR20	0.002	-0.042	0.022	0.60
20	LO90	0.001	0.207	0.022	0.60
21	SHR50	0.021	-0.031	0.011	0.57
22	ASNO_MAX	0.021	-0.006	0.011	0.56
23	S	0.025	-0.022	0.017	0.56
24	SLOPE_MAX	0.043	0.042	0.008	0.56
25	SHR70	0.114	-0.026	0.005	0.55
26	CL	0.128	-0.075	0.008	0.55
27	ASEA_MEAN	0.115	-0.004	0.005	0.54
28	PLAN_MEAN	0.099	24.689	0.006	0.54
29	LO70	< 0.001	-0.025	0.138	0.54
30	PROF_MIN	0.137	-68.827	0.004	0.54
31	SLOPE_MEAN	0.126	0.056	0.005	0.54
32	DEC90	0.137	-0.344	0.009	0.52

APPENDIX D

Summary statistics for vegetation variables at both spatial scales. Variable statistics are only for landscapes where BCVI were present (n = 26).

Vegetation Variables	**Description**	**Coryell Creek (100m)**				**Coryell Creek (400m)**			
		Mean	St. Dev.	Min	Max	Mean	St. Dev.	Min	Max
JUN20	Ave. ashe juniper cover > 20%	52.3	25.1	6.3	91.4	49.6	16.5	18.3	85.2
JUN50	Ave. ashe juniper cover > 50%	46.2	26.6	0.0	88.6	44.3	17.8	13.2	82.9
JUN70	Ave. ashe juniper cover > 70%	33.6	24.2	0.0	85.7	33.9	17.0	6.4	70.4
JUN90	Ave. ashe juniper cover > 90%	15.5	17.0	0.0	60.0	14.6	9.9	0.5	35.5
LO20	Ave. live oak cover > 20%	22.9	16.9	3.1	63.0	19.0	5.9	8.0	32.4
LO50	Ave. live oak cover > 50%	19.2	17.1	0.0	59.4	14.6	5.6	5.5	26.9
LO70	Ave. live oak cover > 70%	13.1	11.7	0.0	45.7	8.3	3.1	3.7	16.3
LO90	Ave. live oak cover > 90%	1.3	2.5	0.0	9.4	0.7	0.5	0.0	1.6
DEC20	Ave. deciduous cover > 20%	34.0	23.4	0.0	82.4	34.9	17.0	8.2	67.7
DEC50	Ave. deciduous cover > 50%	30.8	24.8	0.0	82.4	32.6	17.5	6.3	66.6
DEC70	Ave. deciduous cover > 70%	24.4	23.3	0.0	82.4	24.6	15.6	1.4	55.0
DEC90	Ave. deciduous cover > 90%	0.1	0.6	0.0	2.8	0.1	0.1	0.0	0.4
PO20	Ave. post oak cover > 20%	17.0	13.7	0.0	54.1	18.4	8.6	6.3	42.8
PO50	Ave. post oak cover > 50%	14.17	12.5	0.0	48.7	16.0	8.4	4.5	39.3
PO70	Ave. post oak cover > 70%	10.0	11.9	0.0	46.0	13.0	8.2	2.3	33.0
PO90	Ave. post oak cover > 90%	0.00	0.0	0.0	0.0	0.1	0.1	0.0	0.5
SO20	Ave. spanish oak cover > 20%	14.8	13.1	0.0	54.3	13.8	6.3	3.2	24.0
SO50	Ave. spanish oak cover > 50%	12.6	12.2	0.0	45.7	11.0	5.3	2.5	20.3
SO70	Ave. spanish oak cover > 70%	8.0	8.9	0.0	34.3	6.9	3.6	1.4	14.1
SO90	Ave. spanish oak cover > 90%	1.3	3.4	0.0	14.3	0.9	0.7	0.0	3.1
SHR20	Ave. shrub cover >70%	16.4	11.3	3.1	56.3	13.3	3.4	6.9	18.8
SHR50	Ave. shrub cover >50%	14.6	10.7	2.9	46.9	11.3	2.9	6.3	16.8
SHR70	Ave. shrub cover >70%	9.7	8.3	0.0	28.1	7.2	2.3	3.6	12.8
SHR90	Ave. shrub cover >90%	3.1	4.0	0.0	14.3	2.3	0.8	0.9	4.3

APPENDIX E

Summary statistics for geomorphic variables at both spatial scales. Variable statistics are only for landscapes where BCVI were present (n = 26).

