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

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

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

## Final Project Report



Kristine Johnson, Lynn Wickersham, Jacqueline Smith, Giancarlo Sadoti,  
Teri Neville, John Wickersham, and Carol Finley  
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## ABSTRACT

As part of a four-year study, we investigated pinyon-juniper habitat use by Gray Vireos (*Vireo vicinior*) and Pinyon Jays (*Gymnorhinus cyanocephalus*) at multiple scales. The Year 1 report focused on landscape-scale habitat use. The Year 2 report included results for the nest (both species) and territory (Gray Vireo)/colony (Pinyon Jay) scales. This final report incorporates all Year 1 and Year 2 results. Also incorporated are new 2012 nest- and territory-scale data for Gray Vireos at White Sands Missile Range (WSMR) and nest-scale data for Pinyon Jays at Kirtland Air Force Base (KAFB) and WSMR. KAFB landscape-scale models were also revised for this final report.

At Camel Tracks Training Area (CTTA), Gray 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. At WSMR, territories were closer to roads than non-territories and were more likely to occur at intermediate elevations and on less-steep south-facing slopes having more concave curvature and lower annual solar radiation. Gray Vireos at CTTA showed weak selection for nest sites farther from buildings. No other infrastructure measure at any installation was significantly associated with vireo nest placement. Parameter estimates indicated that, across CTTA, KAFB, and WSMR, Gray Vireos selected nest sites on more southward-facing aspects, with a slightly more negative (bowl-shaped) curvature, and having both more and taller trees relative to unused random plots within each territory.

At WSMR in 2010, Pinyon Jays abandoned a traditional colony site and moved to a nearby location, then moved to a third location in 2012. Vigor declined from an average index value of 3.81 in 2005 to 3.09 in 2010, most commonly exemplified by the loss or browning of nearly half of a tree's needles. The overwhelmingly supported model of vigor decline indicated the index of vigor declined 0.12 units per year. Mean vigor was overall higher among trees in colonized areas than in abandoned areas in both years the colony moved.

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, the re-modeling effort identified seven potential predictive territory polygons. Field validation of the KAFB colony-scale model revealed 18 of 20 (90%) validation nests falling within a predicted colony polygon. 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 homogeneous at WSMR, or modeling at KAFB could have been strongly influenced by the unique characteristics of the two colonies used to create the model. Of 12 validation nests, 8 (67%) fell within the WSMR colony-scale predictive model.

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.

We recommend that 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 are maintained at densities similar to those on our nest plots. We recommend that KAFB and CTTA continue to restrict training activities in the Gray Vireo nesting areas from May to July. Based on weak 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.

Management of pinyon-juniper habitat for Pinyon Jay nesting should include maintaining tree 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. Lower-elevation Juniper Woodland and Savanna habitat is also necessary for wintering Pinyon Jays. We recommend that no new roads or infrastructure be constructed any closer to traditional Pinyon Jay colonies than what currently exist. Ground training activities should not be conducted within 2 km of traditional Pinyon Jay colony sites between March and July. In most years, ground training should not be conducted within 2 km 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 2 km 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 US 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, insect pests, and drought also play critical roles in the establishment and demise of these woodlands (Romme et al. 2009). Pinyon Jays (*Gymnorhinus cyanocephalus*) 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 evident in recent years, with the drought-induced expansion of pinyon bark beetle (*Ips confusus*) impacts across the western United States. From 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<sup>2</sup> (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).

