Department of Defense

Legacy Resource Management Program

PROJECT NUMBER 10-425

Habitat Use at Multiple Scales by Pinyon-Juniper Birds on Department of Defense Lands II: Nest and Territory/Colony Scale

Kristine Johnson, Lynn Wickersham, Teri Neville,
Giancarlo Sadoti, Jacqueline Smith, John Wickersham, & Carol Finley

March 2012

Habitat Use at Multiple Scales by Pinyon-Juniper Birds on Department of Defense Lands II: Nest and Territory/Colony Scale

Year 2 Final Report

Kristine Johnson, Lynn Wickersham, Teri Neville, Giancarlo Sadoti, Jacqueline Smith, John Wickersham, and Carol Finley
Natural Heritage New Mexico Publication 12-GTR-366
March 2012

Table of Contents

Table of Figures

List of Tables

ABSTRACT

 As part of a four-year study, we investigated pinyon-juniper habitat use by Gray Vireos and Pinyon Jays. The Year 1 report focused on landscape-scale habitat use; this report includes results for the nest (both species) and territory (Gray Vireo)/colony (Pinyon Jay) scales. We collected data for Gray Vireos at Camel Tracks Training Area (CTTA) and Kirtland Air Force Base (KAFB) and for Pinyon Jays at KAFB and White Sands Missile Range (WSMR). Also included in an appendix is a landscape-scale model for Gray Vireos at WSMR, created in Year 2.

Gray Vireos at CTTA showed weak selection for nest sites farther from buildings than random sites. No other infrastructure measure at any installation was significantly associated with vireo nest placement. Parameter estimates indicated that Gray Vireos selected nest sites on more southward-facing aspects having more trees and a higher (but not too high) mean tree heights relative to non-unused random plots within each territory. At CTTA, vireo territories were farther from infrastructure than non-territories and were more likely to occur on slopes with more north-facing aspects, be at higher elevations, have intermediate slopes, and have lower overall solar radiation than unused areas. At KAFB, Gray Vireo territories were more likely to have more intermediate aspects (e.g., eastern- or western-facing), lower elevations, and more intermediate evergreen greenness (measured from January NDVI) than unused areas. Territories were closer to two-track roads than unused areas.

Pinyon Jays nested in trees with greater total canopy cover, larger root crown diameters (indicating larger trees), and higher litter cover on the ground within 5 m of the nest, relative to non-nest trees within the colony. At WSMR, Pinyon Jays abandoned a traditional colony site and moved to a nearby location in 2010. Tree vigor declined at the abandoned colony on WSMR from 2005-2011. In 2011, pinyon trees at the new colony had higher vigor scores and produced more cones than trees at the abandoned site, suggesting that a decline in tree health was associated with the move to a new site. To model colony-scale habitat use for Pinyon Jays, we gathered GIS data at the KAFB and WSMR colonies and, based on these variables, classified the entire study area at each installation, to find similar sites. At KAFB, 12 potential colony sites resembled the south colony site. At WSMR, however, we were unable to find distinct areas similar to the colony site, and we concluded that the entire area similar to the colony site should be classified as one large map unit covering 52% of the Pinyon Woodland unit of the landscape model. At the colony scale, habitat may be more continuous at WSMR, or modeling at KAFB could have been strongly influenced by the unique characteristics of the south site at KAFB. Colony-scale habitat selection may not be the most appropriate concept for Pinyon Jays. Choice of a colony site could be a result of the combined nest-scale choices made by many individual pairs of jays.

We recommend that intermediate and large junipers, with the possible exception of senescent trees, not be removed from Gray Vireo nesting areas and that juniper trees in potential and actual nesting areas should be maintained at densities similar to those on our nest plots. Management of pinyon juniper habitat for Pinyon Jays should include maintaining densities similar to those reported here, with most

areas dominated by pinyon trees. We recommend no net loss of mature, healthy pinyon stands, to retain pinyon seed production areas and options for new colonies. We recommend that KAFB and CTTA continue to restrict training activities in the Gray Vireo nesting areas from May to July. Based on some evidence that vireos avoid infrastructure when siting nests and territories, we recommend that new infrastructure such as buildings, power lines, or shooting ranges not be constructed closer to territories than infrastructure that is currently present.

We recommend that no new roads or infrastructure be constructed any closer to traditional Pinyon Jay colonies than what currently exist. We recommend that ground training activities not be conducted within one kilometer of traditional Pinyon Jay colony sites between March and July. In mast years, ground training should not be conducted within one kilometer of areas where jays are harvesting pinyon seeds between August and October. We recommend against any activities that create loud noises or destroy habitat (such as bombing) within one kilometer of a nesting colony. No activities that carry high potential for wildfires should be conducted within a flock's breeding home range.

INTRODUCTION

Pinyon-Juniper Habitats and Wildlife

Pinyon-juniper (*Pinus edulis*, *P. monophylla*, *P. cembroides*, *Juniperus* spp.) woodlands cover approximately 40 million hectares of the western US (Romme et al. 2009). They represent the dominant woody vegetation and contain the most biodiverse terrestrial habitats on at least six DoD installations (Figure 1). Pinyon-juniper habitats throughout their range, including on military installations, are currently threatened by drought, insects, disease, and fire, all of which can be exacerbated by climate change. Since 2001, dramatic, rapid, large-scale mortality of pinyon pine trees has occurred in the southwestern U.S. due to drought-related insect and disease outbreaks (Allen-Reid et al. 2005, Breshears et al. 2005). In addition to natural impacts, some private, state, and federal land managers are implementing pinyon-juniper management programs that include thinning, mechanical clearing, herbicides, and fire (Bureau of Land Management, BLM, 2009). Outside DoD lands, development and livestock management also contribute to degradation of pinyon-juniper woodlands. Unlike private lands, which are subject to development, management for livestock, and fuelwood exploitation, woodlands on military installations have been managed relatively sustainably.

Although fire has been found to play a role in structuring pinyon-juniper woodlands on New Mexico military installations (Muldavin et al. 2003) and across the region (Baker and Shinneman 2004), fire is only one factor affecting the processes and patterns of this complex ecosystem. In addition, recent research indicates that fire has not historically been an important factor in structuring some types of pinyon-juniper woodlands (Romme et al. 2009). Birds, particularly Pinyon Jays (*Gymnorhinus cyanocephalus*), drought, and insect pests also play critical roles in the establishment and demise of these woodlands (Romme et al. 2009). Pinyon Jays serve as short- and long-distance seed dispersers for pinyon pines, and the pines in turn provide mast crops of pinyon seeds that ensure Pinyon Jay population viability (Ligon 1978, Marzluff and Balda 1992). Adapted for carrying and caching millions of seeds in a few weeks, Pinyon Jays are the only seed disperser capable of re-planting an entire woodland decimated by fire, chaining, or insect pests. It has been suggested that an evolved keystone mutualism between the tree and the bird ensures their mutual, long-term sustainability (Ligon 1978, Lanner 1996).

The impacts of insects on pinyon-juniper ecosystems have become poignantly evident in recent years, with the drought-induced expansion of pinyon bark beetle (*Ips confusus*) impacts across the western United States. In 2002-2003, regional-scale die-off of *P. edulis* occurred across the Southwest. At one site, >90% of pinyon trees died. The mortality was detectable in a remotely- sensed index of greenness, the Normalized Difference Vegetation Index, over 12,000 km^2 (Breshears et al. 2005). In addition, wildfire and management for livestock grazing have recently removed significant areas of pinyon-juniper woodland in New Mexico and the Southwest (BLM 2009). Global climate change is expected to bring increased temperatures and frequent drought, which will only exacerbate insect and wildfire impacts. The range of pinyon-juniper habitat is predicted to contract significantly in southern New Mexico, Utah, and Arizona under climate change (Thompson et al. 1998, Cole et al. 2007) and expand in northern New Mexico and Colorado (Cole et al. 2007).
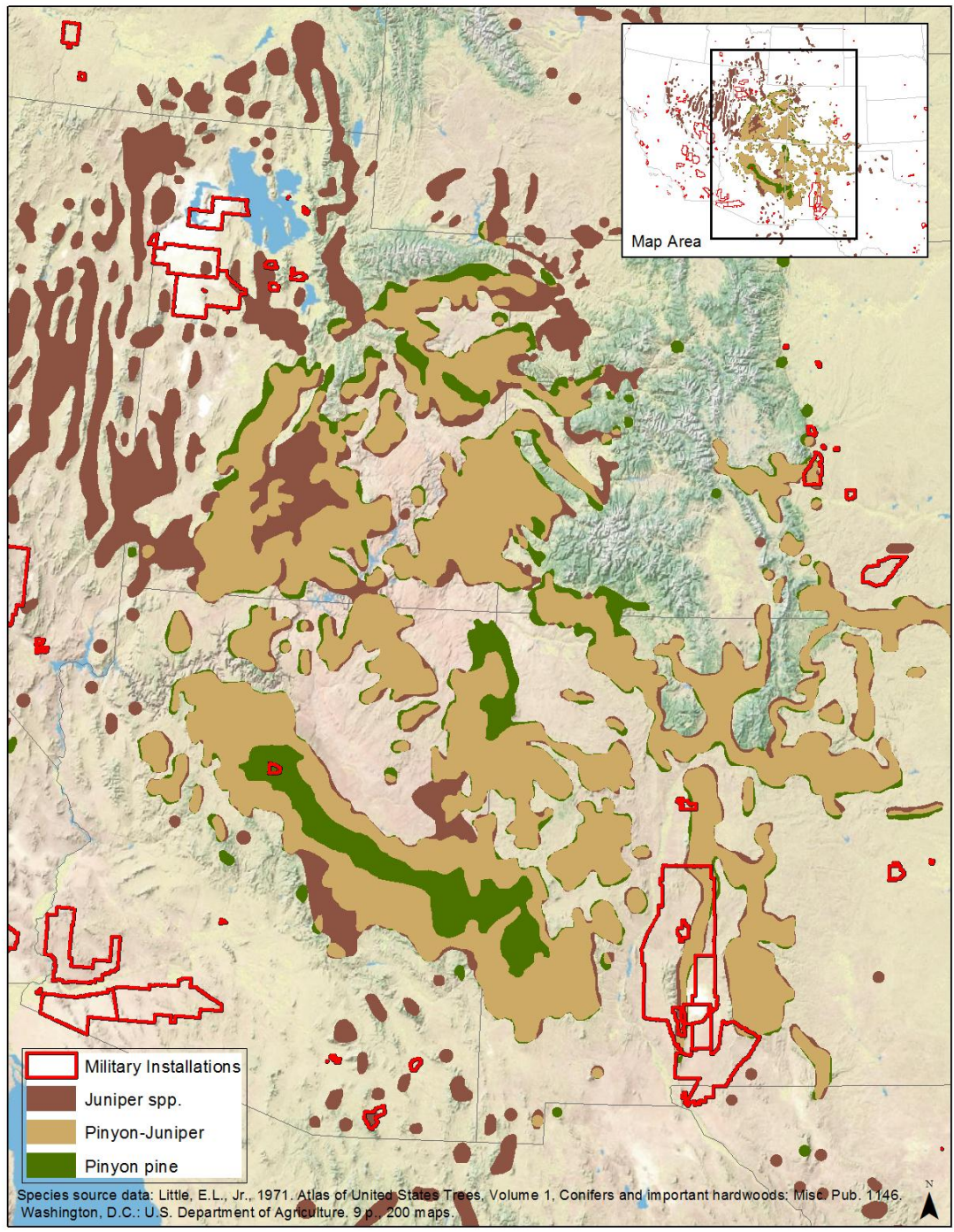
Figure 1. Military installations in SW US, showing distribution of pinyon-juniper habitats.

The insecure status of several native pinyon-juniper wildlife species provides further evidence that these habitats are threatened. The Gray Vireo (*Vireo vicinio*r) is a DoD Species at Risk (SAR), listed as threatened by the state of New Mexico, a US Forest Service Sensitive Species (Region 3), and a New

Mexico Partners in Flight (NM PIF) Level 1 Species of Concern. The Pinyon Jay is a DoD SAR and a NM PIF Level 1 Species of Concern (NMPIF 2007). Both species are on the North American Partners in Flight Watch List (Rich et al. 2004 and the DoD PIF Priority Species list (DoD PIF 2011), which lists 68 species determined by DoD PIF to have the greatest potential impact on the DoD mission, should they become listed. Both are identified as Species of Greatest Conservation Need (SGCN) by the states of Colorado and New Mexico, and the Gray Vireo is a SGCN in Utah (Sutter et al. 2005, Colorado Division of Wildlife 2006, New Mexico Department of Game and Fish 2006).

Other pinyon-juniper bird and mammal species that occur on DoD lands are also at risk; for example, Oscura Mountains Colorado chipmunk (*Neotamias quadrivittatus oscuraensis*), Black-throated Gray Warbler (*Dendroica nigrescens*), and Juniper Titmouse (*Baelophus ridgwayi*). All are SGCN in New Mexico, the latter two in Colorado, and the warbler in Utah (Sutter et al. 2005, Colorado Division of Wildlife 2006, New Mexico Department of Game and Fish 2006).

In contrast to the Pinyon Jay, which is resident, omnivorous, and highly social (flocking in winter and nesting colonially and cooperatively), the Gray Vireo is migratory, insectivorous, and territorial. The jay nests largely in pinyon-dominated vegetation types. The vireo nests primarily in juniper and has not evolved the mutualism shared by Pinyon Jays and pinyon pines. In spite of the differences in their natural histories, both are species of concern. This, in addition to the other pinyon-juniper species that are at risk, suggests that impacts to pinyon-juniper habitats are far-reaching.

Gray Vireo

Gray Vireos are short-distance migrants that breed in the southwestern US and northwestern Mexico (Figure 2). Throughout their range, Gray Vireos prefer pinyon-juniper, scrubland, or chaparral habitats in arid, mountainous terrain or high plains (Barlow et al. 1999). In New Mexico, they are primarily associated with juniper woodlands and savannas of the foothills and mesas, usually with a well-developed grassy understory and, in some areas, a pinyon or oak component (New Mexico Department of Game and Fish 2005). Diet includes a variety of large arthropods, including grasshoppers, cicadas, and caterpillars. In the winter, they may also eat fruit (Barlow et al. 1999). Distribution of the Gray Vireo in New Mexico is patchy, and the majority of occupied habitats contain fewer than 10 territories (DeLong and Williams 2006). Reported density estimates have been as low as 0.005 and as high as 0.069 birds/ha throughout the species' range (Weathers 1983, Colorado BLM 1995, Giroir 2001, DeLong and Williams 2006, Hutton et al. 2006, Schlossberg 2006, Wickersham and Wickersham 2007). Breeding territory size has not been well-documented; however, a few studies have reported territories ranging from 2–10 ha (Barlow et al. 1999, J. Wickersham and L. Wickersham unpublished), and singing males have been reported every 300 m in Texas and Arizona (Wauer 1983 in Barlow et al. 1999, Barlow 1978, respectively). Gray Vireos are commonly parasitized by Brown-headed Cowbirds (*Molothrus ater*), but the impact on vireo population viability is not well understood.

Pinyon Jay

Pinyon Jays are year-round residents in pinyon-juniper habitats across the southwestern US (Figure 2). They also occur in Idaho, Montana, Wyoming, and central Oregon, where they inhabit woodlands and

scrublands containing ponderosa pine (*Pinus ponderosa*), juniper, and chaparral vegetation (Balda 2002). They nest colonially and breed cooperatively on traditional nesting grounds. Pinyon jays are omnivorous, taking pine seeds, acorns, juniper berries, arthropods, and small vertebrates, but they especially depend on the seeds of pinyon pines. With their ability to carry up to 50 pinyon seeds at a time, Pinyon Jays are the main long-distance seed disperser for pinyon trees. In return for seed dispersal services, the trees provide mast crops of abundant, highly nutritional seeds. Cached seeds sustain Pinyon Jays over winter, support successful nesting, and strongly influence jay population viability (Marzluff and Balda 1992). Pinyon Jays form large winter flocks that historically have numbered up to several hundred birds and range widely in search of pinyon seeds and other foods. Due to its unique keystone mutualism with pinyon trees (Ligon 1971, 1974, 1978), the Pinyon Jay is likely the most important avian indicator of pinyon woodland productivity. The pinyon pine's most important seed disperser is considered to be at risk because populations range-wide have been declining significantly for over 40 years (Sauer et al. 2007).

The Project

The predominance of pinyon-juniper woodlands on military installations in the Southwest, along with the current threats to these habitats and their wildlife, underscore the need for information on proper management of pinyon-juniper. The management history of pinyon-juniper woodlands on military lands makes them excellent laboratories for the study of the habitat needs of pinyon-juniper wildlife and the compatibility of at-risk species with military activities.

For this project, we are investigating pinyon-juniper habitat use by two avian SAR, Pinyon Jay and Gray Vireo. We are collecting data on habitat use at multiple scales (landscape, territory, and nest) at three installations: White Sands Missile Range (WSMR), Kirtland Air Force Base (KAFB), and Camel Tracks Training Area (CTTA) (Figure 3). CTTA has ~1200 ha of juniper woodland/savanna (Arbetan et al. 2002), and WSMR and KAFB have ~54,100 ha and ~6507 ha of pinyon-juniper habitat, respectively (Muldavin et al. 2000a, b; USGS 2004). This study of habitat use by two at-risk species that differ in seasonal movements, social structure, and foraging habits, viewed at multiple scales and several installations, will provide a broad perspective on the proper management of pinyon-juniper woodlands. This report covers the second year of the project, in which we focused on habitat use at the nest and colony/territory scales. We have requested funding for a third year of support to collect additional nest-scale data and refine and finalize models at all scales.
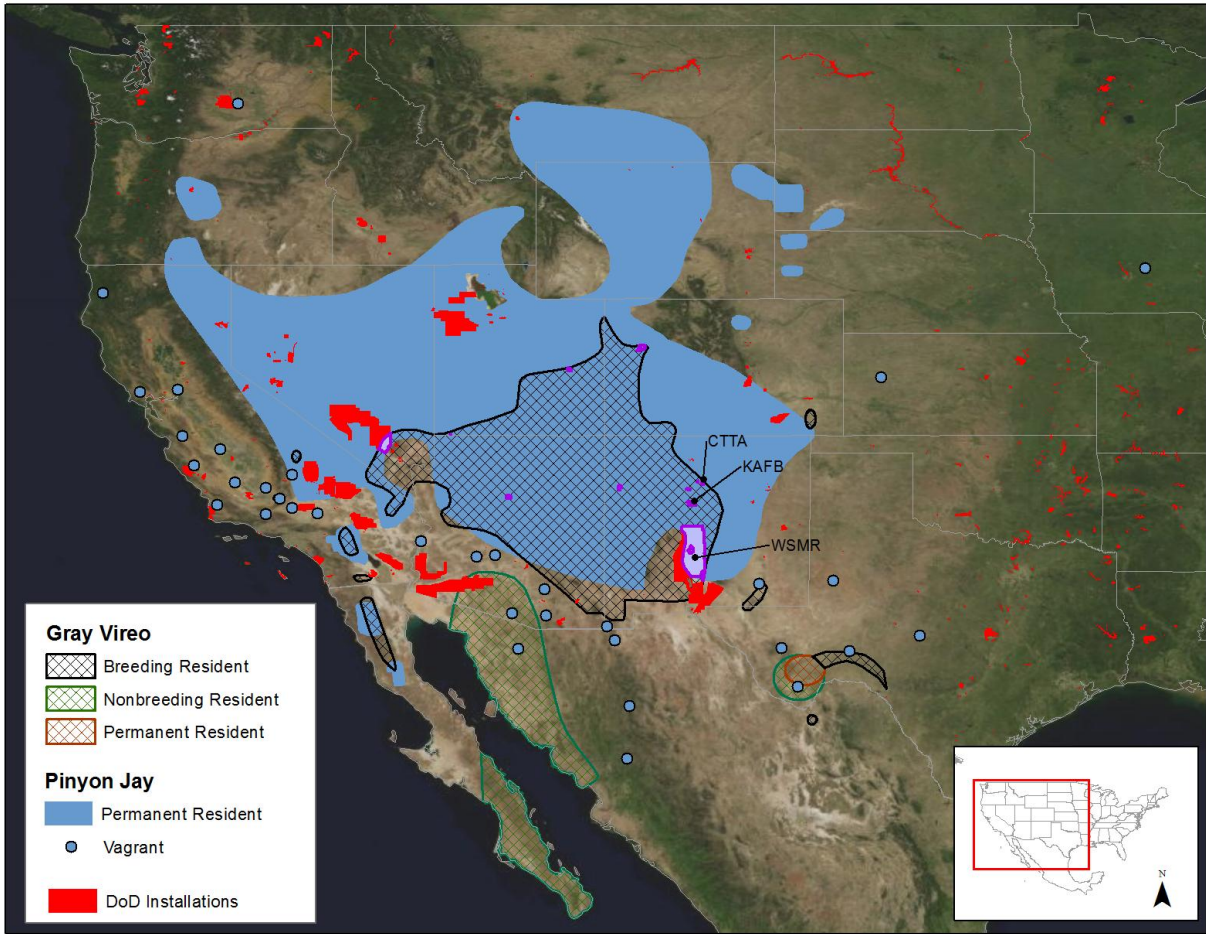
Figure 2. Gray Vireo and Pinyon Jay distributions, showing DoD installations.
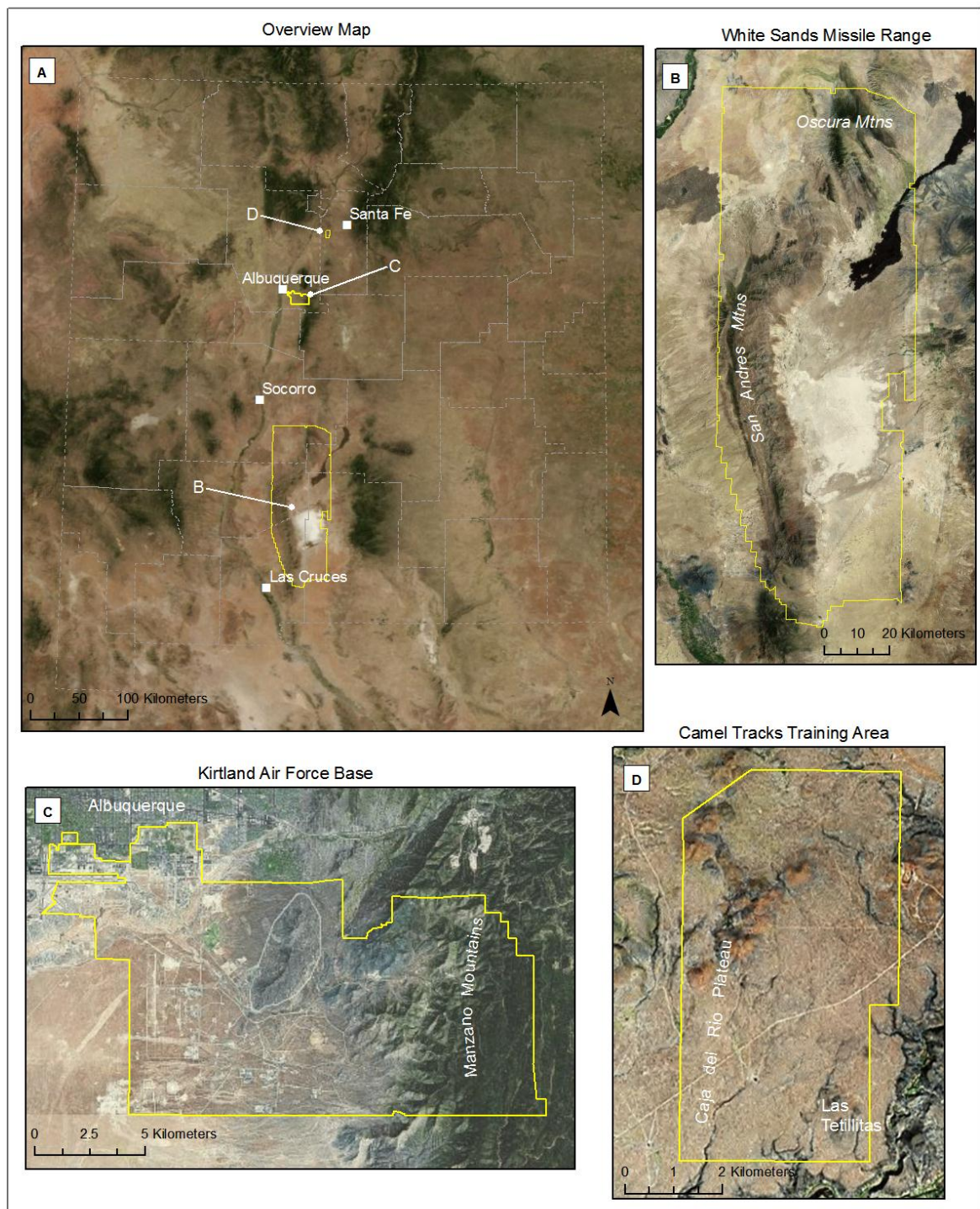
Figure 3. Study area maps for the three DoD installations in New Mexico: a) overview map of all installations, b) White Sands Missile Range, c) Kirtland Air Force Base, and d) Camel Tracks Training Area.