		Coryell Creek (100m)				Coryell Creek (400m)			
Geomorphic Variables		Mean	St. Dev.	Min	Max	Mean	St. Dev.	Min	Max
SLOPE_MAX	Ave. maximum slope	10.71	4.49	3.02	20.81	16.67	5.51	8.74	28.49
SLOPE_MEAN	Ave. mean slope	5.74	3.26	1.23	14.21	5.13	1.38	2.36	7.49
SLOPE_MIN	Ave. minimum slope	1.43	1.72	0.00	5.79	0.04	0.19	0.00	0.95
PROF_MAX	Ave. maximum profile curvature	0.07	0.05	0.02	0.27	0.01	0.00	0.00	0.01
PROF_MEAN	Ave. mean profile curvature	0.00	0.01	-0.01	0.01	0.00	0.00	0.00	0.00
PROF_MIN	Ave. minimum profile curvature	-0.08	0.04	-0.13	-0.01	-0.01	0.00	-0.01	0.00
PLAN_MAX	Ave. maximum plan curvature	0.00	0.00	0.00	0.01	14.02	33.10	0.06	95.00
PLAN_MEAN	Ave. mean plan curvature	0.00	0.00	0.00	0.00	4.81	12.58	0.00	47.73
PLAN_MIN	Ave. minimum plan curvature	0.00	0.00	-0.01	0.00	-0.14	0.09	-0.27	0.00
ASNO_MAX	Ave. maximum departure from north	132.10	44.53	29.74	180.00	180.00	0.00	180.00	180.00
ASNO_MEAN	Ave. mean departure from north	71.06	32.55	11.73	153.54	79.76	18.49	51.37	118.51
ASNO_MIN	Ave. minimum departure from north	16.54	31.01	0.00	108.43	0.00	0.00	0.00	0.00
ASEA_MAX	Ave. maximum departure from east	147.55	39.15	67.38	180.00	179.16	4.28	158.20	180.00
ASEA_MEAN	Ave. mean departure from east	86.60	40.50	35.87	172.96	77.51	17.37	48.14	119.61
ASEA_MIN	Ave. minimum departure from east	26.70	40.17	0.00	153.43	0.00	0.00	0.00	0.00
CL	Ave. cover of clay loam (%)	0.16	0.60	0.00	3.01	0.01	0.02	0.00	0.05
LB	Ave. cover of loamy bottomland (%)	3.45	17.58	0.00	89.63	0.11	0.20	0.00	0.69
LS	Ave. cover of low stoney hill (%)	38.32	37.25	0.00	100.00	0.24	0.22	0.02	0.90
S	Ave. cover of shallow (%)	0.89	3.44	0.00	16.49	0.02	0.04	0.00	0.16
SC	Ave. cover of stoney clay loam (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
SA	Ave. cover of low steep adobe (%)	57.18	38.26	0.00	98.06	0.63	0.24	0.10	0.97
Other	Ave. cover of all other ecological site	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05

APPENDIX F

Summary statistics for vegetation variables at both spatial scales. Variable statistics are only for landscapes where GCWA were present (n = 129).

		Coryell Creek (100m)				Coryell Creek (400m)			
Vegetation Variables	**Description**	Mean	St. Dev.	Min	Max	Mean	St. Dev.	Min	Max
JUN_GR20	Ave. ashe juniper cover > 20%	58.3	22.9	5.7	100.0	50.0	14.6	13.4	85.2
JUN_GR50	Ave. ashe juniper cover > 50%	54.5	23.5	2.9	100.0	45.7	15.0	10.5	82.9
JUN_GR70	Ave. ashe juniper cover > 70%	43.9	22.4	0.0	100.0	36.1	13.8	6.5	70.3
JUN_GR90	Ave. ashe juniper cover > 90%	19.5	14.8	0.0	80.6	15.8	8.3	1.3	41.6
LO_GR20	Ave. live oak cover > 20%	15.4	11.4	0.0	57.1	18.0	5.0	7.0	32.4
LO_GR50	Ave. live oak cover > 50%	11.8	10.5	0.0	51.4	14.0	4.5	4.8	26.3
LO_GR70	Ave. live oak cover > 70%	7.5	6.8	0.0	34.3	8.2	2.8	2.3	15.8
LO_GR90	Ave. live oak cover > 90%	1.2	2.0	0.0	9.4	0.8	0.5	0.0	2.3
DEC_GR20	Ave. deciduous cover > 20%	43.3	22.6	0.0	94.3	37.3	13.5	7.6	72.9
DEC_GR50	Ave. deciduous cover > 50%	41.4	22.9	0.0	94.3	35.1	13.8	6.1	71.3
DEC_GR70	Ave. deciduous cover > 70%	32.9	22.0	0.0	94.3	27.2	12.7	2.5	63.4
DEC_GR90	Ave. deciduous cover > 90%	0.0	0.5	0.0	5.4	0.1	0.2	0.0	1.3
PO_GR20	Ave. post oak cover > 20%	20.6	14.6	0.0	68.8	18.8	8.1	2.1	43.9
PO_GR50	Ave. post oak cover > 50%	18.8	13.9	0.0	65.7	16.5	7.5	1.8	40.2
PO_GR70	Ave. post oak cover > 70%	16.1	13.3	0.0	65.6	13.5	7.1	1.1	36.7
PO_GR90	Ave. post oak cover > 90%	0.1	0.5	0.0	3.1	0.1	0.2	0.0	0.7
SO_GR20	Ave. spanish oak cover > 20%	8.8	9.4	0.0	54.3	10.8	4.7	2.9	26.6
SO_GR50	Ave. spanish oak cover > 50%	6.6	8.0	0.0	45.7	8.4	3.8	2.1	22.0
SO_GR70	Ave. spanish oak cover > 70%	4.0	5.4	0.0	34.3	5.2	2.5	1.3	12.8
SO_GR90	Ave. spanish oak cover > 90%	0.7	1.8	0.0	14.3	0.7	0.5	0.0	3.1
SHR20	Ave. shrub cover > 20%	11.1	7.8	0.0	38.2	12.2	2.9	5.4	20.0
SHR50	Ave. shrub cover > 50%	9.5	7.7	0.0	35.3	10.3	2.8	3.6	16.1
SHR70	Ave. shrub cover > 70%	6.6	6.5	0.0	26.5	6.7	2.2	1.4	12.7
SHR90	Ave. shrub cover > 90%	2.0	3.2	0.0	14.3	1.9	1.0	0.0	5.0