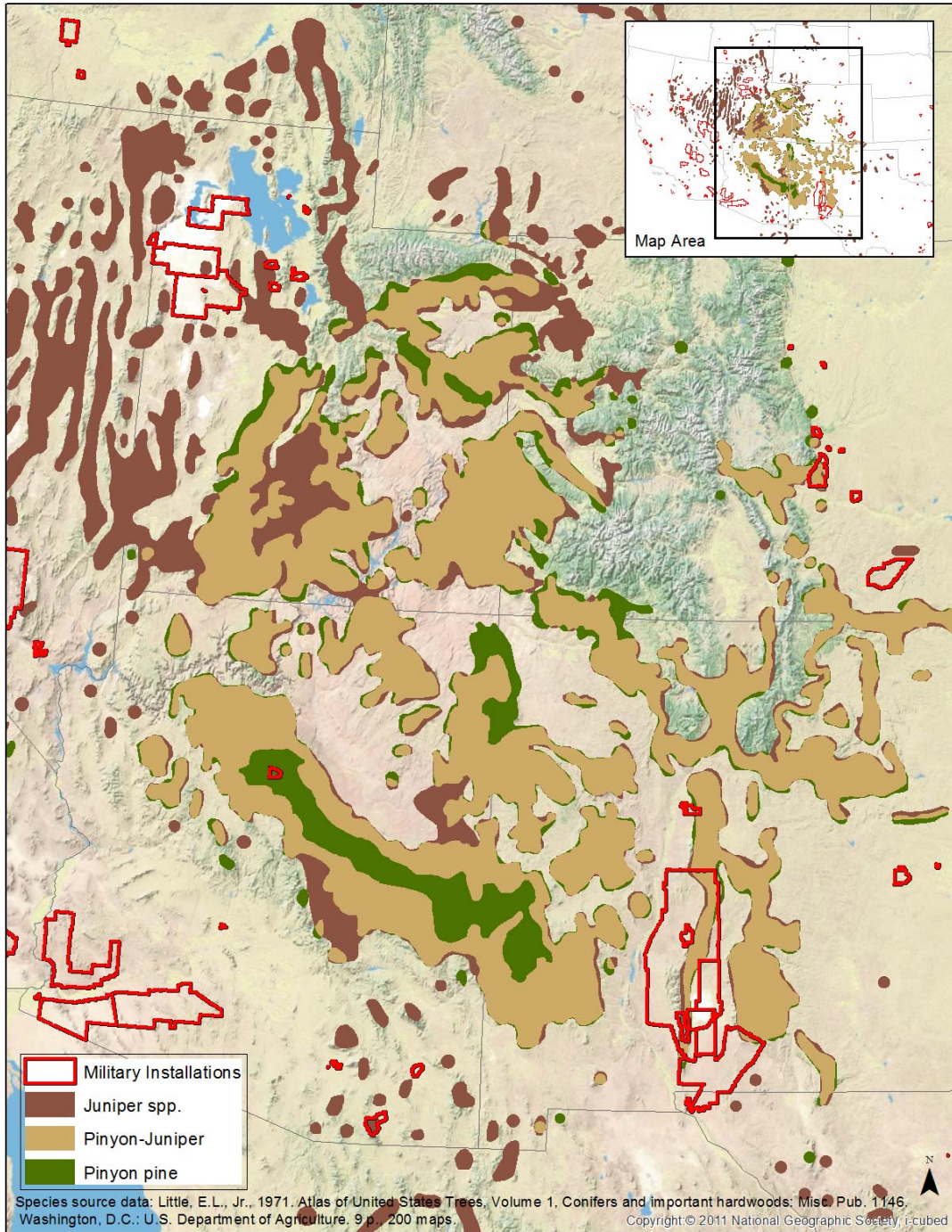


Figure 1. Military installations in SW US, showing distribution of pinyon-juniper habitats.



The insecure status of several native pinyon-juniper wildlife species provides further evidence that these habitats are threatened. The Gray Vireo (*Vireo vicinior*) 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 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 (*Setophaga 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).

The Pinyon Jay is resident, omnivorous, and highly social, flocking in winter and nesting colonially and cooperatively. In contrast, 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. Despite the differences in their natural histories, both are species of concern. The insecure status of Gray Vireos and Pinyon Jays, in addition to the other pinyon-juniper species that are at risk, suggest 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 2012). 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 1977, 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 prefer 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 turn, 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, historically numbering 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. 2011).

### **The Project**

The abundance 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 investigated pinyon-juniper habitat use by Pinyon Jays and Gray Vireos, both DoD SAR. We collected data on habitat use at multiple scales (landscape, territory/colony, and nest) at three installations: White Sands Missile Range (WSMR), Kirtland Air Force Base (KAFB), and Camel Tracks Training Area (CTTA) (Figure 3) between 2009 and 2012. We did not receive Legacy funding in 2011 but did conduct limited field work using matching funds. 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, provides a broad perspective on the management of pinyon-juniper woodlands for wildlife. This is the final report for the project, in which we present the final landscape, territory/colony, and nest models for both species.