Study Areas

Camel Tracks Training Area. CTTA, an area of ~3345 ha, is owned by the BLM and used by the US Army National Guard for military training. It is located approximately 22.5 km southwest of Santa Fe, NM and is bounded on the north and west by the Santa Fe National Forest. Our study area included only the northwestern portion of CTTA, where most of the suitable Gray Vireo habitat occurs. Natural Heritage New Mexico has monitored a breeding population of Gray Vireos there since 2001 (Figure 3). Topography in the study area is relatively flat to rolling and ranges in elevation from approximately 1950 to 2100 m. Vehicle traffic is minimal during the Gray Vireo breeding season due to a seasonal closure to military training activities. CTTA has approximately 1200 ha of juniper woodland habitat (Arbetan et al. 2002). Habitat in the study area is primarily one-seed juniper (*Juniperus monosperma*) woodland, with ≤5% pinyon pine. Understory vegetation is dominated by native grasses, tree cholla (*Cylindropuntia imbricata*), yucca (*Yucca* spp.) and prickly pear cactus (*Opuntia phaecantha*). Shrub density is relatively low, but the most common species include antelope bitterbrush (*Purshia tridentata*), Sonoran scrub oak (*Quercus turbinella*), and wolfberry (*Lycium* spp.).

Situated mid-way between the Sangre de Cristo Mountains to the east and the Jemez Mountains to the west, CTTA receives relatively low average annual precipitation of 21 cm with nearly 40% of total precipitation occurring during the summer monsoons (Western Regional Climate Center 2010). Monthly temperatures range from a low of -7.5° C in January to relatively mild summer highs averaging 30° C (Western Regional Climate Center 2010).

Kirtland Air Force Base. KAFB, 20,359 ha in area, is located at the southeast corner of Albuquerque, NM. Pinyon-juniper habitats at KAFB occur primarily on the western slopes and bajadas of the Manzanita Mountains, a north-south chain that connects the relatively higher Sandia Mountains to the north (elevation 3255 m) and Manzano Mountains (elevation 2802 m) to the south. KAFB has about 6507 ha of juniper and pinyon-juniper habitats (USGS 2004) ranging in elevation from 1888 to 2427 m. These habitats are situated between lower-elevation desert shrubland and grassland and higher-elevation ponderosa pine woodland.

Climate at KAFB is characterized by low precipitation and wide temperature extremes. Precipitation comes primarily during the summer months, in the form of heavy, short-duration thunderstorms. Annual precipitation varies from 20.3 cm in arid valleys and mesas to 76.2 cm in the Sandia Mountains (Kirtland Air Force Base 2007). At the Albuquerque Airport weather station, the average monthly temperature ranges from 6.2^0 to 21^0 C (Western Regional Climate Center 2010).

Our Gray Vireo study area includes a portion of the known Gray Vireo breeding habitat on KAFB located east of the Withdrawal Area boundary in the foothills of the Manzanita Mountains. It includes areas north and south of Arroyo del Coyote and the adjacent Coyote Springs Road and includes Madera, Lurance and Sol se Mete Canyons. Historically-occupied Gray Vireo habitat occurs primarily on toe slopes, although some territories also extend into side canyons or relatively flat terrain at the base of the foothills. Elevation ranges between approximately 1676-2137 m. Habitat is juniper woodland and savanna, with approximately 90% juniper and 10% pinyon. Understory vegetation is dominated by

native grasses, tree cholla, yucca, and prickly pear. While shrub density is relatively low, some common species include fourwing saltbush (*Atriplex canescens*), mule fat (*Baccharis salicifolia*), Sonoran scrub oak, wolfberry, and big sagebrush (*Artemisia tridentata*).

Our Pinyon Jay study area at KAFB partially overlaps the Gray Vireo study area in lower-elevation juniper woodland habitat but extends through higher-elevation, mixed pinyon-juniper woodlands and into pinyon-dominated woodland with varying ages of pinyon, including many large trees. Our study focused on two disjoint areas, the northern area along Coyote Springs Road, and the southern area in steep, isolated terrain near the southern installation boundary. Shooting and ground-based military training occur in the northern area. The area between these two focal areas was included in the study area, but birds were rarely detected there.

White Sands Missile Range. WSMR, an area of ~ 885,910 ha, excluding buffer extension areas, is located in south-central New Mexico. The installation includes three major mountain ranges, the Oscura Mountains (maximum elevation 2431 m at North Oscura Peak, NOP) in the north, the San Andres Mountains (maximum elevation 2733 m at Salinas Peak) in the south, and a portion of the Organ Mountains in the southwest corner of the missile range. The San Andres Mountains are a large, west-tilted fault block with precipitous, east-facing escarpments and long, gentle slopes to the west. The Oscuras are also fault-block mountains but are tilted downward toward the east, with escarpments facing west. WSMR has about 54,100 ha of juniper, pinyon, and pinyon-juniper woodlands and savannas within the mountain ranges (Muldavin et al. 2000 a, b).

The climate in the mountains of WSMR is semi-arid, with annual precipitation averaging between 31-35 cm. Salinas Peak averages greater precipitation than North Oscura Peak. The average annual precipitation At San Andres Canyon, in the Gray Vireo landscape model area, is 26.4 cm. The majority of precipitation comes during the summer in the form of short-duration, intense thunderstorms (Muldavin et al. 2000b) throughout July and August (WSMR Climate Stations 2009). Average temperatures range from -3.1° C in January to 27.1° C in June at NOP. At San Andres Canyon, average monthly temperatures range from 0.83° C in December to 33.8° C in July.

GRAY VIREO: METHODS

Gray Vireo: Within-territory nest-scale analyses
Field measurements. We collected nest-scale data following a modified BBIRD protocol (Martin et al. 1997). At the nest, we recorded nest tree species and measured nest height, nest aspect, nest tree height, mean width of nest tree foliage, number and mean diameter of branches supporting the nest, and distance from the nest to the outer tree edge. We collected habitat data on an 11.3-m radius (0.04 ha) circular plot centered at each nest tree. For each nest tree, we collected data from a plot at a paired, non-nest tree located 100 m from the nest tree in a random direction. We collected the following data within the circular plots: elevation; plot slope; plot aspect; number of trees and snags greater than 1.0 m tall; number of shrubs, saplings, and tree cholla 0.5−1.0 m tall; tree and shrub species

composition; mean tree height; canopy cover; and indices of live and non-live ground cover. Canopy cover was measured with a vertical canopy densitometer at the center of each plot and at 1-m intervals along the four cardinal directions out to11 m. In addition, we also measured mean foliage width of random plot center trees for comparison with nest trees.

Derived measurements. The tendency of Gray Vireos in nearby New Mexico locations to nest on slopes with western aspects (Delong and Cox 2005) suggests a potential sensitivity of Gray Vireos to solar exposure. We therefore derived several additional topography-related variables. We first used a 10-m resolution digital elevation model (DEM) to derive elevation, slope, and aspect for each plot. We acquired distances from each nest and random plot to the nearest road and building using USDA National Agriculture Imagery Program (NAIP) 1-m digital ortho quarter quads (DOQQs) acquired in 2009. We also calculated a simple north-south aspect index from the cosine of the plot aspect; values ranged from -1 (south-facing) to 1 (north-facing). We also calculated curvature of the nesting areas using the same DEM described above, because the location of Gray Vireo nests in more enclosed, bowl-shaped sites at the foot of steeper slopes (Arbetan and Neville 2009, L. Wickersham unpublished data) suggested these areas may provide protection from winds. Negative values indicate a concave curvature, while positive values indicate a convex curvature.

Statistical analysis. We modeled nest-site selection using case-control conditional logistic regression (Menard 2009) with a matched pair structure where each nest plot was paired with a random, unused plot at approximately 100 m from the nest location at a random bearing within the estimated boundaries of each territory. In this way, varying vegetation and other conditions between years and sites were treated as nuisance effects that were controlled by accounting for spatial variation between territories and sites, and temporal variation between years of the study (e.g., in live ground cover). This was achieved during modeling by using a "strata" statement denoting a unique year-site-territory combination for each nest plot and random unused plot. All models were built using the survival package (Therneau 2009) in the R statistical environment (R Development Core Team 2009). Conditional logistic models employing state-dependent samples (selected based on outcome - nest vs. unused plot in our study) and where intensity of sampling of used and unused resource units is not random (Keating and Cherry 2004) are particularly appropriate when positive outcomes (e.g., nest sites) are rare and when the assumption that the probability of inclusion of one sample is independent of another is violated (e.g., within space and time; Boyce 2006, Menard 2009). To avoid pseudo-replication due to the inclusion of re-nesting attempts by individuals within the same year and site, we randomly selected one nest and paired random plot for inclusion in our analysis.

We used a combination modeling approach by first employing exploratory data analysis to identify important predictors (Stephens et al. 2007) and second using *a priori* multi-model inference (Burnham and Anderson 2002) to identify the best-performing nest-site selection models. We also examined Pearson correlations among predictors, avoiding issues of multi-collinearity by ensuring no variable pairs with |r|>0.5 were included together in models. Following this, we categorized variables as falling

into three variable groups associated with the natural history or management of the species: 1) topographic (e.g., slope, aspect, elevation), 2) vegetation (e.g., characteristics of nest trees, canopy and understory), and 3) military infrastructure (distance to nearest road and building). Within each group, we built a global model using all variables and their quadratic terms. We then used a stepwise variable selection process to allow variables to enter or leave the model until the lowest Akaike Information Criterion (AIC) value was reached.

Using variables from both the best stepwise topographic and vegetation models, we built a final candidate set of 11 models representing *a priori* hypotheses (military infrastructure models were considered separately). We considered any model with a sample-size adjusted AIC value (AIC_C) < 2 units greater than that of the lowest-AIC_C model to be competitive. If multiple models were competitive, we used model averaging based on the weight of evidence for each model to generate parameter estimates (Burnham and Anderson 2002). We assessed the discriminatory power of each model by calculating the area under the curve (AUC) statistic from receiver operator curves generated for each model. The AUC represents the probability that a model will rank a randomly chosen positive occurrence (nest in our study) higher than a randomly chosen negative occurrence (non-nest in our study). An AUC of 0.7 to 0.8 indicates that a model provides acceptable discriminatory power (0.5 is expected by chance), an AUC of 0.8 to 0.9 indicates good discriminatory power, and an AUC > 0.9 indicates excellent discriminatory power (Fielding and Bell 1997, Hosmer and Lemeshow 2000).

Gray Vireo: Territory-scale statistical analysis

In addition to within-territory analysis, we modeled the probability of territory selection within suitable habitat on CTTA and KAFB. We omitted WSMR from territory-scale analysis because the sample of nests was small ($n = 12$) and would have left WSMR under-represented in the analysis. If Year 3 funding is provided, we intend to increase our sample size of nests and territories at WSMR and include WSMR in a revised model. Available habitat was juniper woodland and savanna (Johnson et al. 2010) and comprised 797 ha on CTTA and 4,409 ha on KAFB.

GIS variables. In contrast to within-territory modeling of nest-site selection, we did not use field-derived data as predictors in modeling the probability of territory distribution on CTTA and KAFB. For the territory-scale analysis, we were interested in defining habitat features important at the territory scale. Hence, we applied topographic and satellite-derived data available at territory-and-above scales. To this end, we used: 1) topographic predictors derived from DEMs, 2) seasonal solar radiation, 3) vegetation indices derived from Landsat 5 Thematic Mapper satellite data collected during winter, summer, and fall of 2005, and 4) distances to infrastructure, roads, and two-track roads. Additionally, we suspected Gray Vireos may respond more favorably to intermediate levels of these predictors, so we included quadratic terms of each variable in analyses.

Using ESRI ArcToolBox (ESRI 2011), we derived our topographic predictors from a composite of 10-m DEMs for each of the sites. Each 10^2 m cell represents elevation above sea level in meters. From the DEMs we processed various derivatives including aspect, degree slope, and curvature. Aspect is

calculated in a 3 x 3 window for each cell using its neighbors to identify the maximum rate of change in the downslope direction, then converted to compass direction. Resulting values ranged from 0 to 360 and were converted to direction of the aspect (e.g, more northerly versus southerly aspect) using the cosine of aspect. Values closer to 1 were northerly and those nearer -1 were southerly. Degree slope is a measure of the steepness of a slope from 0 to 90 degrees calculated as the maximum change in elevation from each cell using a 3 x 3 window. Curvature is essentially the slope intended to model topographic features; our interest was in bowl-shaped sites within foothills identified by others as indicative of Gray Vireo nesting sites.

We used the ArcGIS Solar Radiation tool set (ESRI 2011) to create solar radiation surface models from 1 May – 10 June 2011. Territories are established during this time. Solar radiation determines micro-environmental factors on the Earth's surface that may affect where birds place nests. We used the solar radiation gridded data set produced using the State University of New York Albany (SUNY) model as reference for collected solar radiation values. The SUNY data are available as part of the National Solar Radiation Database (2007). To generate a solar radiation surface over the geographic extent of our study areas, we compared point solar radiation values calculated for our study area to solar radiation values measured at a collection site in the KAFB study area. The solar radiation model accounts for site latitude and elevation, surface orientation, shadows cast by surrounding topography, daily and seasonal shifts in solar angle, and atmospheric attenuation. To make the model representative of the designated time period, we parameterized the components of atmospheric attenuation, transmissivity, and diffuse proportion by testing different combinations and comparing our point results to the measured solar radiation value based on the SUNY collected data. The best combination of transmissivity and diffuse proportion values resulted in only a 2% difference from the measured SUNY data. These tested atmospheric variables were then used in the surface solar radiation calculation based on our 10-m DEM for both KAFB and CTTA.

With ERDAS Imagine Spatial Modeler (ERDAS IMAGINE 2011), we created Normalized Difference Vegetation Indices (NDVIs) for the study areas using Landsat 5 data acquired in 2005. January, July and October scenes were acquired to maximize information on seasonal changes and potentially differentiate structural and compositional elements in vegetative cover. The index emphasizes relative plant vigor by taking advantage of the plant's near infra-red (NIR) reflected response of green leaf concentration against the visible red radiation (VIR) response which is absorbed by green vegetation:

Eq1: NDVI= (NIR – VIR) / (NIR + VIR).

Prior to developing the indices, we exoatmospherically and radiometrically corrected the Landsat multispectral reflective bands 1-5 and 7, following Chander et al. (2009). These correction procedures account for inconsistencies due to changes in sensor calibration and differences in illumination. Radiometric calibration converts the 8-bit digital numbers (Q_{cal}) representing brightness values between 0 and 255 to radiance values ($L\mu$) while accounting for the variations in gains ($G_{rescale}$) and biases ($B_{rescale}$) of individual sensors due to sensor degradation:

Eq. 2: $L\mu = (Q_{cal} * G_{rescale}) - B_{rescale}$.

The exoatmospheric correction applied to the individual pixels for each band accounts for the seasonal differences of the Earth-Sun distance (d), solar elevation angle (Θ), and band-width variations in solar irradiance ($ESUN\mu$). Outputs from the model are surface reflectance values (ρ):

Eq. 3: $\rho = L\mu * \pi * d^2 / ESUN\mu * \cos \Theta$.

We developed a "deciduous greenness" index by subtracting the January NDVI, when vegetation was senescent, from the October NDVI (indicating maximum "green-up") to determine if other vegetation such as grasses and shrubs within the juniper savanna and woodland were important. The Landsat data were resampled from 30 m to 10 m to match the other digital datasets.

We used estimated territories derived from 2009 and 2010 re-sighting observations of banded individuals and unbanded birds showing strong fidelity to a territory, using each within-year territory as an independent observation for analysis. At least one bird of each annual pairing was banded in 42 territories. Twenty-three of the remaining 40 territories had at least one nest detected during the breeding season. Observations of birds traveling to and from nests aided in territory delineation for these territories. Nests were not detected in the remaining 18 territories of unbanded individuals, though only three of these territories were adjacent to other territories of unbanded individuals without nests. Territory delineation was based on 95% minimum convex polygons (average re-sightings = 6.7, SE = 0.5) augmented by observations of unidentified birds (e.g., heard but not seen). We augmented this dataset using nest locations from P. Arbetan and R. Frei held in the Natural Heritage New Mexico NMBiotics database (Natural Heritage New Mexico 2011; Kirtland AFB 2005, 2006; respectively), using only those nests found after 2000. We delineated these last territories (based on nest locations) as 11.8-ha, circular areas centered on nests. This area was the median territory size of birds observed on CTTA and KAFB from 2009-2010 ($n = 82$ territories). We used median territory size instead of mean because the mean values may have been skewed by a few disproportionately large territories (>20 ha). If multiple nesting attempts by the same individuals were observed within a given year, we used the average nest location as the center for these additional territories.

A sample of unused, available areas ("non-territories") was necessary for modeling the probability of territory selection. To this end, we centered 11.8-ha, circular non-territories (194- m radius, 388-m diameter) within all juniper grassland or juniper savanna habitat on CTTA and within juniper grassland or juniper savanna habitat in a core area on KAFB surveyed for Gray Vireos in 2009 and 2010 (Figure 4). All unused areas were centered a minimum of 388 m apart and at least 194 m from boundaries of territories used in 2009 and 2010 or estimated (circular) boundaries of territories used between 2000 and 2008 (Figure 5). Means of each GIS-based environmental variable were calculated within each territory and non-territory. While few studies can say with 100% certainty that any suitable habitat was unused (e.g., never occupied during a study season), the duration and intensity of surveys in our study produced clear areas where no Gray Vireos were detected in 2009 and 2010. Additional data from Rob Frei
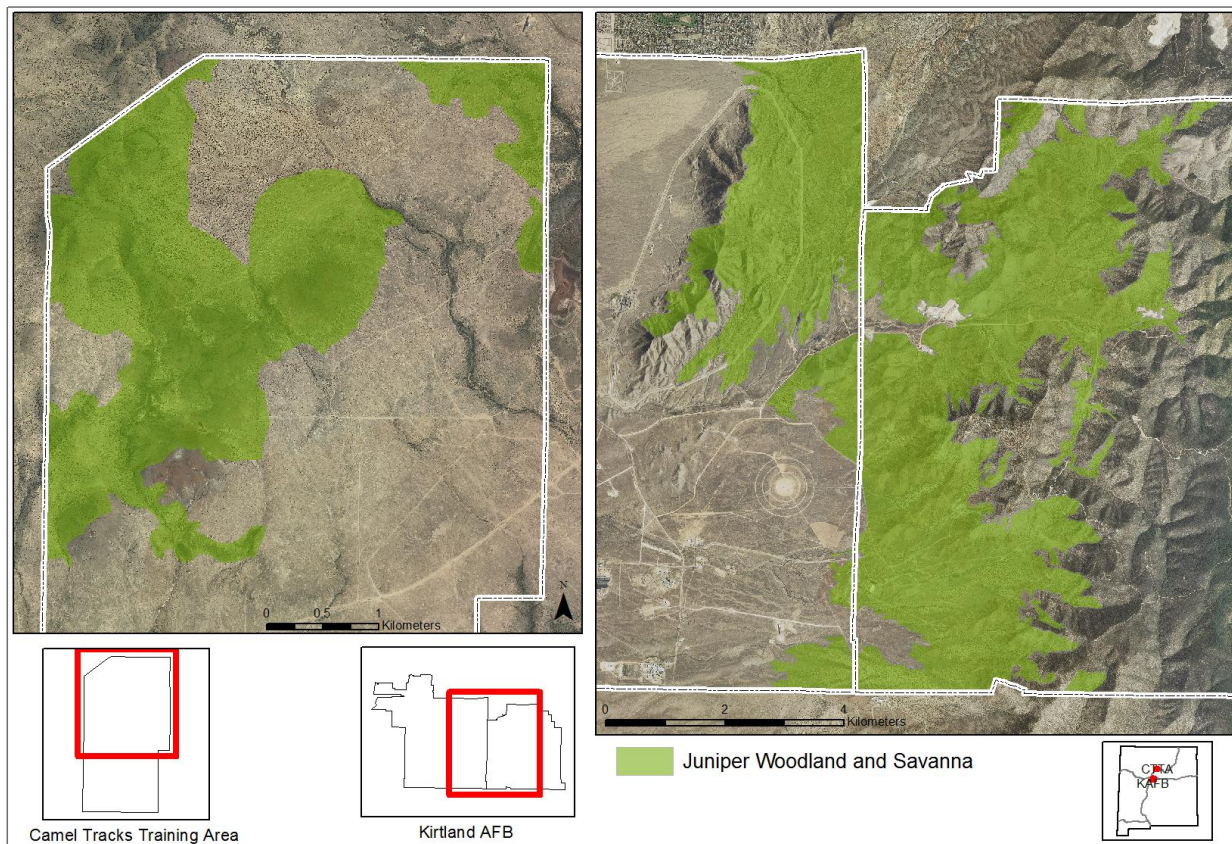
Figure 4. Juniper woodland and savanna habitat at CTTA and KAFB.

(Kirtland AFB 2005, 2006) revealed very few detections in the areas we defined as unused. Territories and non-territories did not overlap, which reduced "contamination" (Keating and Cherry 2004) when comparing used vs. available habitat.

We employed standard logistic regression models to discriminate territories from non-territories in a stepwise selection process (both forward and backward) in which additional model improvement was assessed via reductions in the AICc. We did not employ an information-theoretic framework (Burnham and Anderson 2002) in examining a set of *a priori* models at the territory scale as 1) this analysis was primarily exploratory, and 2) we were primarily interested in effective prediction, rather than in examining competing hypotheses. Using parameter estimates for the stepwise-selected models for CTTA and KAFB, we predicted the probability that each 10-m area of juniper grassland and juniper savanna at both sites was the center of a territory. To account for the area (median = 11.8 ha) of habitat represented in model observations, we applied a 194-m radius moving-average window to 10-m raster maps representing each variable prior to generating site-wide predictions. For the military infrastructure variables, we used standard logistic regression and then took an information-theoretic approach to compare the resulting models.