APPENDIX G

Summary statistics for geomorphic variables at both spatial scales. Variable statistics are only for landscapes where GCWA were present (n = 129).

Geomorphic Variables		**Coryell Creek (100m)**				**Coryell Creek (400m**			
		Mean	St. Dev.	Min	Max	Mean	St. Dev.	Min	Max
SLOPE_MAX	Ave. maximum slope	9.9	5.5	2.0	29.4	17.3	6.1	5.8	29.4
SLOPE_MEAN	Ave. mean slope	5.0	3.1	0.7	16.1	4.8	1.4	1.2	7.8
SLOPE_MIN	Ave. minimum slope	1.2	1.3	0.0	6.1	0.0	0.1	0.0	1.0
PROF_MAX	Ave. maximum profile curvature	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PROF_MEAN	Ave. mean profile curvature	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PROF_MIN	Ave. minimum profile curvature	0.0	0.0	-0.0	0.0	-0.0	0.0	-0.0	0.0
PLAN_MAX	Ave. maximum plan curvature	0.1	0.1	0.0	0.4	6.5	23.2	0.0	95.0
PLAN_MEAN	Ave. mean plan curvature	0.0	0.0	-0.0	0.0	2.5	9.9	-0.0	59.6
PLAN_MIN	Ave. minimum plan curvature	-0.1	0.1	-0.3	-0.0	0.2	1.8	-0.4	10.0
ASNO_MAX	Ave. maximum departure from north	142.3	41.9	45.0	180.0	180.0	0.0	180.0	180.0
ASNO_MEAN	Ave. mean departure from north	79.0	38.2	18.2	169.6	85.2	19.5	51.3	141.5
ASNO_MIN	Ave. minimum departure from north	21.9	32.9	0.0	135.0	0.1	1.2	0.0	14.0
ASEA_MAX	Ave. maximum departure from east	136.4	42.7	45.0	180.0	179.6	2.9	153.4	180.0
ASEA_MEAN	Ave. mean departure from east	76.4	37.5	16.6	159.9	78.3	20.7	43.8	135.2
ASEA_MIN	Ave. minimum departure from east	19.9	30.9	0.0	126.9	0.4	2.8	0.0	26.6
CL	Ave. cover of clay loam (%)	0.5	1.9	0.0	12.0	0.0	0.0	0.0	0.1
LB	Ave. cover of loamy bottomland (%)	6.0	17.0	0.0	96.8	0.2	0.2	0.0	0.8
LS	Ave. cover of low stoney hill (%)	33.2	37.1	0.0	100.0	0.3	0.2	0.0	0.8
S	Ave. cover of shallow (%)	1.6	9.8	0.0	100.0	0.0	0.0	0.0	0.3
SC	Ave. cover of stoney clay loam (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SA	Ave. cover of low steep adobe (%)	58.8	37.4	0.0	100.0	0.5	0.3	0.0	1.0
Other	Ave. cover of all other ecological site (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

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Submitted Publications-

Cummins, T., and N.A. Slade. Summer capture of *Reithrodontomys megalotis* in elevated traps in eastern Kansas. The Southwestern Naturalist.

Manuscript in progress-

Cummins, T. and N. Wilkins. The use of GIS and remotely sensed data in predicting the occurrence of two endangered avian species in central Texas.

Vowels, K.M., B. Furman, T.Cummins, and J. Gassett. Population estimate of the American black bear (*Ursusamericanus*) in wildlife management areas in eastern Kentucky