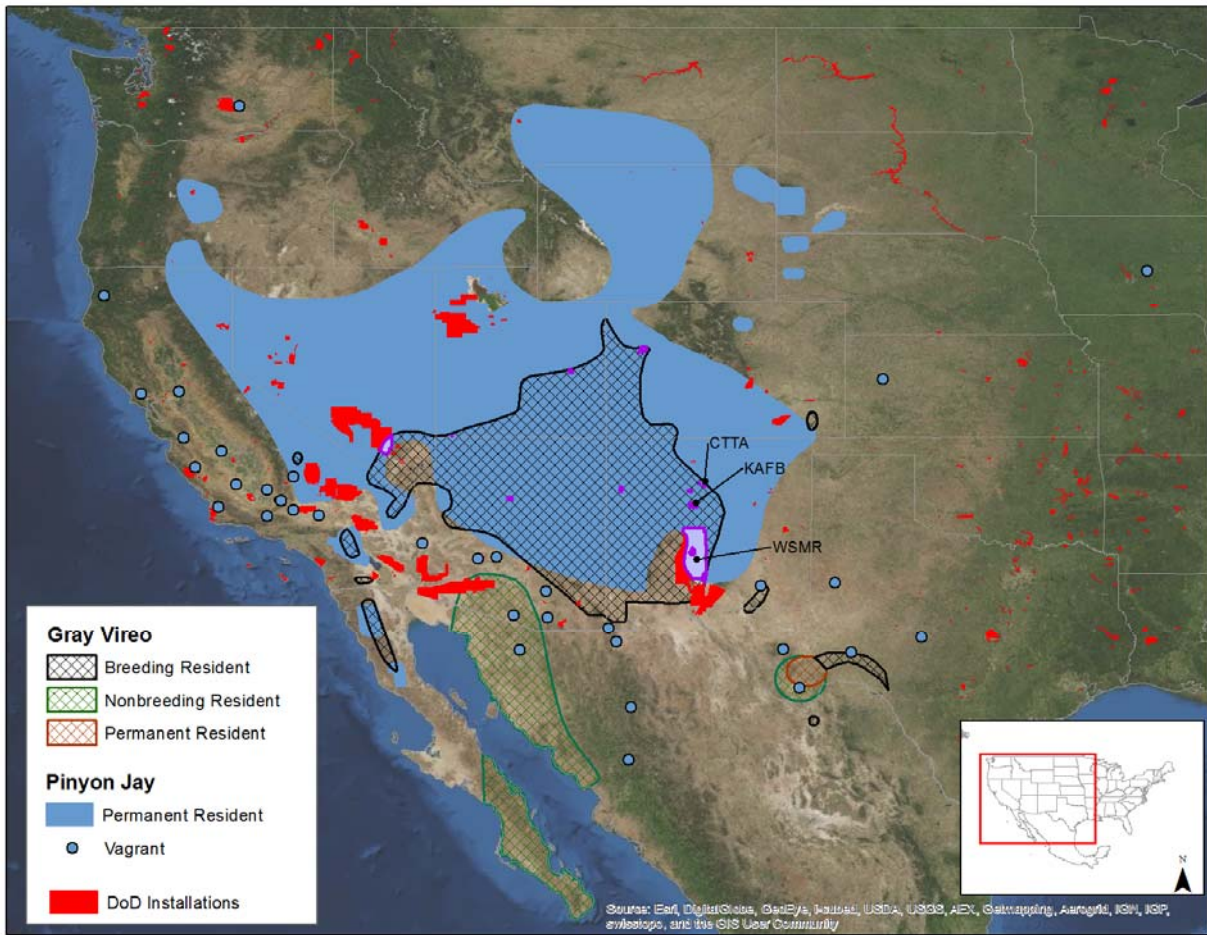
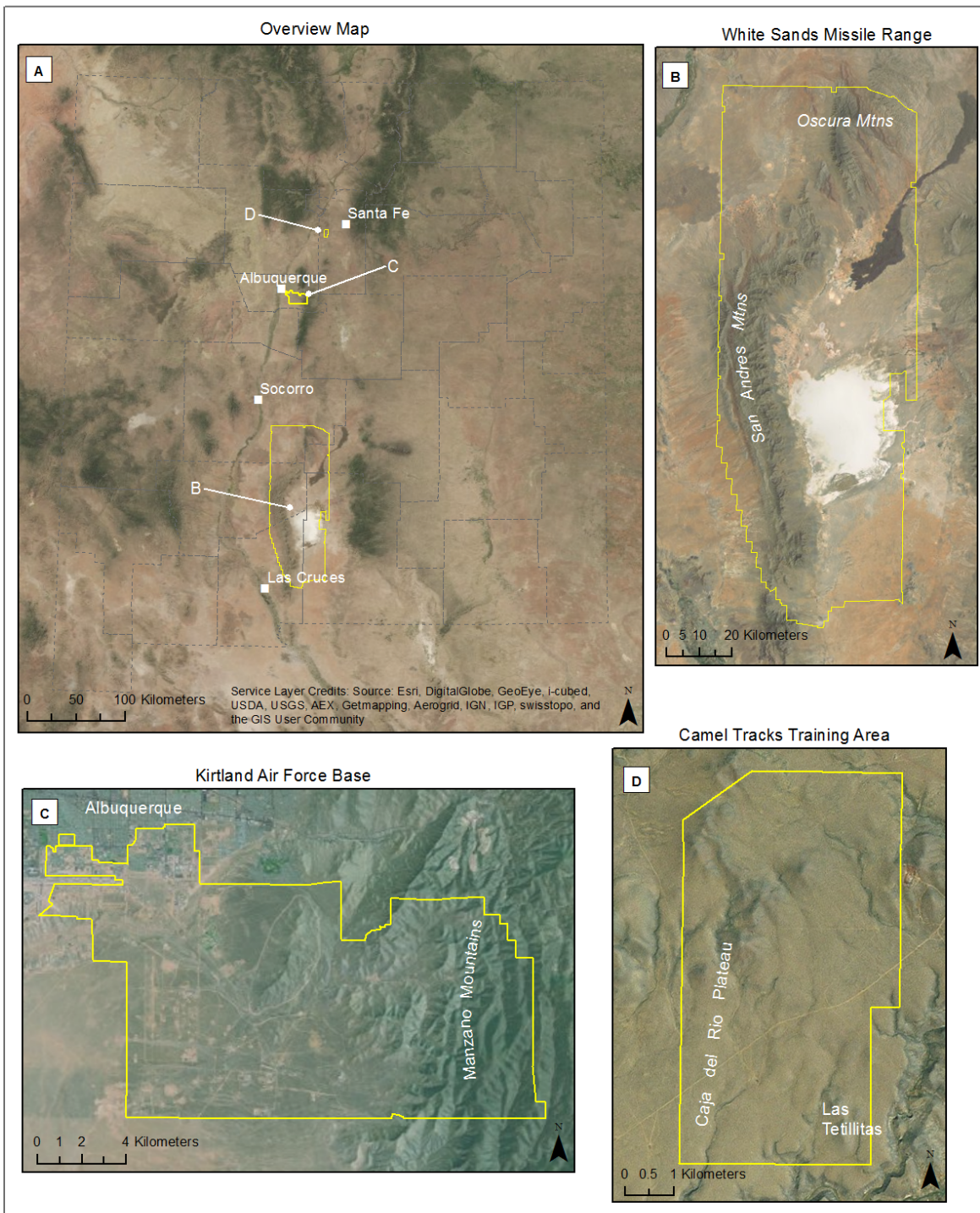