18
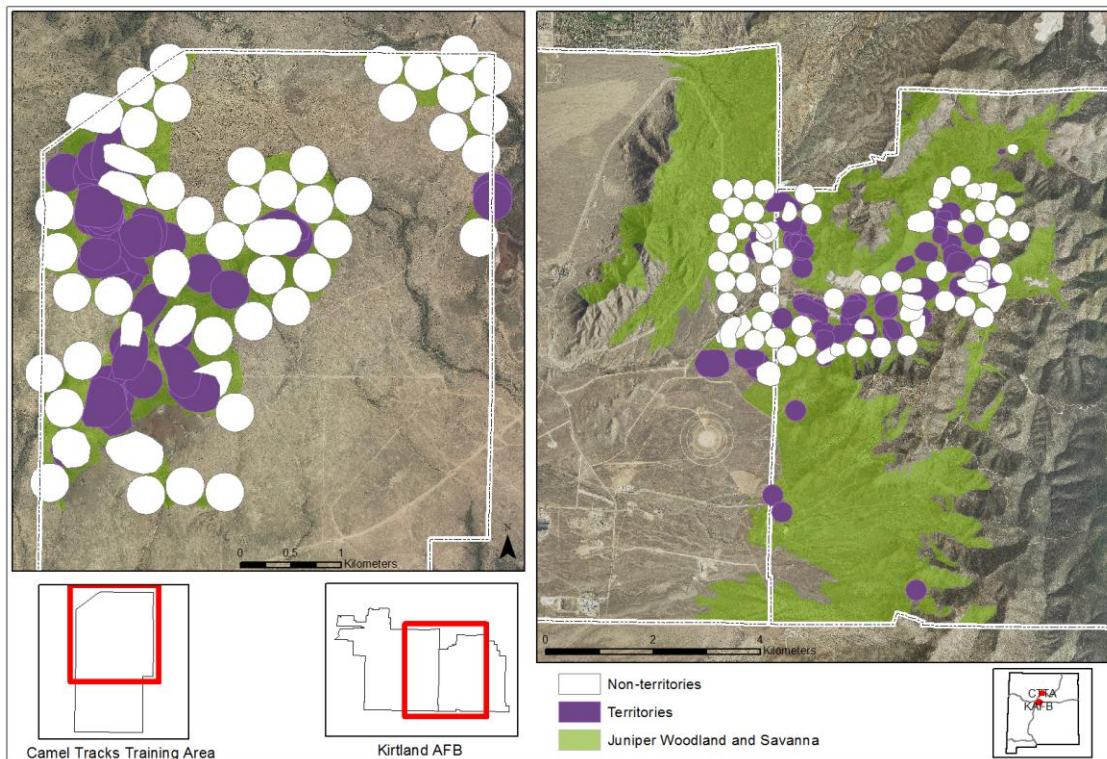
Figure 5. Gray Vireo territories and non-territories, CTTA and KAFB.

We validated models using an independent dataset of Gray Vireo observations at KAFB (independent data were not available for CTTA). If observations were detections of birds away from nests, we assessed the ability of models to correctly classify these observations by determining the proportion of observations falling within 194 m of a 10-m pixel with a predicted probability ≥ 0.5. This was the radius of the median 2009-2010 territory size (11.8 ha), and we assumed all observations were within this distance of territory center.

GRAY VIREO: RESULTS

Gray Vireo: Within-territory nest-site selection

We found and measured vegetation attributes of 77 nests on CTTA, KAFB, and WSMR from 2009-2010. Sixteen nests were re-nesting attempts within each season and territory and were removed from further analysis. In total, 16 nests on CTTA, 34 on KAFB, and 12 on WSMR were included in our analysis.

Military infrastructure. Using conditional logistic regression, we compared distance to military infrastructure (gravel road, two-track road, and building) from nest plots versus random plots at all installations. One model (distance to building) was competitive for CTTA (Table 1) and had good

classification (AUC=0.832). Parameter estimates of this model indicated a weak selection ($P < 0.10$) for nest locations farther from buildings (Table 2). However, most buildings were not being used for military activities, which were restricted at the CTTA study site during the vireo nesting season. One model (which also included distance to buildings) was competitive with the no-parameter (null) model on KAFB, but parameter estimates did not indicate a clear pattern (P = 0.43) associated with building distance. No model at WSMR was competitive with the null model.

Topography and Vegetation. The number of trees/ha on the nest plots ranged from 25-425 (mean=99, SE=7.26). Most plots had 200 or fewer trees/ha (Figure 6).

Trees per Hectare
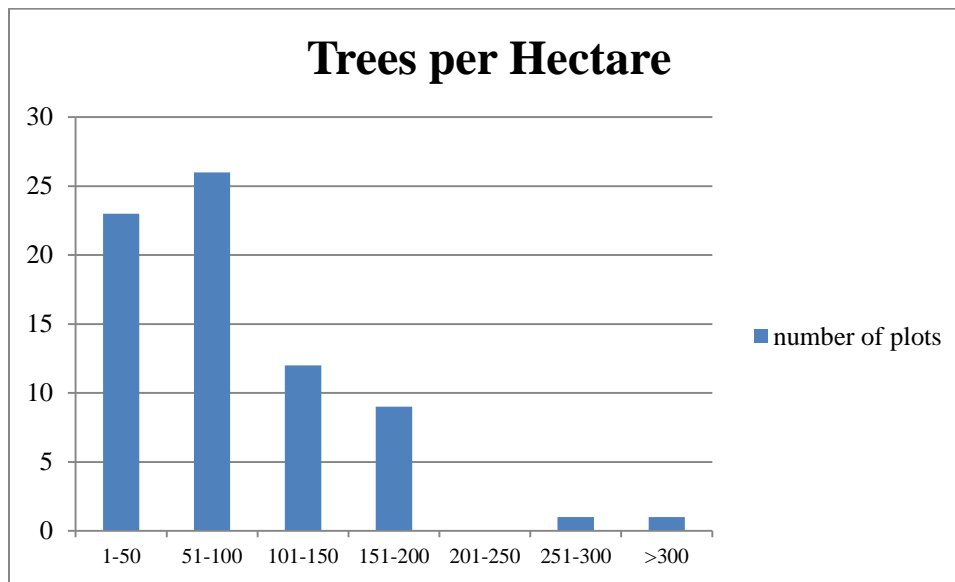
Figure 6. Distribution of tree density on Gray Vireo nest plots, 2009-2010.

Stepwise models indicated the two topographic variables, elevation and aspect, might be useful in modeling nest-site selection within territories. The vegetation stepwise model suggested that number of trees and the quadratic function of mean tree height within plots would be potentially useful in discriminating nests from non-nests within territories (Table 3). One model in the final candidate set was competitive ($\Delta AIC_C < 2$, Table 4). This model had a weight of 58% of the model set and included all five variables. The evidence ratio between this model and the next-best model was 3.70. This model had an AUC value greater than 0.8, indicating good model discrimination between nests and non-nests. Parameter estimates (Table 5, Figure 7) indicated Gray Vireos selected nest sites on more southward-facing aspects having more trees and a higher (but not too high) mean tree heights relative to non-unused random plots within each territory. While elevation was generally lower in nest plots when compared to unused plots within territories, parameter estimates for this variable bounded zero, indicating weak directional influences.

Table 1. Comparisons of models predicting within-territory selection of nest-sites by Gray Vireos relative to infrastructure features. One model (distance to buildings) was competitive for CTTA, while the same model for KAFB was competitive with the intercept-only model.

Site	Model	k	-LL	AIC$_C$	ΔAIC$_C$	w$_i$	AUC
CTTA	Distance to buildings	2	-7.801	20.526	0.000	0.758	0.832
	Distance to two-track road	2	-9.764	24.451	3.926	0.106	0.707
	Null model	1	-11.090	24.466	3.941	0.106	0.500
	Distance to major road	2	-11.033	26.988	6.463	0.030	0.230
KAFB	Null model	1	-23.567	49.259	0.000	0.475	0.500
	Distance to buildings	2	-23.228	50.843	1.584	0.215	0.545
	Distance to two-track road	2	-23.554	51.495	2.236	0.155	0.510
	Distance to major road	2	-23.562	51.512	2.253	0.154	0.562
WSMR	Null model	1	-9.534	21.468	0.000	0.543	0.500
	Distance to major road	2	-9.139	23.612	2.144	0.186	0.639
	Distance to two-track road	2	-9.394	24.121	2.653	0.144	0.757
	Distance to buildings	2	-9.525	24.384	2.916	0.126	0.611

Table 2. Parameter estimates from competitive models of within-territory nest-site selection by Gray Vireos relative to infrastructure. Birds on CTTA nested marginally further from buildings, while birds on KAFB showed no strong patterns. No WSMR model was competitive with the null model.

Site	Variable	Estimate	SE	z-value	P
CTTA	Distance to buildings	0.014	0.007	1.931	0.053
KAFB	Distance to buildings	-0.001	0.002	-0.792	0.428

Table 3.Variables used in models discriminating Gray Vireo nest plots from unused plots within territories on CTTA, KAFB, and WSMR, 2009-2010. Nest plots were 0.04-ha circles (11.3-m radius) centered on each nest and random unused locations. Values are means.

Variables	Explanation	CTTA		KAFB		WSMR	
		Nest plots	Unused plots	Nest plots	Unused plots	Nest plots	Unused plots
Topography							
ELEV	Elevation of plot calculated from 10-m digital elevation model (DEM) (m)	2005 (7)	2011 (7)	1863 (7)	1865 (7)	550 (6)	552 (6)
ASP_COS	Cosine of plot aspect (in degrees) from DEM. Varies between -1 (south) to 1 (north)	-0.14 (0.13)	-0.12 (0.16)	-0.06 (0.12)	0.16 (0.11)	0.01 (0.17)	0.15 (0.21)
SLOPE	Slope degrees, angle of inclination to the horizontal. Varies between 0 (flat) and 90 degrees	5.2 (0.6)	6.7 (0.9)	7.7 (0.8)	8.9 (1.2)	3.6 (0.6)	3.6 (0.5)
CURVE	Curvature; value of the concavity (negative values) or convexity (positive values) index, calculated from the DEM. Curvature of each 10-m pixel calculated from the eight surrounding 10-m pixels.	-0.27 (0.12)	0.01 (0.12)	-0.21 (0.06)	-0.15 (0.06)	0.06 (0.09)	0.02 (0.05)
Vegetation							
CANCOV	Mean canopy cover; assessed from presence of cover at 45 locations (1-m increments in each cardinal direction (%)	22.2 (1.8)	14.1 (1.3)	17.8 (1.6)	13.9 (1.4)	19.8 (2.8)	28.2 (3.0)
MNTREEHT	The mean height of all trees (m)	3.7 (0.2)	3.1 (0.2)	3.3 (0.1)	2.9 (0.1)	3.6 (0.2)	4.0 (0.3)
NTREES	The number of trees > 1 m in height (n)	2.9 (0.3)	2.5 (0.4)	4.1 (0.4)	3.5 (0.4)	4.6 (1.2)	3.3 (0.5)
NSHRUBS	The number of shrubs (all woody species < 1 m tall; n)	13.3 (2.3)	8.6 (1.5)	12.9 (1.9)	18.3 (4.8)	74.3 (23.6)	43.2 (13.0)
TOTAL_LIVE	The average value (0-10) of live vegetation cover across all plot quadrants (5 m radius)	2.9 (0.3)	2.7 (0.2)	2.8 (0.1)	3.0 (0.2)	9.5 (1.2)	6.8 (0.4)

Table 4. Candidate set of conditional logistic regression models discriminating nests from unused sites (0.04 ha) within territories of Gray Vireos on CTTA, KAFB, and WSMR, New Mexico in 2009 and 2010. k is the number of parameters in the model (including a stratification term unique to each territory). -LL is the negative log-likelihood of the model, ΔAIC_C is the difference between the AICc of each model and the model with the lowest AICc, w_i is the weight of each model in the candidate set, and AUC is the area under the receiver operator curve, a measure of model classification accuracy.

Model	k	-LL	AIC_C	ΔAIC_C	w_i	AUC
ELEV + ASP_COS + NTREES + MNTREEHT + MNTREEHT^2	6	-30.820	75.167	0.000	0.584	0.843
ELEV + ASP_COS + MNTREEHT + MNTREEHT^2	5	-33.355	77.781	2.615	0.158	0.818
ELEV + ASP_COS + NTREES + MNTREEHT	5	-33.419	77.910	2.743	0.148	0.806
NTREES + MNTREEHT + MNTREEHT^2	4	-35.799	80.299	5.132	0.045	0.764
MNTREEHT + MNTREEHT^2	3	-37.584	81.582	6.416	0.024	0.740
ELEV + ASP_COS + MNTREEHT	4	-36.884	82.469	7.302	0.015	0.754
NTREES + MNTREEHT	3	-38.166	82.747	7.580	0.013	0.742
ELEV + ASP_COS + NTREES	4	-37.536	83.775	8.608	0.008	0.750
ELEV + ASP_COS	3	-39.657	85.728	10.561	0.003	0.709
MNTREEHT	2	-40.987	86.178	11.011	0.002	0.693
NTREES	2	-42.513	89.229	14.062	0.001	0.642
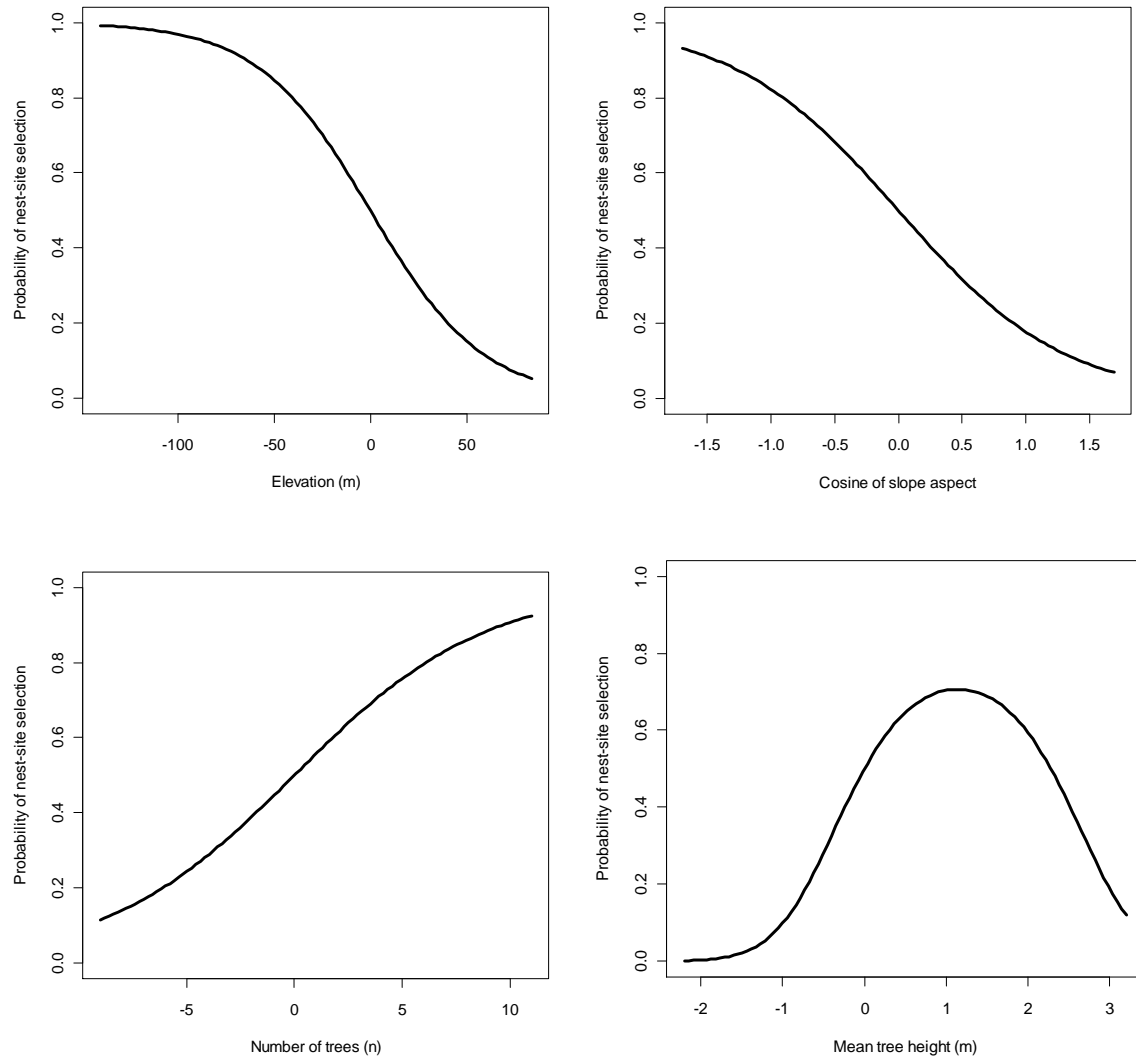
Figure 7. Predicted probability of nest-site selection in response to differences between nest plots and random unused plots within territories. Responses to aspect indicate nests were more likely to be found on more south-facing slopes within territories. The probability of selection in response to mean tree height (d) is a quadratic function, indicating selection for more intermediate tree heights.

Table 5. Model-averaged parameter estimates from candidate logistic regression models discriminating nests from unused sites (0.04 ha) within territories of Gray Vireos on CTTA, KAFB, and WSMR, New Mexico in 2009 and 2010. NTREES and MNTREEHT were log-transformed prior to modeling.

			95% CI	
Variable	Estimate	SE	Lower	Upper
ELEV	-0.034	0.033	-0.100	0.031
ASPECT	-1.535	0.567	-2.647	-0.423
NTREES	0.227	0.109	0.014	0.441
MNTREEHT	1.540	0.512	0.537	2.543
MNTREEHT^2	-0.676	0.321	-1.304	-0.047

Gray Vireo: Territories vs. unused areas

Camel Tracks. Twenty-five territories were identified and delineated from 2009-2010. These territories were augmented by nest records from 2001 to 2008, representing 24 additional territories which were assessed using 11.8-ha circles centered on nests or average locations of multiple nests within territories in the same year. Forty unused areas were identified in areas outside of 2009-2010 delineated territories and at least 194 m from nests found prior to 2009.

The best infrastructure model discriminating territories from non-territories at CTTA was a one-variable model including distance to infrastructure (building, power line, or barrow pit). This model had the lowest AIC_C (110.390) and an AUC of 0.716, indicating acceptable discriminating power between territories and non-territories. The only other competitive model ($\Delta AIC_C < 2.0$) also included two-track. However, we deemed the distance to two-track to be an uninformative parameter (Arnold 2010), as the best model was a subset and parameter estimates for two-track distance bounded zero. Parameter estimates for building distance indicated territories were farther from structures than non-territories.

The best model discriminating territories from unused areas included elevation, north-south aspect, degree slope (quadratic), and solar radiation (Table 6). Parameter estimates indicated that territories were more likely to occur on slopes with more north-facing aspects, be at higher elevations, have intermediate slopes, and have lower overall solar radiation than unused areas. (Table 7, Figure 8). This model had an AUC of 0.940, indicating excellent discrimination between territories and non-use areas.

Table 6. Variables used in models discriminating territories from (unused) Gray Vireo non-territories on CTTA and KAFB. Mean values of each variable were calculated across all 10-m pixels within each territory. Values presented are means ± standard errors across all territories.

GIS variables	Explanation	CTTA		KAFB	
		Territories	Unused areas	Territories	Unused areas
ELEV	Elevation calculated from 10-m digital elevation model (DEM) (m)	2,000 (5)	2,026 (5)	1,888 (9)	1,878 (4)
ASP_COS	Cosine of aspect (in degrees), from DEM. Varies between -1 (south) to 1 (north).	-0.23 (0.06)	-0.11 (0.06)	-0.14 (0.07)	0.07 (0.05)
SLOPE	Slope degrees, angle of inclination to the horizontal. Varies between 0 (flat) and 90 degrees	7.2 (0.7)	12.3 (0.6)	20.9 (1.8)	18.1 (0.9)
CURVE	Curvature; concavity (negative values) or convexity (positive values) index, from DEM. Curvature of each 10-m pixel calculated from the eight surrounding 10-m pixels.	0.004 (0.006)	0.011 (0.019)	-0.005 (0.015)	-0.065 (0.015)
FLOW_ACC	The number of pixels draining into or through each pixel, from DEM (100 m^2)	13.4 (1.3)	25.8 (5.2)	39.8 (6.0)	67.2 (7.3)
SOLAR	Solar radiation incident on each 10-m pixel, calculated based on variables for site latitude and elevation, surface orientation, shadows cast by surrounding topography, daily and seasonal shifts in solar angle and atmospheric attenuation (WH/ m^2).	273,771 (174)	273,575 (204)	254,408 (1827)	253,227 (1124)
JAN_NDVI	Evergreen greenness; normalized difference vegetation index (NDVI[a]) calculated from January, 2005 Landsat imagery (900 m^2 resampled to 100 m^2).	0.165 (0.002)	0.179 (0.002)	0.170 (0.007)	0.181 (0.003)
JAN_OCT_NDVI	Deciduous greenness; the difference in NDVI between October 2005 and January 2005 Landsat imagery (900 m^2 resampled to 100 m^2).	0.051 (0.002)	0.042 (0.002)	0.051 (0.003)	0.051 (0.001)

a. NDVI = (raw NDVI + 1) * 100

Table 7. Parameter estimates from stepwise-selected logistic regression models discriminating territories from unused areas on CTTA and KAFB.

CTTA

Variable	Estimate	SE	z-value	P
Intercept	399.400	158.990	2.512	0.012
ELEV	0.121	0.036	3.325	<0.001
ASP_COS	3.433	1.193	2.879	0.004
SLOPE	2.018	0.697	2.894	0.004
SLOPE^2	-0.176	0.049	-3.628	<0.001
SOLAR	-0.002	0.001	-2.866	0.004

KAFB

Variable	Estimate	SE	z-value	P
Intercept	-946.968	278.069	-3.406	0.001
ELEV	-0.028	0.009	-3.100	0.002
ASP_COS	0.816	0.512	1.591	0.112
ASP_COS^2	-2.856	1.276	-2.239	0.025
JAN_DVI	16.582	4.731	3.505	<0.001
JAN_NDVI^2	-0.069	0.020	-3.442	<0.001

Figure 8. Probability of Gray Vireo territory use on CTTA in relation to GIS variables in the best model discriminating occupied and unoccupied territories. Slope exhibited a quadratic relationship with selection, indicate selection for territories with intermediate slope.

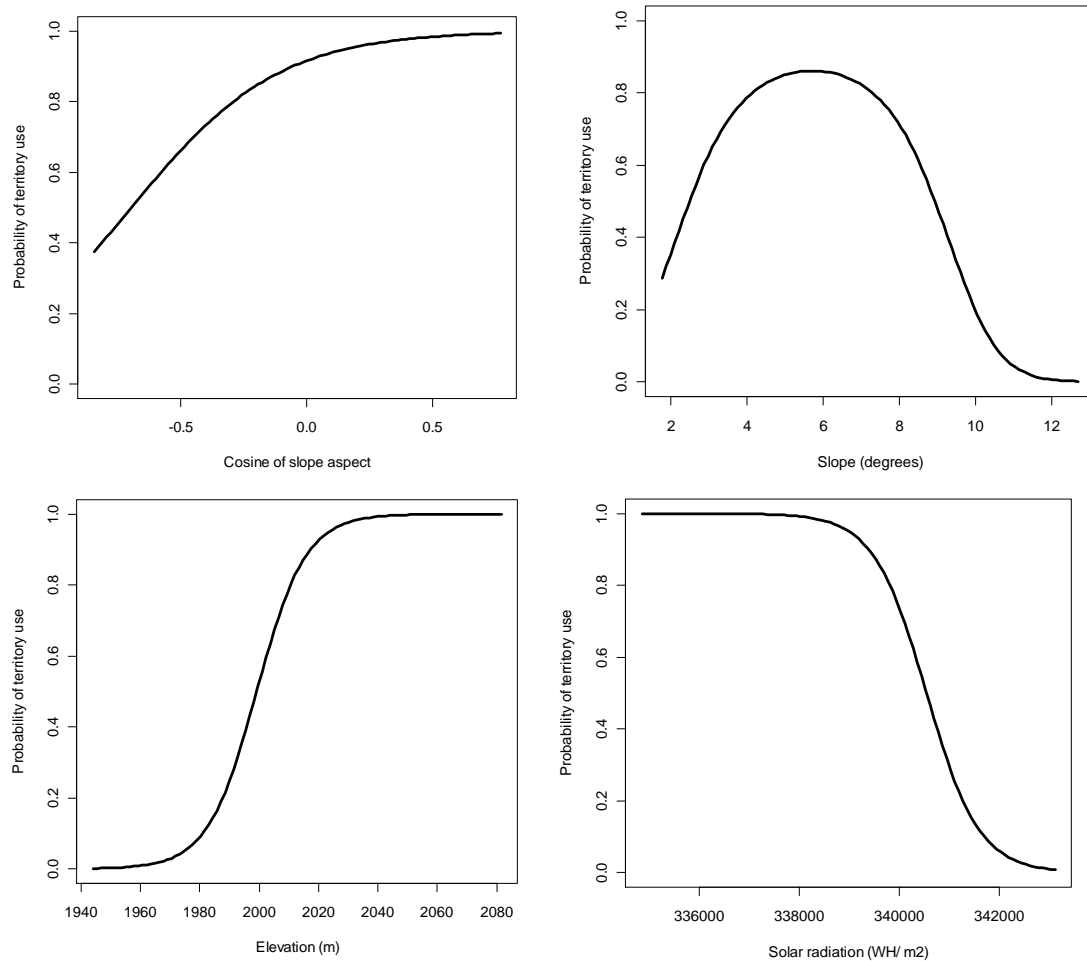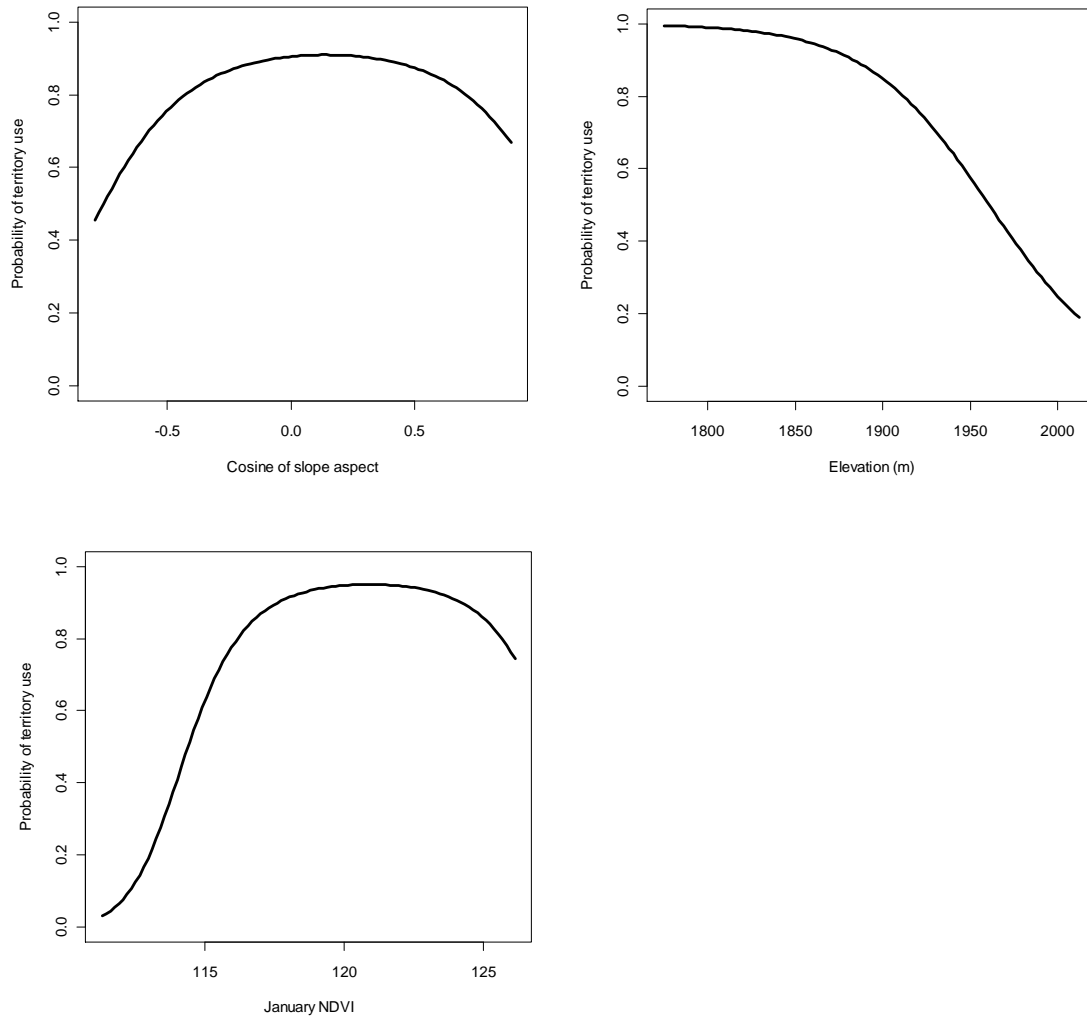**Figure 9. Probability of Gray Vireo territory use on KAFB in relation to GIS variables discriminating occupied and unoccupied territories. Cosine of slope aspect and January NDVI exhibited quadratic relationships with selection, indicating selection for intermediate values.**

Kirtland AFB. Fifty-seven territories were identified and delineated from 2009-2010. These territories were augmented by nest records from 2005 to 2008, representing 22 additional territories. Forty unused areas were identified in areas outside of 2009-2010 delineated territories, at least 194 m from nests found prior to 2009, and within the boundaries of the area that was both searched extensively in 2009-2010 and was the core study area prior to 2009.

Only one competitive model emerged from the territory-scale infrastructure analysis at KAFB. The best model was a single-variable model containing distance to two-track. The two-track model had the lowest AIC_C (138.83) and an AUC of 0.728, indicating acceptable discriminatory power between territories and non-territories (Table 1). The coefficient for two-track was negative, meaning that territories were closer to two-tracks at KAFB than non-territories.

The best model discriminating territories from unused areas included aspect (quadratic), elevation, and evergreen greenness (quadratic, Table 6). Parameter estimates indicated territories were more likely to have more intermediate aspects (e.g., eastern- or western-facing), lower elevations, and more intermediate evergreen greenness, measured from January NDVI values than unused areas. (Table 7, Figure 9). This model had an AUC of 0.814, indicating good discrimination between territories and non-use areas.

Gray Vireo: Model predictions

We applied the logistic regression models for CTTA and KAFB to generate a map of pinyon-juniper habitats with ≥50% probability of being occupied by vireos (Figure 10). The identified areas covered 57% (454 ha) and 42% (1860 ha), respectively, of available juniper woodland and juniper savanna land cover identified by Johnson et al. (2011). At CTTA, potential habitat areas occur in the volcanic hills and extend somewhat into the surrounding lava plains. At KAFB, potential habitat occurs in juniper savannas of low, rolling hills or at low to moderate slopes (mean = 16°) within foothills. At both KAFB and CTTA, territories and potential habitat are near ephemeral drainages.

Gray Vireo: Model validation

Validation data collected by Rob Frei were available for 2003-2006 across approximately 31 km^2 of KAFB (Kirtland AFB 2005, 2006). Of 63 observations, 46 (73%) were within 194 m of a 10-m pixel with a model-predicted probability ≥ 0.5 (50%) of being the center of a territory. Additional survey data at 369 point locations within the juniper extent of the landscape model (Johnson et al. 2011) were acquired in 2010-2011 by Animas Biological Studies (Wickersham and Wickersham 2011). Of 74 vireo observations, 55 (74.3%) were within 194 m of a 10-m pixel with a model-predicted probability ≥ 0.5 (50%) of being the center of a territory.
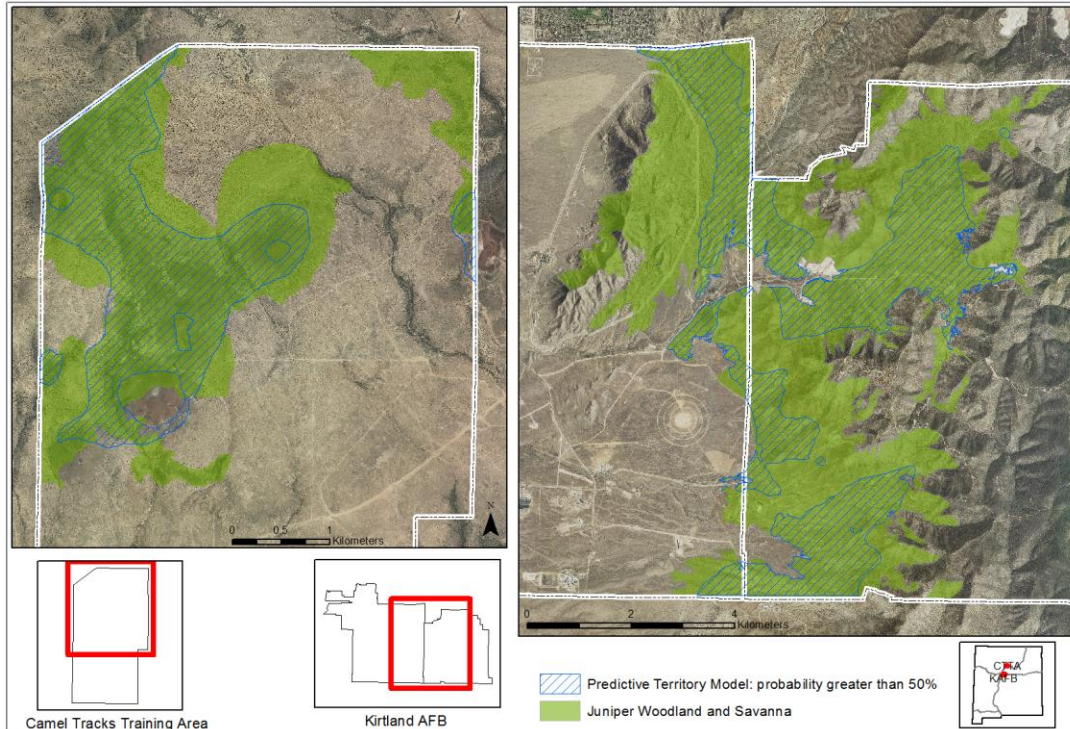
Figure 10. Predictive model of Gray Vireo territory-scale habitat at CTTA and KAFB.

GRAY VIREO: DISCUSSION

Gray Vireo: Within-territory nest-site selection

Military infrastructure. We found little indication that distance to road, two-track road, or building differed between nest and random plots, when data from all three installations were combined. However, one strong model for individual installations, distance to building at CTTA, suggested that military infrastructure may influence Gray Vireo nest site selection. Nest sample size, however, was only 16. Significant differences in scale occurred between the plots (100 m apart) and distances to infrastructure (some in thousands of meters), and no roads or buildings were situated in the area occupied by vireos at CTTA. It is somewhat surprising that even one model was able to distinguish nest from random plots, given these scale effects, which would be expected to obscure differences at the plot scale. In addition, we observed little or no human activity at these distant buildings. Hence, we regard these results with caution.

Topography and vegetation. Our results on nest-site aspect contradict the results of Delong and Cox (2005). Gray Vireos in our study areas selected nest sites with more south-facing aspects, while vireos at Delong and Cox's (2005) study site near Socorro, NM and Santa Fe, NM selected nest sites on more west-facing slopes. This discrepancy may be attributed to the inherent topographical differences between our study sites; however, both south- and west-facing slopes receive more afternoon sunlight and thus may exhibit a warmer microclimate. Sunnier, warmer

conditions may be important for egg viability during the critical laying and incubation stages, especially in May and early June. Nesting data from KAFB also suggest that aspect may influence nesting success (Wickersham and Wickersham 2010). In 2009-2010, nest success at KAFB differed significantly with respect to plot aspect, and over 70% of nests in south-facing slopes were successful. Modeling habitat selection with respect to nesting success is not an objective of this study; however, these data suggest that further study of nest microclimate is warranted.

Our data suggest that Gray Vireos select nest sites with more trees compared with available habitat within their territories. Higher tree density may hide nests from predators and Brown-headed Cowbirds. In addition, Gray Vireos often forage from leaves, branches, and tree trunks (Barlow et al. 1970), so more trees would increase foraging opportunities in close proximity to nests. While vireos also prefer nesting in areas with taller trees, our data suggest a possible avoidance of the tallest available trees in their territories. Taller trees provide better vantage points than shorter trees for broadcasting songs for mate selection and territory defense; however, the tallest trees may also be the most visible to avian predators, such as crows, ravens, and jays, which are common in our study areas. Thus, vireos' preferences for trees of intermediate height may result from balancing predator avoidance with advertisement.

Our best nest-site selection model also included weak preferences by Gray Vireos for lower elevations. The actual difference in mean nest and random elevation is very small (≤ 6 m) at all three sites; therefore, this difference is probably not biologically meaningful.

Gray Vireo: Territories vs. unused areas

Our territory models yielded some different results between study sites. Gray Vireo territories were more likely to occur on north-facing slopes at CTTA, but east- or west-facing slopes at KAFB. These differences are more likely a function of the topography in these areas than varying preferences for aspect by site by vireos. Topography in occupied vireo habitat at KAFB consists predominantly of ridges and drainages with a more north-south orientation, which provides a higher proportion of east-west slopes. In contrast, most unused areas (non-territories) occurred either in the flatter juniper savannas, where a relatively equal proportion of aspects are available, or the steeper terrain above occupied toe slopes, which occur mostly on north- and south-facing aspects. CTTA, in contrast, consists of rolling hills that offer potential vireo habitat on both the north-south and east-west orientations. There, vireos may select more north-facing slopes because they may receive more moisture, where understory vegetation may be denser, which in turn may support more arthropod populations.

Another contradictory variable in the territory models is elevation. Gray vireos appear to occupy habitat at higher elevations than unused areas at CTTA, but lower elevations than unused areas at KAFB. This may also be more related to the inherent differences in elevation between sites than actual preferences by vireos. The elevation range of juniper woodland and savannah habitats at

KAFB is larger (1742-2319 m) than that of CTTA (1935-2100 m; Johnson et al. 2010). While vireos at CTTA appear to prefer habitats at the upper end of the available elevation range, vireos at KAFB may avoid higher elevation juniper woodland and savannah habitats because they encroach on denser pinyon-juniper woodlands, situated on steeper slopes. Such habitats are not present at CTTA.

Other variables that appear to be important to vireo territory selection at CTTA include slope and solar radiation. Vireos appear to select territories on intermediate slopes (the highest probability at approximately 6°), which may also be a function of the rolling topography of the site. Steep slopes do not occur at CTTA; however, the area does include some relatively flat terrain. Thus, Gray Vireos appear to select moderate slopes over flatter terrain at CTTA. Finally, Gray Vireo territories at CTTA have lower overall solar radiation than non-used areas. This is likely related to their territories more often being situated on north-facing slopes, which inherently receive less solar radiation than south-facing slopes.

At KAFB, evergreen greenness was the only additional variable important in distinguishing territories from non-used areas. There, vireos selected areas with intermediate evergreen greenness (the highest probability occurring at an adjusted NDVI of 120 [= raw NDVI of 0.12]), which suggests that vireos prefer breeding territories with tree densities that are higher, but perhaps not too high. This is somewhat consistent with the relationship between nest sites and higher tree density as shown in the nest selection model. More trees offer more perching sites for territory defense and nesting sites; however, as tree density increases at KAFB, so does elevation, and with that the proportion of pinyon trees, until habitat becomes unsuitable for foraging.

The territory-scale analysis of infrastructure indicated that territories are farther from infrastructure than non-territories at CTTA. However, this result may be due more to the spatial distribution of nesting habitat and infrastructure than it is to nesting vireos avoiding infrastructure. At the CTTA study site, most of the unoccupied, apparently suitable nesting habitat was situated to the east of the territories, and the nearest structures − a power line, a borrow pit, and an airfield − were also to the east of the actual territories. This would result in territories being farther from infrastructure than non-territories due to limited availability of suitable nesting habitat, rather than avoidance of infrastructure. Few roads or two-tracks occur near the study area at CTTA, and training is prohibited in the study area during the nesting season. Our analyses of the road and two-track infrastructure might therefore fail to detect birds' sensitivity to these features.

At KAFB, the territory-scale analysis of infrastructure indicated that territories are closer to two-tracks than non-territories. There is no obvious alternative explanation for this result as there is for infrastructure at CTTA. Vireos do not appear to avoid two-track roads when setting up their

territories. Military activities are prohibited at CTTA and infrequent at KAFB during the breeding season, which may reduce traffic on roads and two-tracks such that they do not greatly impact territorial vireos, as they might if activities were not restricted. Given that the Gray Vireo is a state listed species, we recommend that restrictions on military activities during their nesting season remain in place at both installations.

Gray Vireo: Model Predictions and Validation

Validation data suggest that our predictive habitat models were good indicators of Gray Vireo occupancy on KAFB, with 73% and 74.3% of observation points from two data sources falling within the territory-scale model. Model predictability could probably be improved with the inclusion of more vireo territory data in the modeling process and more validation points. One goal for a third year of funding is to increase sample sizes for the modeling at both nest and territory scales.

PINYON JAY: METHODS

Pinyon Jay: Within-colony nest-scale analyses

Field measurements. We collected nest-scale data following a modified BBIRD protocol. Circular nest plots were centered at a nest tree, and non-overlapping random plots were centered at a non-nest tree 100 m in a randomly selected direction from each nest tree. At each plot we collected data within 5-m and 11.3-m (0.04 ha) radius plots. We collected the following data within 11.3-m nest plots: plot slope, plot aspect, number of trees and shrubs, tree and shrub species composition, and tree size class.

At the 5-m plot we collected: elevation, indices of live and non-live ground cover, tree height and root crown diameter, canopy cover, nest tree root crown diameter and height, nest tree width, nest height, nest aspect, distance of nest to tree edge, and number and size of supporting branches. For canopy cover, we used a vertical canopy densitometer to determine the presence or absence of canopy cover at 1, 2, 3, 4, and 5 m from the nest in each of the four cardinal directions. We summed the four readings (1 or 0) taken at each distance and computed percent of the possible score (20 positive readings) for each plot. Root crown diameter is a better measure of tree size than diameter at breast height for juniper trees, which can have multiple trunks. Ground cover was indexed in 10% intervals (e.g., 1-10%=1, 11-20%=2, etc.).

Derived and GIS measurements. Using ESRI ArcToolBox (ESRI 2011), we calculated a north-south aspect index from the cosine of the plot aspect, with values ranging from -1 (south) to 1 (north). We gathered distances from each nest and random tree to edge of habitat, road, building, and military infrastructure using USDA NAIP 1 m digital ortho quarter quads (DOQQs) acquired in 2009.

Statistical analysis. We modeled nest-site selection using case-control conditional logistic regression (conditional logistic regression for related samples, Menard 2009). Because Pinyon Jays are loosely colonial nesters and not territorial, we compared the set of nest plots to the same number of unpaired random plots within the colony site. Among-year and among-site variation were treated as nuisance effects and were controlled by using a "strata" statement denoting a unique year-site combination for each plot. We built models using the Survival package in the R statistical environment (R Development Core Team 2009).

We used a combination modeling approach: exploratory data analysis to identify important predictors (Stephens et al. 2007) and *a priori* multi-model inference (Burnham and Anderson 2002) to identify the best-performing nest-site selection models. We examined Pearson correlations among predictors, avoiding issues of multi-collinearity by ensuring no variable pair with |r|>0.5 was included together in a model. Within each of three groups of variables associated with Pinyon Jay natural history or management, we built a global model using all variables in the group and their quadratic terms. We then using a stepwise (forward and backward) variable selection process to remove variables until the lowest AIC value was achieved. The variable groups were topographic (slope, aspect, and elevation), vegetation (trees and ground cover), and military infrastructure (distance to edge, road, building, and military infrastructure).

Using variables from the best stepwise model among the three groups (which were all vegetation variables), we built a final candidate set of seven models representing *a priori* hypotheses. We considered any model with an $AIC_c < 2$ units above that of the lowest AIC_c model to be competitive. We assessed the discriminatory power of each model based on the area under the curve (AUC) statistic generated for each model. An AUC of 0.7 to 0.8 indicates that a model provides acceptable discriminatory power (0.5 is expected by chance), an AUC of 0.8 to 0.9 indicates good discriminatory power, and an AUC > 0.9 indicates excellent discriminatory power (Fielding and Bell 1997, Hosmer and Lemeshow 2000).

Pinyon Jay: Colony-scale statistical analysis

In this study, we followed just three Pinyon Jay nesting flocks. Small sample sizes of colonies precluded analysis at the colony scale similar to the territory-scale analysis we did for Gray Vireos. We therefore chose two different approaches to colony-scale habitat use. First, during 2008 and 2009, Pinyon Jays abandoned a traditional colony site at WSMR and in 2010 and 2011 nested at a new, nearby site on the study area (see Pinyon Jay: Results for details). This shift provided the opportunity to investigate factors associated with choice of colony site. Second, we collected GIS measures of colony-scale variables at all colonies to provide a range of these measures at the three colonies. At each study site, we created a classification using these variables. Then, elsewhere across the landscape, we mapped the classes we had defined within the colonies.

Abandoned versus new colony sites at WSMR. We analyzed changes in pinyon tree vigor rankings at the old colony over the period that the old colony was occupied. We also compared cone and vigor data at the two sites in 2010 and 2011, after the birds had shifted nesting locations.

Data are from a separate, ongoing tree monitoring study, from points on transects crossing each colony site. Linear transects crossed the WMSR Pinyon Jay flock home range in Pinyon Woodland habitat and consisted of points situated 50 m apart. We had previously adopted a point-centered quarter method (Mitchell 2007) to allow us to compute pinyon tree density and assess tree condition on each transect. Each year in early fall, we assigned a vigor rank to the nearest tree in each quarter at each transect point. Vigor ranks were as follows: 1=dead; 2=dying, most needles lost or brown; 3= half needles lost or brown; 4=few brown needles but generally vigorous; 5=vigorous, foliage green and thick. We stood 5 m from each of the four designated trees at each transect point and counted the number of active cones in three 10 x 42 binocular fields, taking care to choose three fields containing the most cones. We analyzed vigor and cone data from transect points at the old colony from 2005-2011 and similar data at the new colony in 2010 and 2011.

To investigate the hypothesis that tree vigor at the abandoned colony site declined over time, we took a linear mixed model approach (Pinheiro and Bates 2000), using a random-intercepts model with two intercept terms, one at the point level and one at the tree level nested within points. To compare vigor among individual years at the old colony, we compared years with a one-way ANOVA. We compared vigor and cone number between the old and new colonies in 2010 and 2011 using t-tests.