Figure 2. Gray Vireo and Pinyon Jay distributions, showing DoD installations.



**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 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. The only roads within CTTA are primitive, two-track roads; vehicle traffic is minimal during the Gray Vireo breeding season due to a seasonal closure to military training activities. There are no permanent buildings or other military infrastructure within the CTTA study area. 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  $\leq 5\%$  pinyon pine. Understory vegetation is dominated by native grasses, tree cholla (*Cylindropuntia imbricata*), yucca (*Yucca* spp.) and prickly pear cactus (*Opuntia phaeacantha*). 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  $-7.5^{\circ}\text{C}$  in January to relatively mild summer highs averaging  $30^{\circ}\text{C}$  (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  $6.2^{\circ}\text{C}$  -  $2^{\circ}\text{C}$  (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 range of vireo habitat is approximately 1742-2119 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 disjunct 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. The western extent of Chupadera Mesa lies within the northeast portion of the range. 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 Landscape-Scale**

We conducted field work for Gray Vireo landscape-scale habitat use at KAFB and CTTA in 2009 and 2010. We added WSMR as a study site in 2010 because a base-wide survey conducted

in 2009 identified approximately 196 Gray Vireo territories (Hobert et al. 2009). The landscape-scale models for Gray Vireos at CTTA and KAFB were completed in 2010, the WSMR landscape model was completed in 2011, and the KAFB model was revised and finalized in 2012.