Characteristics of occupied colony sites. The final conditional logistic model for Pinyon Jay nest-scale habitat use indicated that tree size and canopy cover are important in siting nests (see Results, Within-colony nest-site selection, below). At the colony scale, jays abandoned a colony with lower tree vigor, a measure of foliage thickness/greenness. We therefore sought to measure amount and greenness of foliage at the colony scale using NDVI. From the elevation dataset we derived: cosine of aspect, curvature, plan curvature, profile curvature, slope, and solar irradiance (using the ArcGIS Solar Radiation Tool Set, ESRI 2011; see Gray Vireo Methods, above, for detail). We used the solar radiation gridded data set produced using the State University of New York Albany (SUNY) model as reference for collected solar radiation values. The SUNY data are available as part of the National Solar Radiation Database (2007). Curvature is a measure of slope with profile indicating the direction of the maximum slope, and plan is perpendicular to the direction of maximum slope. With ERDAS Imagine Spatial Modeler (ERDAS IMAGINE 2011), we created vegetation indices for the study areas using Landsat 5 data acquired in March, July and October, 2005. A normalized difference vegetation index (NDVI, Eq. 1) emphasizes vigorous green plant growth by comparing strong chlorophyll reflectance in the near-infrared

wavelengths (Band 4) against chlorophyll absorption in the visible red wavelengths (Band 3). The normalized difference senescent vegetation index (NDSVI, Eq. 2) enhances the spectral characteristics of senescent vegetation, specifically grasses, which have a relatively low reflectance response in the red wavelengths (VIR, Band 3) and a high reflectance in the mid-infrared wavelengths (MIR7, Band 7). The moisture index (Eq. 3) compares relatively high reflectance values in the shorter wavelengths of the mid-infrared (MIR5, Band 5) against strong absorption at the longer wavelengths of the mid-infrared (MIR7, Band 7) caused by water molecules found in soil and vegetation.(Muldavin et al. 2010).

$$\text{Eq1: NDVI} = (NIR - VIR) / (NIR + VIR)$$
$$\text{Eq2: NDSVI} = (MIR7 - VIR) / (MIR7 + VIR)$$
$$\text{Eq3: Moisture Index} = (MIR5 - MIR7) / (MIR5 + MIR7)$$

All layers were compiled into a single image and re-sampled to 10-m spatial resolution. The image file contained 16 layers available for the classification process.

Using the GIS data for each colony, we performed a clustering analysis, which is based on the natural groupings of pixels. The ISODATA clustering method in ERDAS calculates the distance between the candidate pixel and each cluster mean in multi-dimensional space, and the pixel is assigned to the cluster with the closest mean. In an iterative process, the means of all clusters are recalculated, shifting them in feature space. After a specified number of iterations, the result is a thematic raster layer and signature file. Given that there were 16 image bands, some were likely correlated with one another. We analyzed the resulting class signatures for divergence (i.e., the statistical distance between signatures) to determine if a subset of the bands could maximize the classification. After determining the best combination of bands for the colonies, we then mapped the same classes in the surrounding landscape, outside the colony area, but within the general habitat type delineated in the landscape-scale habitat model (e.g., Pinyon-Juniper Woodland; Johnson et al. 2010) using a minimum-distance decision rule classifier in a supervised classification.

PINYON JAY: RESULTS

Pinyon Jay: Within-colony nest-site selection

In 2010-2011, we found and measured 35 Pinyon Jay nests at KAFB, and we collected data from 34 nests at WSMR from 2009-2011. We collected data at one random plot for each nest plot at both installations.

Military infrastructure. Most of the military structures visible in the image were buildings. The two variables were highly correlated and could therefore not be used in the same conditional logistic model. No model including either variable could distinguish nest from random plots; i.e., all models had $\Delta AIC_C > 2$ units from a model which included no variables.

Vegetation. Density of all species of trees on nest plots at all sites ranged from 25-2725/ha (mean=960/ha, SE=82.4). The most common species/size class was medium-sized pinyon trees (mean/ha=286, Table 8), and the least common class was small junipers (mean/ha=36, Table 8). Most plots had 1400 or fewer trees/ha (Figure 11).

Models containing variables describing tree size and number were the most useful, while neither topographic models nor military infrastructure models discriminated between nest and random plots. Of the ground-cover variables, only litter proved useful (Table 9). Only one model of the final seven-model set was competitive, with the next-best model having a ΔAIC_C=3.954 (Table 10). The best model had a weight of 78% of the model set and included three variables related to the size and canopy cover of the nest tree. Other tree variables also contributed to strong models, but because variables such as nest tree RCD, number of large trees, and total number of trees were highly correlated, we did not include them in the same model. The evidence ratio

Table 8. Summary statistics for trees on 0.04-ha Pinyon Jay nest plots at all sites. pied=Pinus edulis, jumo=Juniperus monsperma, s<7cm, m=7-21cm, l>21cm.

Variable	Min	Min/ha	Max	Max/ha	Mean	Mean per ha	SE	SE/ha
all trees	1	25	109	1635	38.39	960	3.3	82.5
smtrees	0	0	64	960	12.17	304	1.73	43.25
medtrees	0	0	49	735	13.3	333	1.32	33
lgtrees	0	0	34	510	12.91	323	0.91	22.75
pied-s	0	0	64	960	10.75	269	1.71	42.75
pied-m	0	0	47	705	11.45	286	1.29	32.25
pied-l	0	0	20	300	7.39	185	0.68	17
jumo-s	0	0	14	210	1.42	36	0.28	7
jumo-m	0	0	16	240	1.86	47	0.29	7.25
jumo-l	0	0	23	345	5.52	138	0.62	15.5
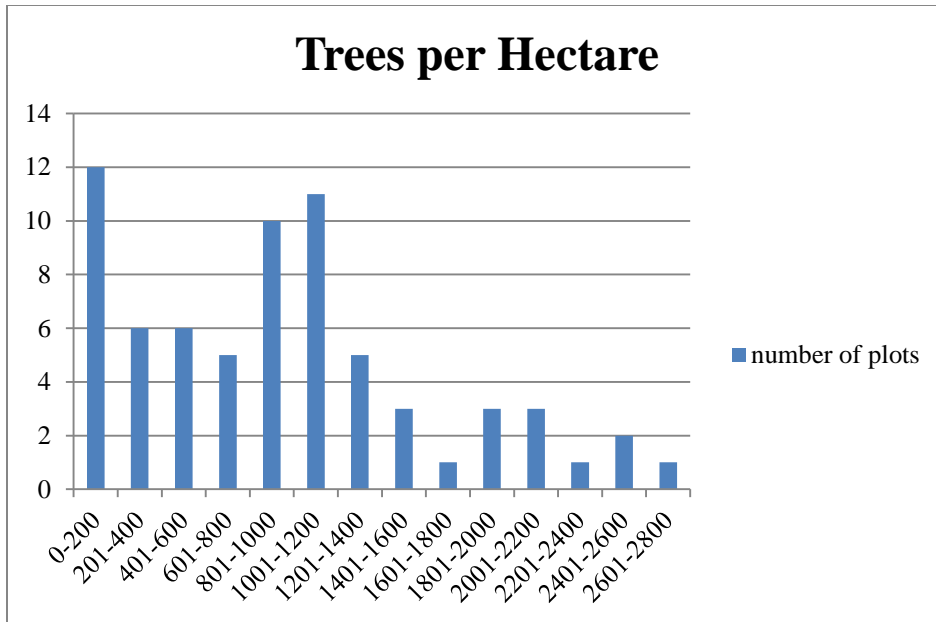
Trees per Hectare

Figure 11. Distribution of tree densities per hectare on Pinyon Jay nest plots, KAFB Winch, KAFB South, and WSMR, 2009-2011.

(ratio of model probabilities) between the highest- and second-highest-weighted model was 7.19, and between the highest- and third-highest-weighted models was 19.46, providing strong support for the highest-weighted model. The AUC for that model was 0.81, indicating good discrimination between nest and non-nest plots (Table 10). Parameter estimates (Table 11, Figure 12) indicated that Pinyon Jays nested in trees with greater total canopy cover (the sum of canopy measures at 1, 2, 3, 4, and 5 m from the nest), larger root crown diameters, and higher litter cover on the ground within 5 m of the nest, relative to non-nest trees within the colony.

Table 9. Variables used in models discriminating Pinyon Jay nest plots from unused plots within colonies at KAFB and WSMR, 2009-2011. Values are means ± standard errors.

Variable	Explanation	KAFB South		KAFB Winch		WSMR	
		Nest Plot	Nonuse Plot	Nest Plot	Nonuse Plot	Nest Plot	Nonuse Plot
elevation	elevation at nest tree	2121.2 (7.44)	2118.9 (10.30)	1873.6 (5.82)	1870.7 (3.11)	2409.4 (9.25)	2397.0 (3.09)
slope	slope of 11.3m plot	19.77 (2.44)	20.91 (2.23)	4.08 (1.35)	5.46 (1.95)	6.97 (0.88)	7.53 (0.60)
aspect2	cosine aspect of 11.3m plot	0.81 (0.05)	0.56 (0.12)	0.80 (0.06)	0.84 (0.05)	0.44 (0.10)	0.55 (0.09)
treeRCD	nest tree RCD	33.66 (5.29)	36.23 (5.67)	79.41 (3.06)	46.29 (6.76)	28.89 (1.63)	23.17 (1.65)
Cancov	% canopy cover	2.36 (0.22)	1.76 (0.20)	2.50 (0.12)	1.60 (0.26)	3.12 (0.09)	2.29 (0.18)
forb	index ground cover forbs on 5m plot	0.55 (90.09)	0.70 (0.07)	0.73 (0.11)	0.71 (0.12)	0.71 (0.07)	0.82 (0.07)
shrub	index ground cover shrubs on 5m plot	0.63 (0.08)	0.75 (0.12)	0.42 (0.11)	0.71 (0.09)	0.93 (0.06)	1.20 (0.12)
bare	index ground cover bare on 5m plot	1.05 (0.10)	0.90 (0.09)	1.90 (0.23)	2.50 (0.40)	1.14 (0.08)	1.00 (0.09)
litter	index ground cover litter on 5m plot	4.53 (0.39)	3.01 (0.27)	3.56 (0.48)	2.02 (0.45)	4.17 (0.31)	3.18 (0.33)
lgtrees	trees >21cm RCD on 11.3m plot	15.09 (1.85)	11.27 (1.90)	4.08 (0.87)	2.85 (0.53)	14.88 (0.90)	12.68 (1.0)
alltrees	tree count, 11.3m plot	40.68 (5.91)	24.05 (4.20)	5.69 (0.92)	4.69 (0.69)	49.41 (3.84)	42.29 (3.39)

Table 10. Candidate model set of conditional logistic regression models discriminating Pinyon Jay nest plots from unused plots at KAFB and WSMR, 2009-2011. k= number parameters in model, including a stratification term, -LL= negative log-likelihood of the model, AIC$_c$ = small sample adjusted Akaike's information criterion value of the model, ΔAIC$_c$ = difference in AIC$_c$ between models with lowest and higher values, w_i = weight of each model in candidate set, and AUC is area under the receiver operator curve, a measure of model classification accuracy.

#	Model	k	-LL	AIC$_c$	ΔAIC$_c$	w_i	AUC
1	Cancov+loglitter+logtreeRCD	4	-63.339	135.304	0.000	0.798	0.810
3	Cancov+logtreeRCD	4	-66.445	139.259	3.954	0.111	0.766
5	Cancov+loglitter+lgtrees	3	-66.303	141.231	5.926	0.041	0.782
2	Cancov+loglitter+alltrees	3	-66.307	141.239	5.935	0.041	0.782
4	Cancov+lgtrees	4	-68.968	144.306	9.001	0.009	0.757
7	litter+bare+shrub+forb	4	-70.738	152.428	17.124	0.000	0.761
6	slope+aspect+elevation	5	-81.859	172.343	37.039	0.000	0.590

Table 11. Parameter estimates from best candidate conditional logistic regression model discriminating Pinyon Jay nest plots from unused plots at KAFB and WSMR, 2009-2011. Litter and tree RCD were log-transformed prior to modeling.

Variable	Estimate	SE	95% CI Lower	95% CI Upper
Cancov	4.755	1.710	1.335	8.175
loglitter	1.248	0.519	0.210	2.286
logtreeRCD	0.923	0.391	0.141	1.705
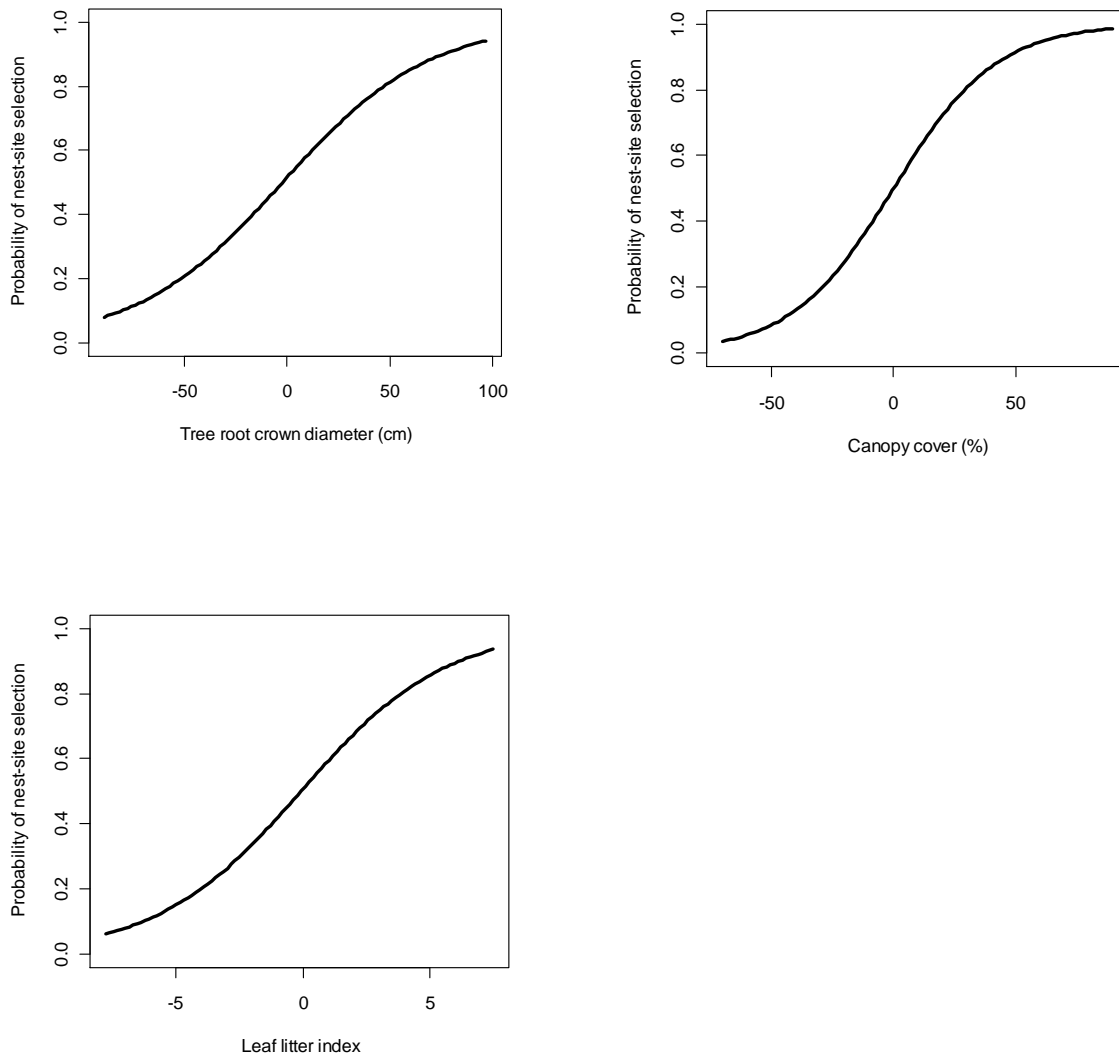
Figure 12. Probability of nest site selection relative to values of each variable in the strongest Pinyon Jay nest site model. X-axes are relative contrasts between nest plots and nonuse plots within the same year and site. For example, the probability of nest-site selection relative to canopy cover was highest when canopy cover was approximately 70% higher among nests vs. nonuse plots, but lowest when approximately 60% lower among nests vs. nonuse plots.

Pinyon Jay: Colony-scale selection

Abandoned versus new colony sites. During 2008 and 2009, Pinyon Jays shifted their nests from a traditional colony site at WSMR to a new, nearby site within the study area. Jays continued to visit the feeder in the old colony site and traveled through the old site, but all 2010 and 2011 nests were south of

the area where the jays nested in 2006-2009. The boundaries of the two colony sites were only 140 m apart at the closest point, and the shortest distance between nests in the two sites was 270 m.

Tree vigor declined at the abandoned colony site from 2005-2011 (Table 12). The linear mixed model showed a significant decline in vigor over time (Table 13). Among-year comparisons showed that vigor was significantly higher in 2005 than in 2008, 2009, 2010, and 2011, and was significantly higher in 2006 than in 2010 and 2011. At the old colony, cone number differed significantly from zero only in 2006, when the mean cone number was 16.15 (SD=26.53; ANOVA: F=27.13, P<0.001, DF=6).

Vigor was significantly higher in 2011 at the new colony than the old colony (mean new=3.36, mean old=2.94, T=3.51, P=0.001, DF=117) and was significantly higher in 2010 at the new colony by a one-tailed test (mean new=3.30, mean old=3.03, T=1.7, P=0.093, DF=76). In 2010, neither colony site produced cones. In 2011, the new site produced significantly more cones than the old colony (mean new=2.33, mean old=0.64, T=2.4, P=0.019, DF=66).

Table 12. Mean vigor ranks of pinyon trees in abandoned Pinyon Jay colony, 2005-2011.

Year	N	Mean Vigor Rank	SD
2005	80	3.58	1.02
2006	80	3.39	0.77
2007	80	3.35	0.73
2008	80	3.16	0.79
2009	80	3.14	0.89
2010	80	3.03	0.81
2011	80	2.94	0.9

Table 13. Results of linear mixed model analysis of change in vigor over time at old Pinyon Jay colony.

Fixed Effects	*Estimate*	*SE*	*t value*	*P*
Intercept	3.2122	0.1206	26.6280	
Year	-0.1010	0.0159	-6.3660	<0.0001

Characteristics of occupied colony sites. At KAFB we selected 20 classes for the unsupervised minimum distance classifier. We evaluated these using the Jeffries-Matusita (JM) Distance formula (Swain and Davis 1978). We found we could eliminate five GIS layers and still maintain high separability (average = 1400.82, 0-1414 is possible) between the 20 classes. The layers we eliminated at KAFB were: July NDVI, January Moisture, October Moisture, Plan Curvature, and Profile Curvature. From the supervised classification applied to the entire study area, we selected the classes that overlay PIJA nests within the colony as a subset and ran a diversity focal analysis (32 x 32 matrix) on these, approximating the smallest colony size (10 ha). We selected those with the largest diversity indices; i.e.,

containing the greatest number of classes that approximated our south site colony at KAFB. This yielded 151 regions which we culled to 12 regions having >50% of the region classified and including at least seven of the 10 classes present at the south colony (Figure 13). The 10 classes were defined by combining the landscape model (Johnson et al. 2010) and the supervised results in an intuitive classification indicative of the heterogeneous PIJA colony site. The classes describe the floristic and topographic diversity within the KAFB colony (E*) and range from low to high slopes of areas dominated by either Pinyon, Pinyon-Juniper, or Juniper. These regions represent areas most similar to the south colony site, as defined by the GIS data used to model them. The locations of these potential colony sites are shown in Figure 14. Together, these 12 regions delineating potential colony sites cover only 8.5% of the available Pinyon Woodland, Pinyon-Juniper, and Juniper Woodland and Savanna map units of the KAFB Pinyon Jay landscape model.

The modeling process at WSMR unfolded quite differently from that at KAFB. Modeling with larger numbers of classes returned many small, highly varied pixels. This uninterpretable pattern likely occurred because the Pinyon Woodland habitat at WSMR is relatively homogenous with respect to the GIS variables (slope, elevation, aspect, NDVI, etc.). We tried several iterations using ever-smaller numbers of classes, finally stopping at five. Evaluation of divergence among the classes was less rigorous than for the KAFB dataset since the unsupervised classification resulted in a non-invertible matrix. However, using the Euclidean Distance measure, we found the greatest separation among the classes occurred between class 1 and the remaining four classes.
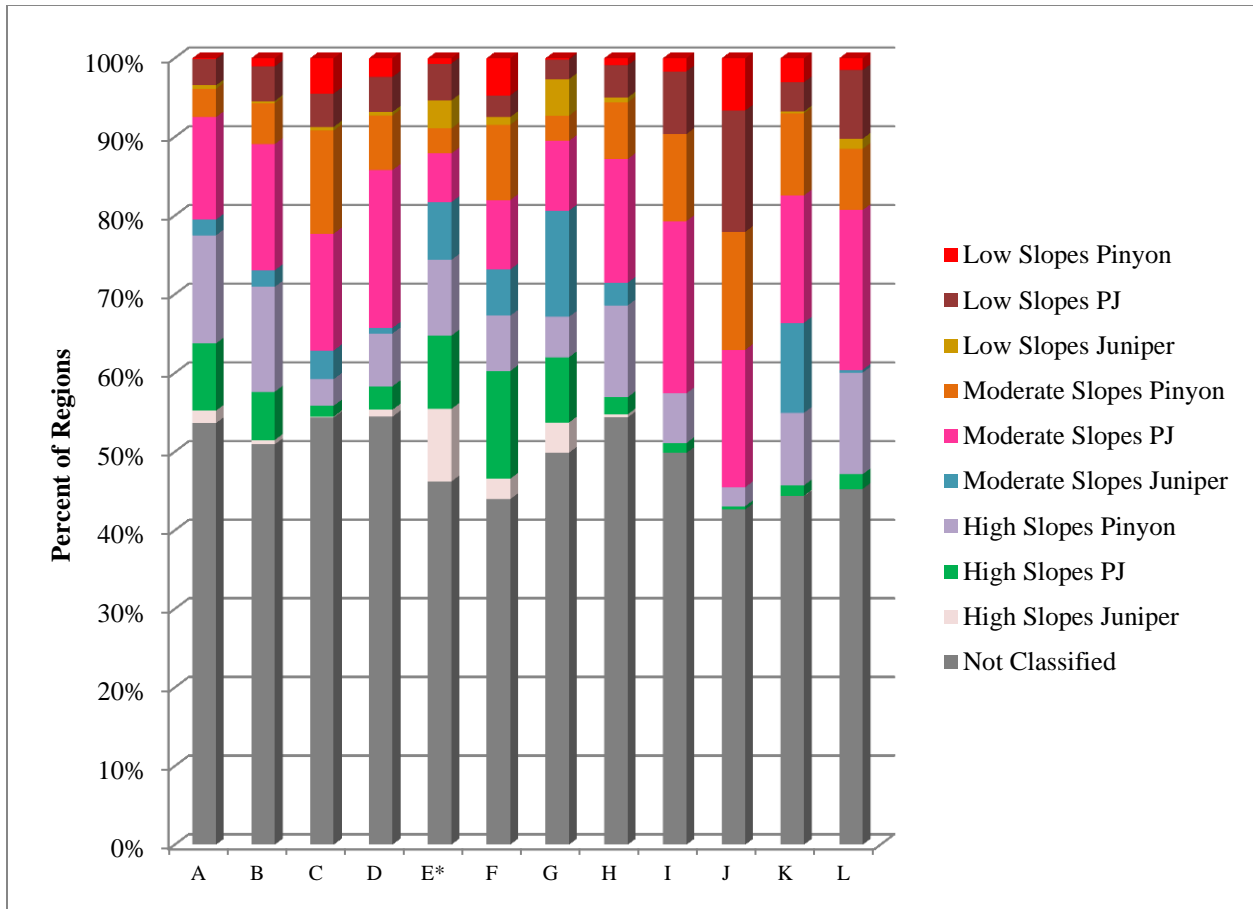
Figure 13. KAFB modeled Pinyon Jay colony sites. Existing colony (E*) was used as the reference site.

Further, we were unable to evaluate the signatures using the JM formula due to the non- invertible matrix. This prevented further reduction of the dimensionality of the data; thus we were left with the original 16 layers for the classification. We attempted to develop intuitive class assignments to the five classes that were applied to the remaining study area. Nest sites were found within classes 2-5, with class 1 consolidating remaining areas not of interest, such as juniper-dominated landscapes. Since our colonies on WSMR were much less diverse both in terms of floristics and topography, attempts to apply focal analysis to aggregate classes based on diversity at the 10-ha scale were unsatisfactory. The resulting model shows large areas in which the four classes of interest were relatively equally distributed. Because we were not able to identify distinct areas classified like the colony areas, we

Figure 14. Colony-scale predictive habitat model for Pinyon Jay colonies at KAFB.

Figure 15. Colony-scale predictive habitat model for Pinyon Jays at WSMR. Inset: by 2010, Pinyon Jays had moved nests from the traditional north colony site to the south colony site.

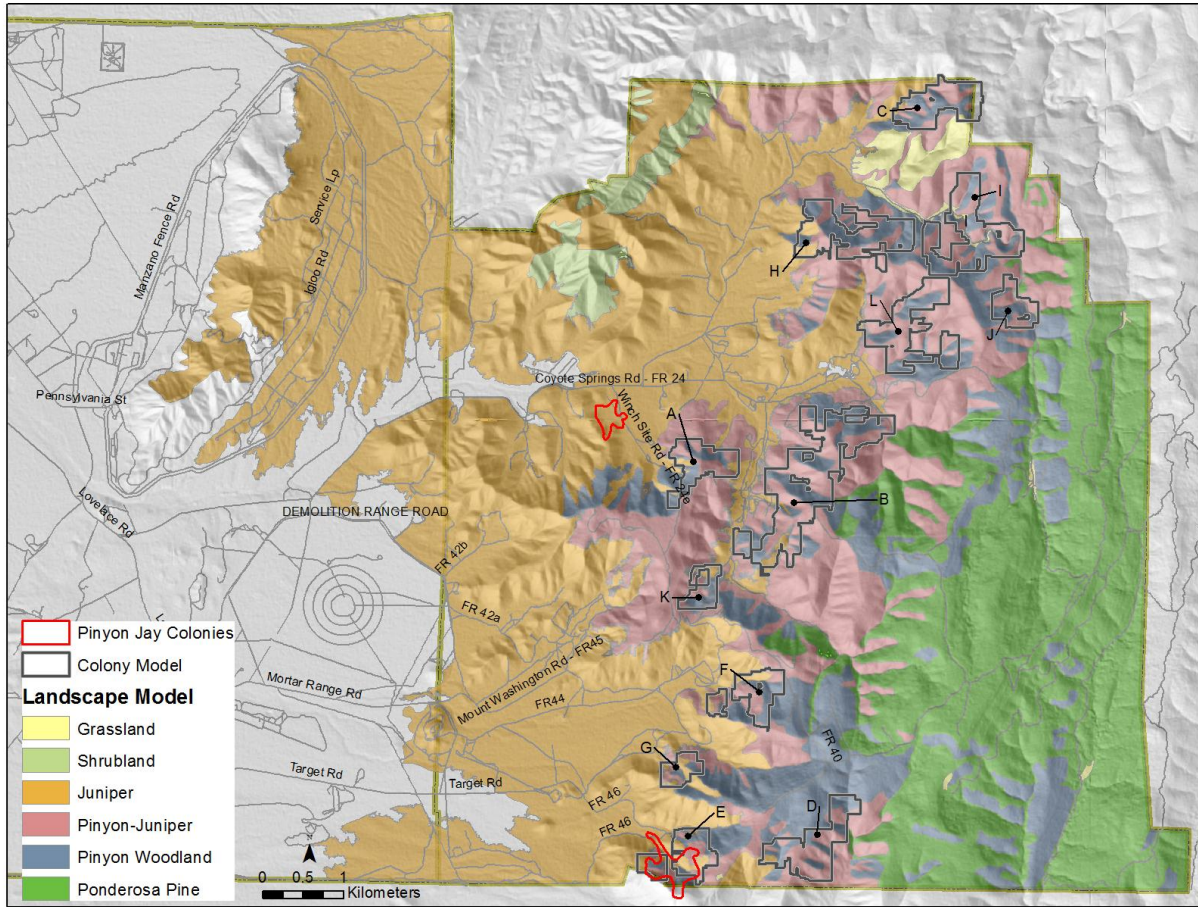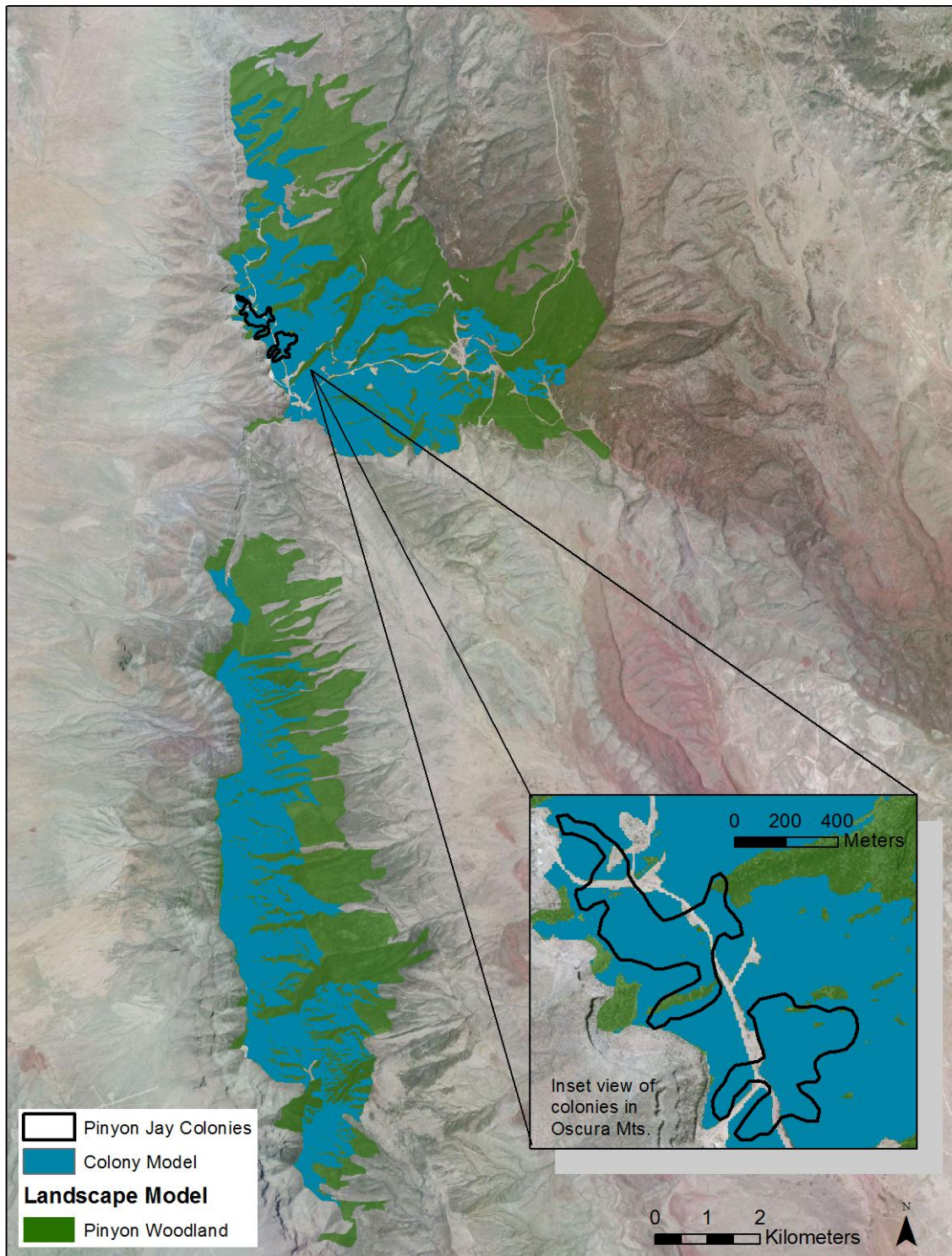concluded that the entire area similar to the colony sites should be classified as one map unit (Figure 15). This map unit occupies 2,927 ha (52%) of the Pinyon Woodland unit of the landscape model (Johnson et al. 2010) and shows little variation in the GIS measures we used in modeling (slope, aspect, elevation, NDVI, etc.).

PINYON JAY: DISCUSSION

Pinyon Jay: Within-colony nest-site selection

Topography. None of the topographic variables or models discriminated between nest and random plots. This result could be due to the scale of the nest and random plot measures; slope, aspect, and elevation did not vary greatly over the 100-m distance between nest and random plots. However, each of the three Pinyon Jay study sites had quite different elevations, slopes, and aspects, suggesting that jays choose colony sites based on variables other than topography. Our nest- and colony-scale results indicate that tree size is the feature of importance to Pinyon Jays choosing nest sites.

Military infrastructure. Analysis of distance to various types of military infrastructure revealed no differences between nest and random plots. In this case, it is possible that the scale of the plots prevented us from detecting any tendency of the jays to avoid military structures. At KAFB, mean distances to buildings were 750.5 m (Range 595 m-887 m) at the Winch Site and 1712.4 m (Range 1431 m-2723 m) at the south site. At these distances, the impact from military activities would probably not differ appreciably between the random and nest plots, which were only 100 m apart.

Due to the small sample size of colonies in our study, it was not possible to explore infrastructure impacts to Pinyon Jays at the colony scale, as we did for Gray Vireos at the territory scale. However, distances to roads and edges at all sites and distances to buildings at WSMR were much lower (mean = 432.4 m, Range 103 m-816 m) than distances to buildings at KAFB. Twenty-two nests were situated <100 m from a road. In general, nests were farther from buildings and other infrastructure than from roads. In light of the potential complications of scale mentioned above, we cannot conclude that Pinyon Jays do not avoid nesting near military infrastructure, but our analyses failed to detect any strong avoidance of roads, buildings, or other infrastructure.

It is clear, however, that nesting Pinyon Jays and parents with fledglings are quite sensitive to the approach of humans on foot. It is difficult to approach jays closely enough to read color bands with binoculars because birds alarm call and fly away on our approach. Below, our recommendations regarding military activities are discussed in light of these results.

Vegetation. The best model to emerge from the conditional logistic regression analyses contained three variables: tree root crown diameter, canopy cover, and litter. Nest trees had larger root crown diameters than trees on nonuse plots. Canopy cover, taken at 1, 2, 3, 4, and 5 m in the four cardinal directions from the nest, was higher in nest than non-use trees, and the index of litter cover on the 5-m plot was higher in

the nest than the random plots. This suggests that Pinyon Jays placed nests in larger than average trees providing more complete canopy cover than non-use trees. When substantial litter cover was present in the 5-m plot, the litter comprised mainly needles from the nest tree, which were all either pinyon or juniper. The higher ground cover of litter on nest plots may thus be an indicator of the density of the nest tree canopy in previous years.

The jays probably placed nests in trees with dense canopies to hide their nests from potential predators. Common Ravens (*Corvus corax*) were the most abundant potential nest predators at all three sites. We frequently observed Peregrine Falcons (*Falco peregrinus*) at the KAFB South and WSMR colonies, and we saw falcons chase and, on one occasion, capture a Pinyon Jay on our study site. Potential mammalian nest predators such as ringtails (*Bassariscus astutus*) would probably not be deterred by canopy cover but might be less likely to climb large trees to access nests.

Pinyon Jay: Colony-scale selection

Pinyon Jays nest in loose colonies and do not defend nesting or feeding territories. Although they may occasionally forage within the nesting colony, they typically range widely outside the nesting colony to forage. Small groups of male Pinyon Jays forage outside the colony and return to feed incubating and brooding females, which come off their nests and beg to their arriving mates. The male groups then leave the colony together and return with food after ~0.5-2.0 h. The nesting colony is used almost exclusively for nesting; hence the importance of the nest tree in the nest-scale model.

At WSMR, Pinyon Jays moved their colony site from an area of less vigorous trees to a nearby area with healthier trees. In 2005, tree transect 9, which crossed the old colony site, had a smaller percentage of saplings, and trees were taller and more densely packed than transects 7 and 8, suggesting an older age structure at the first colony site. Trees were also more densely packed along transect 9, which was associated with lower vigor and cone production (Johnson and Smith 2006). Hence, the traditional colony probably declined due to competition among densely-packed trees, some of which were also senescent.

At the nest scale, the total number of trees on a plot and the number of large trees were correlated with tree RCD, a significant variable in the strongest model. Pinyon Jays would be expected to choose colony sites based in part on the trees surrounding the single tree chosen for nesting. Because they are highly social and nest colonially, they should nest where other individuals might nest nearby. In addition, nearby trees serve to hide the nest location. Adults rarely go directly to their nests but typically land several trees away from the nest tree and approach the nest surreptitiously from below.

If Pinyon Jays choose colony sites based on the characteristics of the nest trees, colony-scale habitat selection may be a straightforward matter of finding an area containing enough trees of appropriate size and canopy thickness to provide good nest sites for the flock. As the lushness of tree canopies (indicated by vigor rankings) at the abandoned colony site declined, the jays moved to a nearby site where trees

were more vigorous. The larger number of cones produced at the new site in 2011 is additional evidence that trees at the new site were healthier.

We focused colony-scale modeling efforts on the south colony at KAFB and the old and new colonies at WSMR. We avoided colony-scale modeling at the Winch Site, because Pinyon Jays nested there in only one breeding season when we had maintained a pinyon feeder near that site. That colony, in Juniper Woodland and Savannah habitat, may be atypical.

The KAFB south colony site was covered in Pinyon Woodland, Pinyon-Juniper Woodland, and Juniper Woodland and Savanna, as identified in the landscape-scale model (Johnson et al. 2010). The WSMR colonies were in Pinyon Woodland habitat (Johnson et al. 2010). The colony-scale classification process varied between KAFB and WSMR, likely a result of the much greater variability at the colony (GIS variable) scale at KAFB. The KAFB south site was in a canyon and had north-, west-, and east-facing aspects, variable elevation, slopes ranging from nearly level to very steep, and three vegetation types. The WSMR colony, in contrast, had moderate slopes throughout, mainly east-facing aspects, and only Pinyon Woodland vegetation. As a result, the KAFB colony-scale classification contains more classes and allowed delineation of 11 potential sites similar to the south colony site. The WSMR model delineates areas having the four main classes found in the two colony sites, but it was not possible to extract specific sites similar to the colony site, owing to general homogeneity of the Pinyon Woodland habitat.

The greater topographic variation at the KAFB colony probably influenced the modeling process, such that only the most diverse sites, having variable aspect, elevation, slope, and even vegetation were selected. This apparently explains the differences in the modeling process and resulting models at the two installations. It is possible that the process was overly restrictive in attempting to identify sites that approximated too closely the highly variable south site. In the next year of the project we will attempt to modify the modeling parameters to avoid this issue. As this report is finalized, we have found one new colony at KAFB. The inclusion of this colony in a revised colony-scale model will likely result in a more general, more realistic colony-scale model at KAFB.

Due to the issues we encountered in modeling colony-scale Pinyon Jay habitat at the two installations, we have limited confidence in the general applicability of either one. The KAFB model appears to model Pinyon Jay colony-scale habit for KAFB only and is likely overly restrictive even within KAFB. The WSMR model failed to predict potential colony-size sites within the Pinyon Woodland habitat, instead indicating a landscape of continuous suitable habitat. However, the differences in the two sites and the variation within the KAFB south site suggest that Pinyon Jays are not fussy about colony-scale attributes, characterized by GIS measures such as slope, aspect, elevation, and vegetation indices. Except for vegetation indices, those measures did not change at the old WSMR colony between 2005 and 2011, but the birds still moved to a new site.

Colony-scale habitat selection may not be the most appropriate concept for Pinyon Jays. Choice of a colony site could be a result of the combined nest-scale choices made by many individual pairs of jays. The strong sociality of Pinyon Jays and the need for cover around the nest tree suggests that flocks choose colony sites based not only on individual nest trees, but also on the density, size, and vigor of surrounding trees. In summary, we have not found strong evidence that Pinyon Jays choose colony sites based on colony-scale variables, as the Gray Vireos do at the territory scale.

Pinyon Jays tend to return year after year to traditional colony sites (Marzluff and Balda 1992, this study). Colonies do move, but more often than not Pinyon Jays return to old nesting areas (Marzluff and Balda 1992). At WSMR, Pinyon Jays have nested at two adjacent sites within a mainly contiguous stand of uniform, suitable habitat for seven years. Even when the health of trees within the old colony declined, the birds moved their nests to an adjacent area less than a kilometer away. Fidelity to traditional colony sites appears to be a result of strong sociality. Any pair that pioneered a new colony site would be alone, an unacceptable situation for a Pinyon Jay pair. A much less risky strategy would be to colonize a nearby area, so as to be close to flock members. The frequency and behavioral mechanisms of new colony establishment are not well known, in part because such events are rare. Strong site fidelity could severely limit the ability of a Pinyon Jay flock to make use of available habitat. If so, the potential conservation implications of colony site fidelity warrant further investigation.

PINYON-JUNIPER MANAGEMENT

Vegetation/Topography
Trees are clearly important to both Gray Vireos and Pinyon Jays in the nesting season.
Gray Vireos selected nest sites on south-facing slopes with more trees and moderately higher mean tree heights than random plots, and territories at KAFB had intermediate greenness relative to non-territories. Vireo nesting habitat may not be a simple matter of more trees or larger trees being preferred; rather, vireos appear to need larger trees, but perhaps not the very largest. Densities of junipers on Gray Vireo territories ranged from 25-425/ha, with a mean density of 99 trees/ha.

In recent years, tree removal by way of fire, chaining, or thinning has been implemented on public lands to combat pinyon-juniper expansion into grasslands and shrublands (Johnson et al. 2010). In one study in Grand Staircase Escalante National Monument in southern Utah, mechanical thinning significantly reduced relative abundance of pinyon-juniper birds, and Gray Vireos disappeared entirely from treatment sites (Crow and van Riper 2010). We recommend that intermediate and large junipers, with the possible exception of senescent trees (although these trees provide perches), not be removed from Gray Vireo nesting areas and that juniper trees in potential and actual nesting areas be maintained at densities similar to those on our nest plots.

Tree size, canopy cover, and litter were higher at Pinyon Jay nests; a decline in tree health was associated with abandoning a colony; and several measures of greenness were included in colony-scale

GIS models. In addition to providing nest sites and cover, pinyon trees produce nutritionally rich seeds that enhance reproductive success and affect Pinyon Jay population viability (Marzluff and Balda 1992). Larger pinyon trees produce more seeds (Johnson and Smith 2006).

Management of pinyon juniper habitat for Pinyon Jays should include maintaining densities similar to those reported here, with most areas dominated by pinyon trees. The size distribution of pinyon trees is also important. Larger pinyon trees, if healthy, produce the most pinyon seeds. Productivity declines in extremely large, old (≥300 years), senescent trees, but large, healthy trees are essential seed producers and should not be thinned. We recommend no net loss of mature, healthy pinyon stands, to retain pinyon seed production areas and options for new colonies.

Pinyon woodlands appear to be self-thinning on our study sites (K. Johnson unpubl., E. Muldavin pers. comm.). Many pinyon trees die under drought conditions, especially in thick stands of young trees, and thinning is therefore not typically required. However, the range of pinyon-juniper habitat is predicted to contract significantly in southern New Mexico, Utah, and Arizona under climate change (Thompson et al. 1998, Cole et al. 2007) and expand in northern New Mexico and Colorado (Cole et al. 2007). Given the expected impacts of climate change on pinyon-juniper woodlands in central and southern New Mexico, experimental thinning could be a useful exploratory management practice. It should be employed only when densities are very high (~2000 trees/ha or higher), in thick stands of young "doghair" pinyon. Long-term monitoring of tree growth and seed production should accompany any experimental thinning.

The historical role of fire in pinyon-juniper woodlands is not well understood and likely varies with location and woodland type (Romme et al. 2009). Fire frequency has been shown to be quite low in some pinyon-juniper and pinyon woodlands, especially persistent pinyon woodlands (Romme et al. 2009). Hence, fire is not recommended as a management tool in these habitats. In any case, fire would probably not be employed in pinyon-juniper and pinyon woodlands on DoD installations because of potential threats to military infrastructure.

Military Activities

Results of analyses of the effects of military activities/infrastructure on nesting Gray Vireos and Pinyon Jays are not strong, but analyses at both nest and territory scales hint at both tolerance and avoidance by both species. Vireo nest plots were farther from buildings than random plots at CTTA. Vireo territories at CTTA were farther from infrastructure than non-territories, while vireo territories at KAFB were closer to two-track roads than non-territories. However, as suggested in the territory-scale discussion above, some of these results could occur by chance due to the location of buildings and roads relative to limited patches of nesting habitat. In addition, military activities are already restricted in the Gray Vireo nesting season at both CTTA and KAFB, which could make it difficult to detect avoidance of military infrastructure and/or activities. Considering the above factors, it is reasonable to conclude that Gray Vireos do not strongly and consistently avoid roads, infrastructure, and buildings (across all three study sites and both scales).

Pinyon Jays also failed to show strong avoidance of roads or buildings at the nest scale. As with vireos, differences in scale between the nest and random plots (100 m) compared to the much greater distances to infrastructure and roads could reduce our ability to detect avoidance of infrastructure. Two types of anecdotal evidence provide more insight than the regression analyses. First, we found several Pinyon Jay nests within 100 m of gravel roads that experienced intermittently moderate traffic, suggesting that nesting Pinyon Jays are tolerant of moderate-traffic roads. We would expect the jays to show lower tolerance for heavy and/or constant traffic. In addition, the possibility that vehicle traffic or other military activities impact nest success is unexplored. Second, Pinyon Jays clearly avoid people on foot, especially around their nestlings and fledglings, which suggests intolerance of foot traffic.

Human disturbance in occupied vireo habitat during the breeding season at CTTA and KAFB is restricted and therefore minimal. The vireos have been establishing territories and nesting in the same areas each year, which suggests that the restrictions may be supporting the birds' access to preferred nesting habitat. Discontinuing these restrictions could impact the birds, and we recommend that KAFB and CTTA continue to restrict training activities in the Gray Vireo nesting areas during the breeding season. Based on some evidence that vireos avoid infrastructure when siting nests and territories, we recommend that new infrastructure such as buildings, power lines, or shooting ranges not be constructed closer to territories than infrastructure that is currently present.

We recommend that no new roads or infrastructure be constructed any closer to traditional Pinyon Jay colonies than what currently exist. Ground training (including foot traffic and off-road vehicles) in or near a Pinyon Jay nesting area could cause abandonment of nests; we recommend that ground training activities not be conducted within one kilometer of traditional Pinyon Jay colony sites between March and July. In mast years, ground training should not be conducted within one kilometer of areas where jays are harvesting pinyon seeds between August and October, except in the case of a very abundant and widespread mast crop, such that multiple sites are available for harvesting cones. We recommend against any activities that create loud noises or destroy habitat (such as bombing) within one kilometer of a nesting colony. No activities that carry high potential for wildfires should be conducted within a flock's breeding home range.