Each year, we initiated Gray Vireo occupancy surveys in May, generally following the playback method developed by DeLong and Williams (2006). We focused our survey efforts within traditional Gray Vireo territories identified at each installation in prior years (Arbetan and Muldavin 2006, Arbetan 2009, Wickersham and Wickersham 2009, Hobert et al. 2009). We conducted surveys between sunrise and noon when birds are most vocal. We walked transects through traditional territories, stopping and using playback surveys about every 200–300 m. Each stop began with an approximately 1 min listening period. If no vireos were 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° 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 completed one set of occupancy surveys at each study site by the end of May of each year.

After initial occupancy surveys in 2009 and 2010, we conducted targeted mist netting and color banding at KAFB and CTTA (Figure 4) to assist in identifying individual Gray Vireos and delineating territories (Detailed methods in Johnson et al. 2011). In 2010 and 2012 at WSMR, we marked the locations of adult vireos in the field using Garmin GPS units whenever possible and mapped them in ArcGIS but we did not capture birds.



In June and July of each year, we revisited all occupied Gray Vireo territories and gathered GPS locations for inclusion in the landscape-scale GIS habitat model. We marked the locations of adult vireos in the field whenever possible and mapped them in ArcGIS. We created estimated territory boundaries based on the point locations and our field observations. These estimated territory boundaries were revised as we acquired additional location data. After fieldwork was complete, we created Minimum Convex Polygons (MCP) in ArcGIS for each Gray Vireo territory for which we recorded at least three GPS locations.

**Figure 4. Banded Gray Vireo.**

We calculated the area of each MCP using ArcGIS. MCPs were used as a reference for the GIS habitat model and to create baseline data on Gray Vireo territory size and movements. Nest searching, monitoring, and associated vegetation sampling were conducted at KAFB and CTTA in 2009 and 2010 and at WSMR in 2010 and 2012.

### **Gray Vireo and Pinyon Jay Landscape Scale**

*CTTA.* An unpublished CTTA vegetation map (P. Arbetan, unpublished data) was available to use as a guide to identify landscapes dominated by juniper woodland and savanna. 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 map, we used the aerial photography to delineate a separate set of map units to encompass the area occupied by Gray Vireos in this and previous studies (DeBruin 1995, 1996; Arbetan et al. 2002; Arbetan and Muldavin 2003, 2004a, 2004b, 2006; Chauvin and Arbetan 2005; Arbetan 2007). Color, texture, and size of landscape elements were used to delineate the map units. When Gray Vireo observations and nest locations were added to the GIS overlay, it became evident that geology and vegetative cover together play an important role at CTTA. We therefore incorporated surface geology and landform into the CTTA landscape-level model.

*KAFB.* Because a vegetation map did not exist for the entire study area at KAFB, we created our own vegetation layers for the landscape-scale habitat modeling. The Mid-Region Council of Governments provided six-inch-resolution, natural color ortho-imagery of Bernalillo County. The imagery, flown in March and April 2008, covered all pinyon-juniper habitats of interest at KAFB. Using GIS, we delineated polygons that contained similar habitat types in juniper woodland and savanna, pinyon-juniper woodland, and pinyon pine woodland, surrounding areas with Gray Vireo territories and Pinyon Jay colonies. We then visited a subset of these polygons and collected the following data at each polygon: date, GPS coordinates, aspect of the described slope, percent cover class of the nine dominant species, canopy cover, and relative cover of pinyon and juniper. We used these data to drive the delineation of map units for a classification of landscape-scale vegetation in Pinyon Jay home ranges and Gray Vireo territories. At a scale range of 1:3,000-6,000, we applied aerial photo interpretive techniques of visual landscape elements including color, texture, and size, with overlays of elevation contours and field data descriptions to refine the previously mapped areas. We delineated all landscapes where the birds were observed, using data collected under this contract, as well as previously collected datasets (Black 1994, Mehlhop and DeBruin 1995, Frei 2007). In 2012, we revised the map units for greater spatial detail and specificity of plant associations.

*WSMR.* 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. 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 see Methods for CTTA and KAFB, above) and focused our survey efforts in areas where Gray Vireos had been detected during the 2009 survey (Hobert et al. 2009).

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 map (Muldavin et al. 2000 a, b), 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 the Hobert et al. (2009) density rankings.