LITERATURE CITED

Allen-Reid, D., J. Anhold, D. Cluck, T. Eager, R. Mask, J. McMillan, S. Munson, T. Rogers, D. Ryerson, E. Smith, B. Steed, and R. Thier. 2005. Piñon pine mortality event in the Southwest: an update for 2005. US Forest Service. Accessed at: http://fhm.fs.fed.us/posters/posters05/pinon_pine.pdf

Arbetan, P. and T. Neville. 2009. Modeling Gray Vireo habitat – general considerations *In* Walker, H. A. and R. H. Doster, eds. 2009. Proceedings of the Gray Vireo symposium co-sponsored by the

New Mexico Department of Game and Fish and the New Mexico Ornithological Society, 12–13 April 2008. Albuquerque, NM. The New Mexico Department of Game and Fish, Santa Fe, New Mexico. pp. 17-19.

Arbetan, P., E. Muldavin, P. Neville, and Y. Chauvin. 2002. The vegetation of the New Mexico Army National Guard Camel Tracks Training Site. Natural Heritage New Mexico Publ. No. 02-GTR-221. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 48 pp.

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74:1175-1178.

Baker, W. L. and D. J. Shinneman. 2004. Fire and restoration of piñon–juniper woodlands in the western United States: a review. Forest Ecology and Management 189:1–21

Balda, R. P. 2002. Pinyon Jay (*Gymnorhinus cyanocephalus*). *In* The Birds of North America, No. 605 (A. Poole and F Gill, eds.). The Birds of North America, Inc. Philadelphia, PA.

Barlow, J. C., R. D. James, and N. Williams. 1970. Habitat co-occupancy among some vireos of the subgenus *Vireo* (Aves: Vireonidae). Can. J. Zool. 48:395-398.

Barlow, J. C. 1978. Effects of habitat attrition on vireo distribution and population density in the northern Chihuahuan Desert. Pp. 391–596 *in* Transactions of the symposium on the resources of the Chihuahuan Desert region—U.S. and Mexico (R. H. Wauer and D. H. Riskind, eds.). USDI, Natl. Park Serv. Trans. Proc. Ser. 3.

Barlow, J.C., S.N. Leckie, and C.T. Baril. 1999. Gray Vireo (*Vireo vicinior*). *In* The Birds of North America, No. 447 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Boyce, M.S. 2006. Scale for resource selection functions. *Diversity and Distributions* 12:269-276.

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings National Academy Sciences 102:15144-15148.

Bureau of Land Management. 2009. Restore New Mexico. Accessed 17 August 2010 at: http://www.blm.gov/nm/st/en/prog/restore_new_mexico.html.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York.

Chander, G., B.L. Markham, and D.L. Helder. 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment* 113:893-903.

Cole, K.L., K. Ironside, S. Arundel, P. Duffy, and J. Shaw. 2007. Modeling future plant distributions on the Colorado Plateau: an example using *Pinus edulis*. Pp. 319-330 *in*: the Colorado Plateau III; Integrating research and resources management for effective conservation. C. van Riper III and M. Sogge, eds. University of Arizona Press, Tucson, AZ.

Colorado Bureau of Land Management (BLM). 1995. Analysis of the Colorado BLM nongame bird monitoring point count transects. Bureau of Land Management, Grand Junction, CO.

Colorado Division of Wildlife. 2006. Colorado's comprehensive wildlife conservation strategy and wildlife action plans. Prepared in fulfillment of Title IX, Public Law 106-553 and Title I, Public Law 107-63 (State Wildlife Grants Program).

Crow, C., and C. van Riper. 2010. Avian community responses to mechanical thinning of a pinyon-juniper woodland: specialist sensitivity to tree reduction. Natural Areas Journal 30:191-201.

Delong, J.P., and N.S. Cox. 2005. Nesting ecology of gray vireos in central New Mexico: 2005 results. Prepared for the Bureau of Land Management and the New Mexico Department of Game and Fish. 15 pp.

Delong, J.P. and S.O. Williams. 2006. Status report and biological review of the gray vireo in New Mexico. Unpubl. report to New Mexico Department of Game and Fish, Santa Fe, NM. 50 pp.

DoD Partners in Flight. 2011. DoD priority PIF species. Department of Defense Partners in Flight Program. Accessed 19 Jan 2012 at: http://www.dodpif.org/downloads/factsheet11_priority-species_hi.pdf.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

ERDAS IMAGINE 2011. ERDAS IMAGINE: Release 10. Norcross, GA: ERDAS, Inc.

Fielding, A.H., and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental conservation* 24:38-49.

Giroir, G. 2001. Final report on the breeding bird inventory at Colorado National Monument, western Colorado. Unpublished report for Colorado National Monument. Rocky Mountain Bird Observatory, Grand Junction, CO.

Hosmer, D.W., and S. Lemeshow. 2000. Applied Logistic Regression. John Wiley & Sons.

Hutton, K, G. Giroir, R. Sparks, A. Panjabi, and D. Hanni. 2006. Bird monitoring in the National Park Service, Northern Colorado Plateau Network: 2005 field season report. Tech. Rep. M-NCPN05-01. Rocky Mountain Bird Observatory, Brighton, CO.

Johnson, K. and J. Smith. 2006. Interdependence of pinyon pines and pinyon jays, White Sands Missile Range, NM, 2004-2005 final report. Natural Heritage New Mexico Publication No. 06-GTR-309. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM.

Johnson, K., L. Wickersham, T. Neville, J. Wickersham, J. Smith, M. Baumann, and C. Finley. 2010. Habitat use at multiple scales by Pinyon-Juniper Birds on Department of Defense Lands: landscape scale. Natural Heritage New Mexico Publ. No. 10-GTR-360. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 51 pp.

Keating, K.A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. *Journal of Wildlife Management* 68:774-789.

Kirtland AFB. 2005. Final surveying report for Mountain Plover and Gray Vireo populations at Kirtland AFB. Albuquerque, NM. August. 76 pp.

Kirtland AFB. 2006. Final surveying report for Gray Vireo populations at Kirtland Air Force Base. Albuquerque, NM. October. 76 pp.

Kirtland Air Force Base. 2007. Integrated natural resources management plan for Kirtland Air Force Base. Kirtland Air Force Base, Albuquerque, NM. 143 pp.

Lanner, R.M. 1996. Made for each other: a symbiosis of birds and pines. Oxford University Press, New York, NY.

Ligon, J.D. 1971. Late summer-autumnal breeding of the Piñon Jay in New Mexico. Condor 73:147-153.

Ligon, J.D. 1974. Green cones of the piñon pine stimulate late summer breeding in the Piñon Jay. Nature 250:80-82.

Ligon, J.D. 1978. Reproductive interdependence of piñon jays and piñon pines. Ecological Monographs 48:111-126.

Martin, T.E., C. Paine, C.J. Conway, W. M. Hochachka, P. Allen, and W. Jenkins. 1997. Breeding Biology Research and Monitoring Database (BBIRD). Montana Cooperative Wildlife Research Unit, University of Montana, Missoula, MT.

Marzluff, J.M. and R.P. Balda. 1992. The pinyon jay: the behavioral ecology of a colonial and cooperative corvid. T & AD Poyser, London. 317 pp.

Menard, S.W. 2009. Logistic Regression: From Introductory to Advanced Concepts and Applications. SAGE Publications, Thousand Oaks, CA.

Mitchell, K. 2007. Quantitative analysis by the point-centered quarter method. Accessed online 5 December 2011 at: http://people.hws.edu/mitchell/PCQM.pdf.

Muldavin, E., Y. Chauvin, and G. Harper. 2000a. The vegetation of White Sands Missile Range, New Mexico Volume I: handbook of vegetation communities. Natural Heritage New Mexico Publ. No. 00-GTR-299. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 236 pp.

Muldavin, E., G. Harper, P. Neville, and Y. Chauvin. 2000b. The vegetation of White Sands Missile Range, New Mexico Volume II: vegetation map. Natural Heritage New Mexico Publ. No. 00-GTR-299. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 100 pp.

Muldavin, E., C. Baisan, T. Swetnam, L. DeLay, and K. Morino. 2003. Woodland fire history studies in the Oscura and northern San Andres Mountains, White Sands Missile Range, New Mexico. Natural Heritage New Mexico Publ. No. 03-GTR-256. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 35 pp.

Muldavin, E., A. Kennedy, C. Jackson, T. Neville, P. Neville, K. Schulz, and M. Reid. 2010. A vegetation classification and map report: Bandelier National Monument. Natural Resource Technical Report NPS/SCPN/NRTR-2-1-/00X, National Park Service, Fort Collins, CO.

National Solar Radiation Database 1991-2005 Update: User's Manual. 2007. Technical Report NREL/TP-581-41364. National Renewable Energy Laboratory, Golden, CO.

Natural Heritage New Mexico. 2011. NMBiotics Database. Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM. Online: http://nhnm.unm.edu. Accessed on 09-17-2010.

New Mexico Department of Game and Fish. 2005. Threatened and endangered species of New Mexico, 2004 biennial review. New Mexico Department of Game and Fish, Conservation Services Division, Santa Fe, NM. March 2005. 112 pp.

New Mexico Department of Game and Fish. 2006. Comprehensive Wildlife Conservation Strategy for New Mexico. New Mexico Department of Game and Fish. Santa Fe, NM. 526 pp. + appendices.

New Mexico Partners in Flight. 2007. New Mexico Bird Conservation Plan, version 2.1. C. Rustay and S. Norris, compilers. Albuquerque, NM.

Pinheiro, J.C., and D.M. Bates. 2000. Mixed-effects models in S and S-PLUS. Springer Verlag.

R Development Core Team. 2009. R: A language and environment for statistical computing. Version 2.10.1. R Foundation for Statistical Computing, Vienna, Austria.

Rich, T.D., C.J. Beardmore, H. Berlanga, P.J. Blancher, M.S.W. Bradstreet, G.S. Butcher, D.W. Demarest, E.H. Dunn, W.C. Hunter, E.E. Iñigo-Elias, J.A. Kennedy, A.M. Martell, A.O. Panjabi,

D.N. Pashley, K.V. Rosenberg, C.M. Rustay, J.S. Wendt, and T.C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology. Ithaca, NY.

Romme, W.H., C.D. Allen, J.D. Bailey, W.L. Baker, B.T. Bestelmeyer, P.M. Brown, K.S. Eisenhart, M.L. Floyd, D.W. Huffman, B.F. Jacobs, R.F. Miller, E.H. Muldavin, T.W. Swetnam, R.J. Tausch, and P.J. Weisberg. 2009. Historical and modern disturbance regimes, stand structures, and landscape dynamics in piñon-juniper vegetation of the western United States. Rangeland Ecology and Management 62:203-222.

Sauer, J.R., J.E. Hines, and J. Fallon. 2007. The North American Breeding Bird Survey, Results and Analysis 1966 - 2005. Version 6.2.2006. US Geological Survey, Laurel, MD.

Schlossberg, S. 2006. Abundance and habitat preferences of gray vireos (Vireo vicinior) on the Colorado Plateau. Auk 123:33-44.

Stephens, P.A., S.W. Buskirk, G.D. Hayward, C.M. Del Rio, and Hm. 2007. A call for statistical pluralism answered. Journal of Applied Ecology 44:461-463.

Sutter, J.V., M.E. Anderson, K.D. Bunnell, M.F. Canning, A.G. Clark, D.E. Dolson, and F.P. Howe. 2005. Utah comprehensive wildlife conservation strategy. Utah Divison of Wildlife, Salt Lake City, UT.

Swain, P.H. and S.M. Davis. 1978. Remote Sensing: The Quantitative Approach. New York: McGraw Hill Book Company.

Therneau, T. 2009. survival: Survival analysis, including penalised likelihood. *R package version 2.35-8.*

Thompson, R.S., S.E. Hostetler, P.J. Bartlein, and K.H. Anderson. 1998. A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States. USGS Circular 1153. Accessed 6 August 2010 at: http://pubs.usgs.gov/circ/1998/c1153/.

USGS National Gap Analysis Program. 2004. Provisional land cover map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.

Wauer, R.H. 1983. Checklist of birds of the Big Bend. Big Bend Natural History Association, Big Bend National Park, Brewster Co., TX.

Weathers, W.W. 1983. Birds of southern California's Deep Canyon. University of California Press, Berkeley, CA.

Western Regional Climate Center. 2010. Albuquerque WSFO Airport, New Mexico. Period of record monthly climate summary. Accessed on 17 August 2010 at: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nmalbu.

White Sands Missile Range Climate Stations. 2009. Excel spreadsheets from Thomas Blaine for stable WSMR climate stations.

Wickersham, L.E. and J.L. Wickersham. 2007. Density and habitat use of gray vireo (*Vireo vicinior*) in northwestern New Mexico: 2006-07 final report. Prepared for the New Mexico Department of Game and Fish, Santa Fe, NM. 15 pp. + appendix.

Wickersham, L.E. and J.L. Wickersham. 2010. Gray Vireo (*Vireo vicinior*) Population Monitoring Project: 2010 Annual Report, Kirtland Air Force Base, Albuquerque, New Mexico, Unpublished report to Kirtland Air Force Base, Animas Biological Studies, Durango, CO . 23 pp. + Appendices A−D.

Wickersham, J. L., and L. E. Wickersham. 2011. Gray Vireo (*Vireo vicinior*) base-wide survey, Kirtland Air Force Base, Albuquerque, NM. Unpublished report to Kirtland Air Force Base. Animas Biological Studies, Durango, CO. 11 pp. + Appendix A.

APPENDIX 1: Gray Vireo Landscape Model for White Sands Missile Range

Introduction

We delivered landscape-scale models for Pinyon Jays (KAFB and WSMR) and Gray Vireos (CTTA and KAFB) with the Year 1 report for this study (Johnson et al. 2010). In 2009, the first year of this project, surveys for Gray Vireos had not been completed at WSMR. We therefore delayed surveying and monitoring Gray Vireo territories and nests at WSMR until 2010, and the WSMR Gray Vireo landscape-scale model is included as an appendix to this, the Year 2 report.

As at CTTA and KAFB, vireos at WSMR occurred in juniper-dominated habitats near drainages. However, Gray Vireo habitat at WSMR has a more diverse shrub component than the Juniper Woodland and Savanna habitats at CTTA and KAFB. The WSMR vireo model is therefore important as an indicator of the shrub diversity and geographic variation in vireo habitats.

Methods

In May 2010, we initiated surveys for Gray Vireos at Rhodes Canyon, WSMR. We followed the playback method developed by DeLong and Williams (2006) and focused our survey efforts in areas where Gray Vireos had been detected during the 2009 survey (Hobert et al. 2009). We conducted playback surveys between sunrise and noon when birds sing most, broadcasting Gray Vireo vocalizations about every 200–300 m. Each stop began with a ~1-min listening period. If vireos were not detected during the listening period, we broadcast Gray Vireo songs for approximately 20–30 s using MP3 players with external speakers. The broadcast period was followed by another 1-min listening period. We continued this cycle of playbacks and listening, rotating the direction of the playback to ensure songs were broadcast 360^0 from each survey point. Where Gray Vireos were detected, we marked their locations in the field using GPS units. We mapped each Gray Vireo detection using ArcGIS.

We visited areas occupied by Gray Vireos and gathered GPS locations for inclusion in the landscape-level GIS habitat model. We marked the locations of adult vireos in the field using Garmin GPS units whenever possible and mapped them in ArcGIS. We created estimated territory boundaries based on the point locations and our field observations. After field work was complete, we used Hawth's Analysis Tools for ARCGIS (Beyer 2004) to create Minimum Convex Polygons (MCP) for each Gray Vireo territory. We calculated the area of each MCP using ArcGIS. MCPs were used as a reference for the GIS landscape model and to create baseline data on Gray Vireo territory size and movements. We searched for nests in each territory and monitored nest success. We collected vegetation data on nest and random plots following a modified BBIRD method (see methods detail in the main document, above).

A vegetation classification, map and associated plot data (Muldavin et al. 2000 a, b) were available to assist us in classifying vegetation in the WSMR Gray Vireo study area. In addition, we used 1-m, natural-color aerial photography acquired in July 2009 (NAIP 2009). Because the spatial resolution of

the aerial photos was higher than was previously available for the existing (Muldavin et al. 2000 a, b) map, we used the aerial photography to delineate a separate set of map units to encompass the area occupied by Gray Vireos in this study and the 2009 survey (Hobert et al. 2009). We calculated summary statistics for elevation, slope, and aspect for each of the survey locations (positive and negative) by Hobert et al. (2009) and Wickersham in 2010. We used these slope and elevation statistics in delineating potential habitat. We further refined these polygons based on color and texture of the aerial photography to assign the map units. In addition to the Muldavin et al. (2000 a, b) map and plot data, we used overlays of elevation contours and bird observations collected within the study area.

Hobert et al. (2009) described floristic and topographic attributes of areas within the San Andres Mountains, where they ranked relative densities of Gray Vireo territories. For example, within arroyo riparian corridors following the upper Cottonwood Canyon to the Chalk Hills, they found the highest apparent densities of Gray Vireo territories. We developed a GIS of these areas attributed according to vireo densities, as assigned by Hobert et al. (2009). We developed four additional regions based on densities of the 2010 observations. We then assigned density classes in these four 2010 areas following Hobert et al.'s (2009) density rankings.

Exact boundaries along the continuum of juniper savanna to pinyon-juniper woodland landscape are difficult to delineate. Dick-Peddie (in Aldon et al. 1993) defined woodlands as having trees with non-overlapping canopies. He distinguished juniper savanna as scattered stands with densities less than 130 trees/acre 321 trees/ha). Using these definitions as a basis, we differentiated the juniper to pinyon-juniper woodland boundary and classified as pinyon-juniper areas where pinyon accounts for greater than 25% of the cover; this is typically identified by greater density of trees. In New Mexico, pinyon and pinyon-juniper woodlands are considered a high priority for further classification review (Grossman et al. 1998).

Results

Vegetation Map Units for Landscape-scale Models

Vegetation structure and composition drive the broad landscape-scale map units in the landscape-scale models. The majority of these vegetation units are at the Alliance Level according to the National Vegetation Classification (Grossman et al. 1998). For example, the Pinyon Pine Alliance is distributed throughout mountain ranges of New Mexico, southern Colorado, eastern Arizona, and Utah and includes plant associations where pinyon pine is the dominant but can be co-dominant with juniper, having a variety of sub-canopy shrubs and grasses. The Gray Vireo is a woodland, versus grassland, bird found infrequently in scrub and grasslands. Thus, we use more general categories of scrub and grassland where these types dominate. Our minimum mapping unit is 0.10 ha. The model includes most of the woodland patches found within these ranges; however, smaller, isolated patches were excluded, as well as some of the more dense woodlands.

Pinyon Pine Woodland

These woodlands are dominated by pinyon pine that co-occurs with juniper in nearly closed canopies. The cover of pinyon pine relative to juniper exceeds 50% in this unit. Within the Oscura Mountains, this woodland dominates North Oscura Peak (NOP) and continues along the crest of the mountain to the south. Within the San Andres, the height of the stands do not reach those of the Oscura Mountains but tend to be closed to open pinyon stands with a diverse understory of shrubs and grasses that include mountain mahogany, banana yucca, wavyleaf oak (*Quercus pauciloba*), and Scribner's needlegrass (*Achnatherum scribneri*). These woodlands are a minor component within the Gray Vireo landscape model and occur as scattered patches typically on north-facing slopes within the San Andres in sites such as Skillet Knob and the upper slopes of Shannon Canyon covering approximately 311.6 ha (.6%). Elevation ranges from 1862 to 2430 m.

Pinyon-Juniper Woodland

The definition of Pinyon-Juniper Woodland is debated, with some classifying a few scattered pinyon trees within a juniper-dominated landscape as pinyon-juniper (Esteban Muldavin pers. comm.). In contrast, we define this map unit as having between approximately 25% and 50% relative cover of pinyon. When relative cover was ≥50%, we assigned the unit to Pinyon Pine Woodland. Pinyon-Juniper Woodland covers 10,058 ha (17.9%) of the mapped area and occurs in a narrow band on east- to northeast-facing slopes at the lower-elevation margins of the Pinyon Pine Woodlands of NOP and on slopes within the less mesic, lower-elevation ranges of the San Andres Mountains. Larger concentrations of this map unit within the San Andres occur on north-facing slopes above Rosebud, White Rock, and Makinson Canyons and Grandaddy Peak. Elevation ranges are higher than juniper-dominated areas, ranging from 1677 to 2428 m. Species composition within the understory is similar to that of Juniper Woodland and Savanna.

Juniper Woodland and Savanna

Juniper Woodland and Savanna occurs within the Oscura and San Andres Mountains, as well as Chupadera Mesa in the northeast portion of the missile range. One-seed juniper (*Juniperus monosperma*) occurs with open to very open tree canopies having a diverse understory of shrubs and grasses (see Muldavin et al. 2000 for details). Colorado pinyon (*Pinus edulis*) can be scattered throughout this landscape but typically comprises less than 25% cover relative to juniper. This unit covers 25,682 ha (45.6%) of the mapped area and ranges from 1324 m to 2365 m. The largest extents of juniper-dominated landscapes occur within the Oscura Mountains and Chupadera Mesa and within the San Andres Mountains at Rhodes Pass and Rosebud Flat. It covers a broad range of topographic positions at mid-elevations, within drainages to broad valleys and small hills to steep slopes along canyon walls. Shrubs such as hairy mountain mahogany (*Cerocarpus breviflorus)*, banana yucca (*Yucca baccata*) or sacahuista (*Nolina microcarpa*) often occur in the inter-canopy spaces. Grama grasses (*Bouteloua* spp.), curlyleaf muhly (*Muhlenbergia setifolia*), New Mexico needlegrass (*Achnatherum perplexum*) or New Mexico muhly (*Muhlenbergia pauciflora*) are found throughout this unit and can be more abundant than shrubs.

Scrub

The Scrub mapping unit captures woody shrubs and small dispersed grasslands of the montane and chaparral shrublands. Shrubs include mountain mahogany, sacahuista, tree cholla (*Cylindropuntia imbricata*), *Yucca* spp., *Quercus* spp., and *Opuntia* spp. Scrub live oak (*Quercus turbinella*) in association with grama grasses are well represented. *Acacia* spp. and catclaw mimosa (*Mimosa aculeaticarpa* var. *biuncifera*) occur on the more xeric slopes, especially in the southern portion of the San Andres. Within the Oscura Mountains, Scrub delineates broad drainages dominated by fourwing saltbush (*Atriplex canescens*). This unit covers 18,556 ha (33%) of the landscape-scale model and has the broadest range of elevation from 1320 to 2435 m.

Arroyo Riparian

The Arroyo Riparian mapping unit is another broad category in terms of species composition. This unit consists of very narrow bands within canyon bottoms that are flanked by juniper or pinyon-juniper woodlands and/or scrub habitat. While juniper can be scattered throughout, especially within the upper elevation reaches, this unit is often dominated by Apache plume (*Fallugia paradoxa*), resinbush (*Viguiera stenoloba*), and desert willow (*Chilopsis linearis*, Hobert et al. 2009). In more xeric canyons, acacia, mimosa, and common sotol (*Dasylirion wheeleri*) move downslope into the drainage (Hobert et al. 2009). Although this unit covers only 1.8% (1008 ha) of the mapped area, Hobert et al. (2009) surveys within the San Andres detected Gray Vireo territories located only in or adjacent to arroyo riparian corridors. These low-elevation corridors fall within 1353 to 2136 m in elevation.

Grassland

The Grassland mapping unit indicates relatively large areas dominated by grassland but without the woody vegetation characteristic of the woodland and savanna units. These grasslands are typically dominated by grama grasses. Montane grasslands occur within openings of the woodlands but are typically not differentiated from the woodland for mapping at this scale. Within the Oscura Mountains, the grasslands typically occur at the base of low, dry hills where blue grama is associated with sub-shrubs such as winterfat (*Krascheninnikovia lanata*). Tobosagrass (*Pleuraphis mutica*) and alkali sacaton (*Sporobolus airoides*) may be locally dominant. This mapping unit covers approximately 650 ha, 1.2% of the mapped area and is found in mid-elevations ranging from 1749 to 2218 m.

Landscape-scale Habitat Model

The landscape-scale habitat model for Gray Vireos at WSMR covers a portion of juniper-dominated habitats on the missile range, approximately 56,266 ha in the Oscura and San Andres Mountains (Figure A1). It ranges from 1320 to 2436 m in elevation. The landscape map units for Gray Vireo habitat include Pinyon Woodland (<1%), Grassland (1.2%), Arroyo Riparian (1.8%), Scrub (33%), Juniper Woodland and Savanna 45.6%), and Pinyon-Juniper Woodland (17.9%), (Figure A1).

The areas with the highest apparent densities of Gray Vireo territories in 2009 and 2010 were: Cottonwood Canyon, Bear Den Canyon and Bosque Canyon. The lowest apparent density areas were

northern Green Valley and Rhodes Pass, with other areas having apparently high-to-moderate, moderate, or moderate-low vireo densities (Figure A2).

Areas of highest vireo density were not necessarily similar in vegetation composition (Figure A3, Table A1). Cottonwood Canyon was Scrub-dominated (50%), followed by Juniper Woodland and Savanna (30%), with 10% each of Pinyon-Juniper and Arroyo Riparian components. Bear Den Canyon, also an area of high vireo density, had 10% Scrub, 70% Juniper Woodland and Savanna, and 20% Pinyon-Juniper. The third high-density area, Bosque Canyon, was nearly evenly divided between Scrub (40%) and Juniper Woodland and Savanna (50%), with a 10% Pinyon-Juniper component (Figure A3, Table A1).
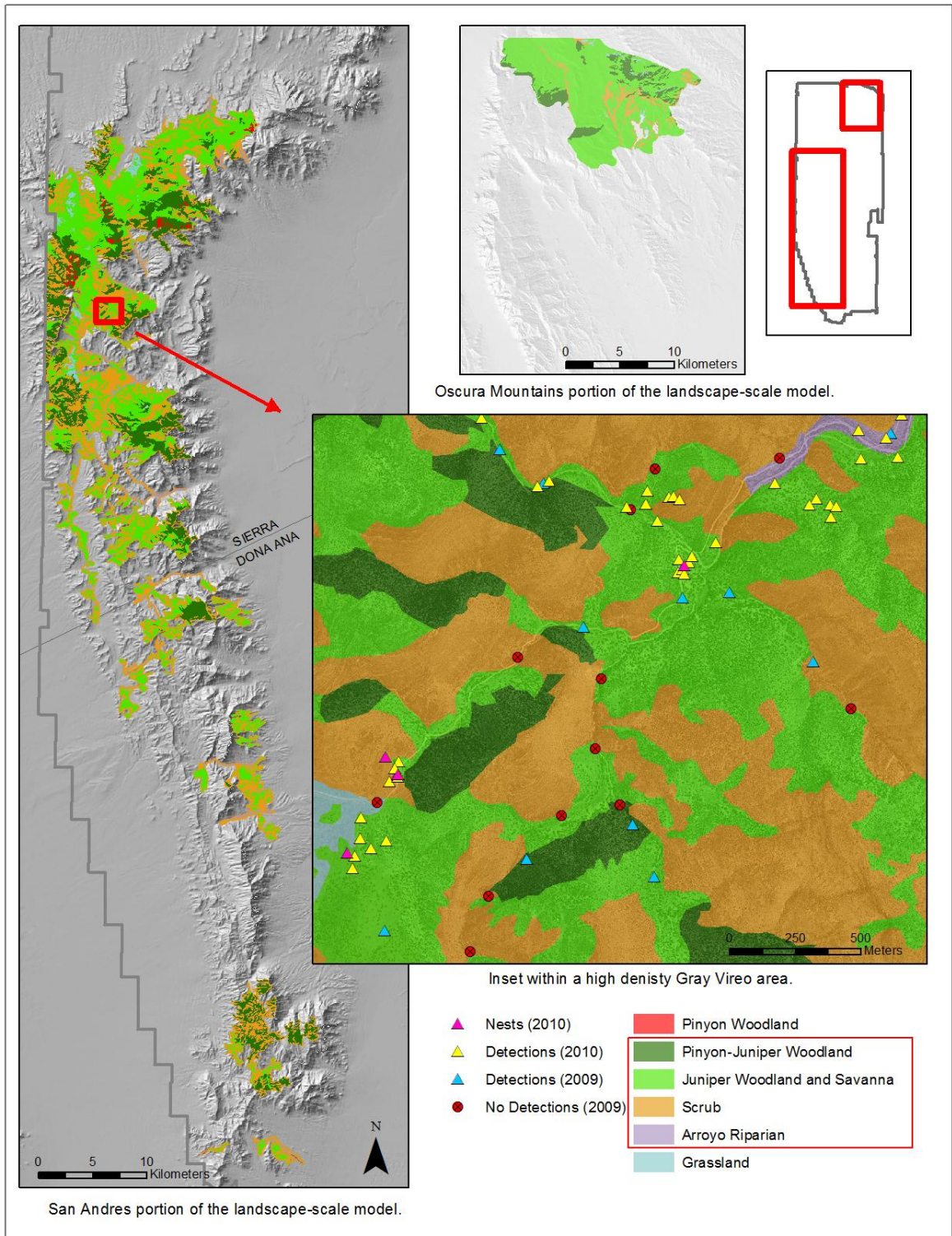
Oscura Mountains portion of the landscape-scale model.

Inset within a high denisty Gray Vireo area.

San Andres portion of the landscape-scale model.

SIERRA
DONA ANA

Symbol	Description
▲ (magenta)	Nests (2010)
▲ (yellow)	Detections (2010)
▲ (blue)	Detections (2009)
● (red)	No Detections (2009)

Color	Type
■ (red)	Pinyon Woodland
■ (dark green)	Pinyon-Juniper Woodland
■ (green)	Juniper Woodland and Savanna
■ (tan)	Scrub
■ (purple)	Arroyo Riparian
■ (light blue)	Grassland

Figure A1. Landscape-scale habitat model for Gray Vireos at WSMR.
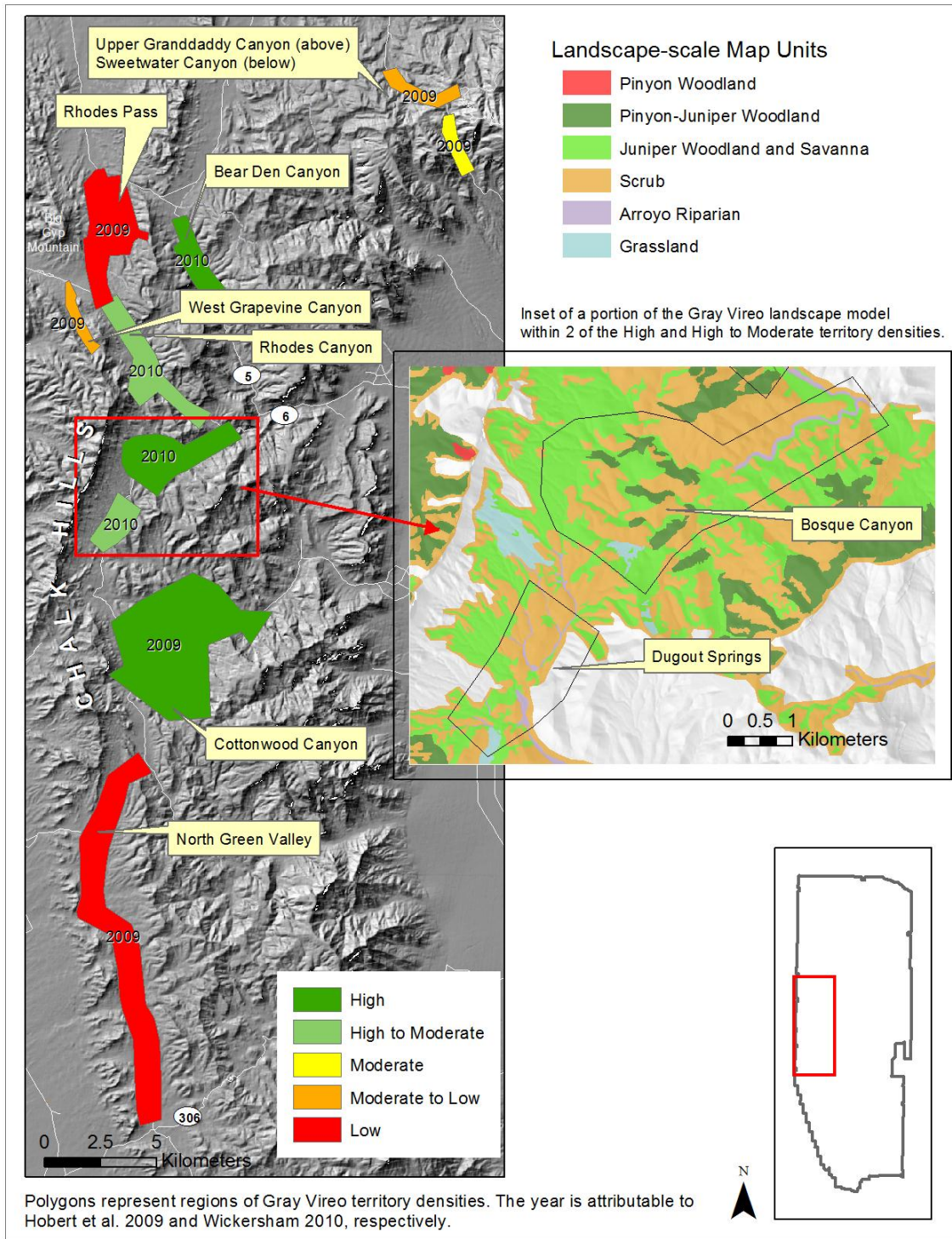
65

Figure A2. Areas of high to low Gray Vireo density at WSMR. Inset shows a portion of the landscape model in two areas of higher vireo density.

	2009						2010			
	Cottonwood Canyon	Sweetwater Canyon	Upper Grandaddy Canyon	West Grapevine Canyon	Rhodes Pass	Northern Green Valley	Bear Den Canyon	Bosque Canyon	Rhodes Canyon	Dugout Springs
Territory Density	*High (%)*	*Moderate (%)*	*Moderate-Low (%)*	*Moderate - Low (%)*	*Low (%)*	*Low(%)*	*High (%)*	*High (%)*	*High To Moderate (%)*	*High to-Moderate (%)*
Pinyon Woodland	0	0	0	0	0	0	0	0	0	0
Pinyon-Juniper Woodland	10	0	0	50	0	0	20	10	10	0
Juniper Woodland & Savanna	30	0	80	50	60	50	70	50	70	30
Scrub	50	70	20	0	30	50	10	40	20	60
Arroyo Riparian	10	30	0	0	0	0	0	0	0	10
Grassland	0	0	0	0	10	0	0	0	0	0

Table A1. Relative cover of vegetation types in areas with various densities of Gray Vireo detections 2009 (Hobert et al. 2009) and 2010 (this study).
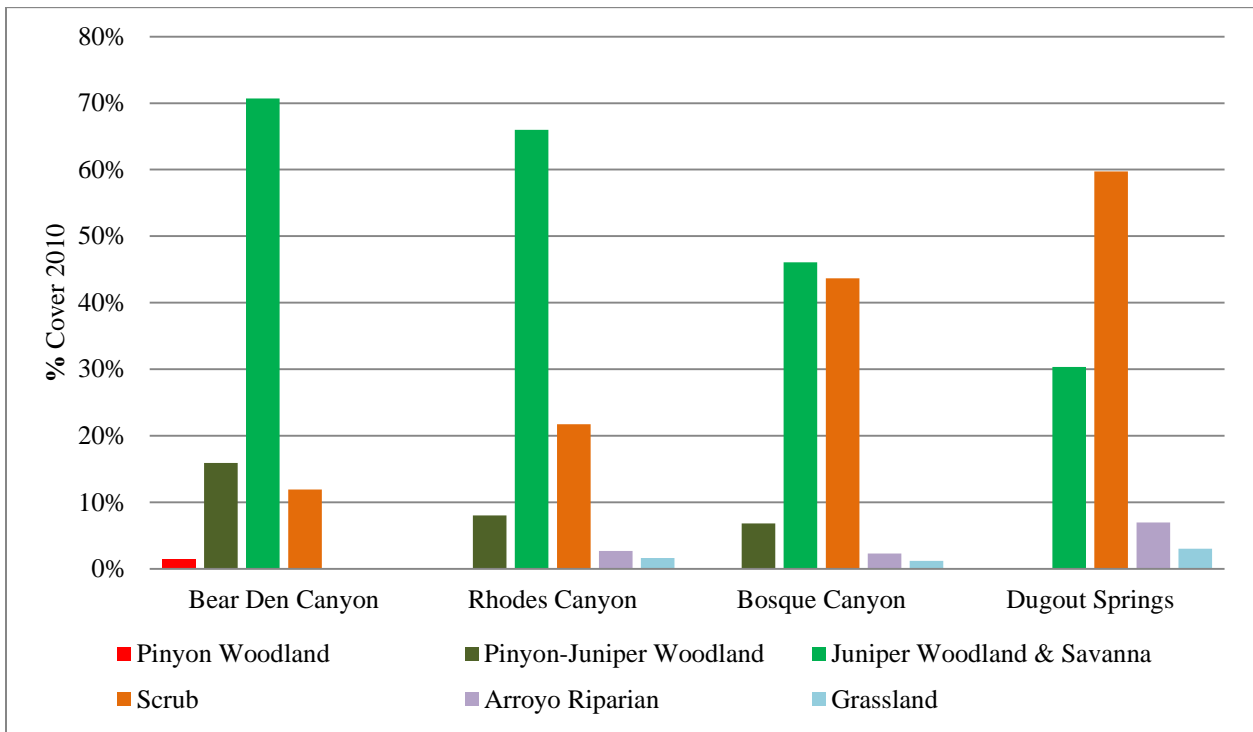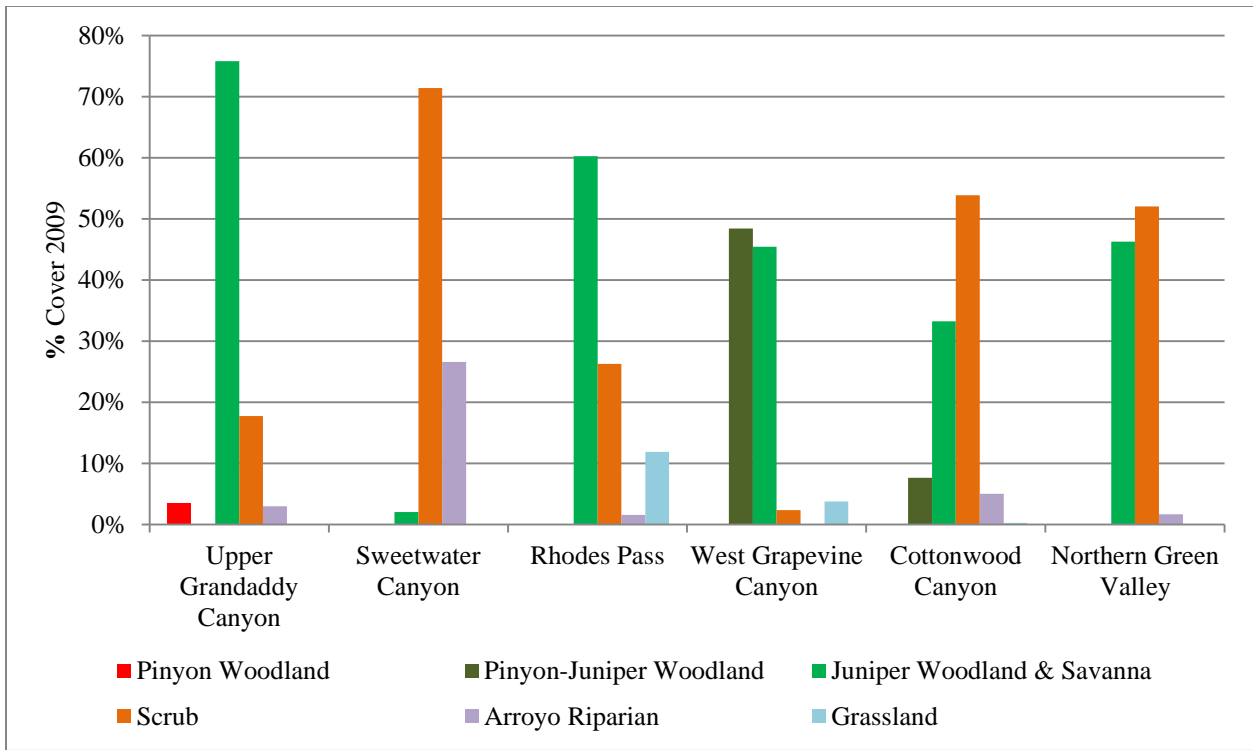
.

Figure A3. Relative proportions of vegetation types in areas occupied by Gray Vireos at WSMR, 2009 and 2010. See Table A1 for occupancy levels.

Dugout Springs and Rhodes Canyon, both with apparently high-to-moderate vireo densities, were almost exactly reversed in their composition of Scrub versus Juniper Woodland and Savanna (60%:30% versus 20%:70%, respectively). The two areas of apparently low vireo density varied widely. Northern Green Valley was half Juniper Woodland and Savanna and half Scrub. Rhodes Pass, in contrast, was Juniper Woodland and Savanna-dominated (60%) with a lesser Scrub component (30%) and 10% Grassland (Figure A3, Table A1).

Of the nests detected by Animas Biological Studies in 2010, 75.0% were in Juniper Woodland and Savanna, with the remaining nests equally distributed between Scrub, Pinyon-Juniper Woodland, and Arroyo Riparian. The majority of detections (83%) were also in Juniper Woodland and Savanna, with 6.7% in Pinyon-Juniper Woodland, 6% in Scrub, and 4% in Arroyo Riparian. In Hobert et al.'s (2009) study, 50.5% of detections were in Juniper Woodland and Savanna, followed by Arroyo Riparian (27.6%), Scrub (12.8%), and Pinyon-Juniper Woodland (8.7%).

Discussion

Perhaps the most striking feature of Gray Vireo landscape-scale habitat use at WSMR is the inclusion of Scrub habitats. Scrub comprised the largest or second-largest proportion of habitat in eight of the 10 Gray Vireo-occupied areas that we classified according to vireo density. Only in West Grapevine Canyon and Bear Den Canyon was Scrub not one of the two most abundant vegetation types (Figure A3, Table A1). Scrub habitats are not a major component of the landscape models at KAFB and CTTA and we therefore included them within other landscape-scale mapping units at those installations (Johnson et al. 2010).

When viewed in terms of relative abundance, Scrub habitats within areas used by Gray Vireos at WSMR appear to be relatively prevalent in the landscape model. Scrub comprises 33% of the landscape model, and 45.6% (2009 areas) and 33% (2010 areas) of the occupied polygons we classified according to vireo density. Juniper Woodland and Savanna comprises 45.6% of the landscape model and 42.5% (2009 areas) and 55% (2010 areas) of the polygons occupied by vireos. Hence, areas occupied by Gray Vireos at WSMR contained similar (2010) or proportionately more (2009) Scrub habitat than was available across the landscape. Vireos occupied Juniper Woodland and Savanna habitats proportionately more than their availability in the landscape in areas surveyed in 2010 but slightly less than their availability in areas surveyed in 2009.

However, Gray Vireos at WSMR placed their nests primarily in Juniper Woodland and Savanna, and most detections in this study and by Hobert et al. (2009) were in that habitat. Detections in this study could have been biased toward Juniper Woodland and Savanna by our focus on finding nests, which occurred mainly in that habitat. Only 8.3% of nests and 6% of detections in this study were in Scrub habitats, and 12.8% of detections in the Hobert et al. (2009) study were in Scrub habitat, considerably lower than Scrub availability across the landscape. Hence, although Scrub habitats were relatively abundant within areas occupied by Gray Vireos, the birds tended to nest and spend time proportionately

more often in Juniper Woodland and Savanna, while nesting and spending proportionately less time in Scrub habitats.

We conclude that WSMR vireo habitat includes a more diverse assortment of vegetation types than that at CTTA or KAFB, probably owing largely to the lower availability of juniper-dominated habitat and its interspersion with Scrub, Arroyo Riparian, and Pinyon-Juniper. When viewed at the landscape scale, Gray Vireos at WSMR appear to occupy habitats containing Scrub and Juniper Woodland and Savanna vegetation similarly relative to their availability, but when viewed at the nest scale, Juniper Woodland and Savanna vegetation is strongly preferred. Management of Gray Vireo habitat at WSMR should include areas delineated in the landscape model, particularly those areas dominated by a mix of Scrub and Juniper Woodland and Savanna habitats. Pinyon-Juniper Woodland and Arroyo Riparian habitats can and should also be included, comprising up to ~20% and ~10%, respectively, of areas managed for vireos, based on high- and high-to-moderate-density vireo occupancy at WSMR.

Literature Cited

Aldon, E.F., D.W. Shaw, tech. coords. 1993. Managing piñon-juniper ecosystems for sustainability and social needs; proceedings of the symposium 1993 April 26-30; Santa Fe, New Mexico. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 169 pp.

Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools.

Delong, J.P. and S.O. Williams. 2006. Status report and biological review of the gray vireo in New Mexico. Unpubl. report to New Mexico Department of Game and Fish, Santa Fe, NM. 50 pp.

Grossman, D.H., D. Faber-Langendoen, A.W. Weakley, M. Anderson, P. Bourgeron, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, and L. Sneddon. 1998. International Classification of Ecological Communities: Terrestrial Vegetation Of The United States. Volume I: The National Vegetation Classification Standard. The Nature Conservancy, Arlington, VA. 92 pp.

Hobert, J., M. Hartsough, and D. Burkett. 2009. Draft gray vireo status and distribution on White Sands Missile Range. White Sands Technical Services, LLC. WSMR, NM.

Johnson, K., L. Wickersham, T. Neville, J. Wickersham, J. Smith, M. Baumann, and C. Finley. 2010. Habitat use at multiple scales by Pinyon-Juniper Birds on Department of Defense Lands: landscape scale. Natural Heritage New Mexico Publ. No. 10-GTR-360. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 51 pp.

Muldavin, E., Y. Chauvin, and G. Harper. 2000a. The vegetation of White Sands Missile Range, New Mexico Volume I: handbook of vegetation communities. Natural Heritage New Mexico Publ.

No. 00-GTR-299. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 236 pp.

Muldavin, E., G. Harper, P. Neville, and Y. Chauvin. 2000b. The vegetation of White Sands Missile Range, New Mexico Volume II: vegetation map. Natural Heritage New Mexico Publ. No. 00-GTR-299. Natural Heritage New Mexico, University of New Mexico, Albuquerque, NM. 100 pp.

National Agriculture Imagery Program (NAIP). 2009. USDA-FSA natural color digital aerial imagery acquired for New Mexico.