Exact boundaries along the continuum of juniper savanna to pinyon-juniper woodland landscape are difficult to delineate. Dick-Peddie (in Aldon and Shaw 1993) defined woodlands as having trees whose canopies do not overlap. He distinguished juniper savanna as scattered stands with densities less than 130 trees/acre. 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, typically identified by a greater density of trees. In New Mexico, pinyon-juniper woodlands are considered a high priority for further classification review (Grossman et al. 1998).

To model landscape-level habitat use by Pinyon Jays at WSMR, we used the existing vegetation map and associated plot data (Muldavin et al. 2000a, b), in combination with the same aerial photography used for CTTA (NAIP 2009) and existing vegetation and Pinyon Jay occurrence datasets (Johnson and Smith 2006, Johnson and Smith 2007, Johnson et al. 2011).

### **Gray Vireo Territory Scale**

Because the three sites were quite different in topography and vegetation, we modeled the probability of territory selection separately for each study site, within suitable habitat. We included 2009 and 2010 territory data for CTTA and KAFB, and 2010 and 2012 data for WSMR. We started field work at WSMR a year later than at the other sites, and we did not receive funding in 2011. Available habitat was juniper woodland and savanna (Johnson et al. 2011) and comprised 797 ha on CTTA, 3552 ha on KAFB, and 17,187 ha at WSMR.

*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. 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, and 3) vegetation indices derived from Landsat 5 Thematic Mapper satellite data collected during winter, summer, and fall of 2005. 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-m cell represents elevation above sea level in meters. From the DEMs derived various measures, 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 areas to solar radiation values measured at a collection site central to all study areas. 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 all three study sites.

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 vegetation 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:

$$\text{Eq1: NDVI}=(\text{NIR}-\text{VIR})/(\text{NIR}+\text{VIR}).$$

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 ( $Q_{\text{cal}}$ ) representing brightness values between 0 and 255 to radiance values ( $L_{\mu}$ ), while accounting for the variations in gains ( $G_{\text{rescale}}$ ) and biases ( $B_{\text{rescale}}$ ) of individual sensors due to sensor degradation:

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

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 ( $\Theta$ ), and band-width variations in solar irradiance ( $ESUN_{\mu}$ ). Outputs from the model are surface reflectance values ( $\rho$ ):

$$\text{Eq. 3: } \rho=L_{\mu} * \pi * d^2 / ESUN_{\mu} * \cos \Theta.$$

We developed a “deciduous greenness” index by subtracting the January NDVI, when vegetation was senescent, from the October NDVI (approximating 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.

*Territories.* We used estimated territories derived from 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. Territory delineation at CTTA and KAFB was based on 95% minimum convex polygons (average re-sightings=6.7, SE=0.5) augmented by observations of unidentified birds (e.g., birds heard but not seen).

We augmented the KAFB dataset using nest locations from P. Arbetan and R. Frei held in the Natural Heritage New Mexico NMBiotics database (Natural Heritage New Mexico 2014; 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.

At WSMR, all 42 territories were based on detections of unbanded birds. Where possible, we assigned each bird to a distinct territory based on its behavior, movements, and the presence/absence of adjacent vireos; however, we omitted detections which we were unable to attribute to a territory with confidence. Because we had fewer detections per territorial bird at WSMR, we were not confident that 95% polygons would accurately represent territories. Instead, we found the mean center of all observations in a specific estimated territory and buffered this center by 115 m, the radius of the largest minimum convex polygon (41,526 m<sup>2</sup>, 4.15 ha) formed by observations in a territory at WSMR.

A sample of unused, available areas (“non-territories”) was necessary for modeling the probability of territory selection. We centered 11.8-ha, circular non-territories (194 m radius, 388 m diameter) within Juniper Woodland and Savanna habitat at CTTA and within Juniper Woodland and Savanna habitat in a core area on KAFB surveyed for Gray Vireos in 2009 and 2010. All non-territories were centered a minimum of 388 m apart and at least 194 m from boundaries of territories used in 2009 and 2010, and from estimated (circular) boundaries of territories used between 2000 and 2008 (Figure 5).

At WSMR, non-territories had the same radius as territories (115 m). We placed 84 non-territories in areas surveyed for GRVI in 2009 (Hobert et al. 2009) as well as during our study in 2010 and 2012 (Figure 6). Non-territories were placed randomly, meeting the following requirements: center points were within 375 m of a previous negative or positive observation (to assure they were within suitable habitat), center points were no closer than 230 m from a positive observation, all were completely within our modeled landscape area, and non-territories contained 21% or more Juniper Woodland and Savanna. We adopted the last requirement because all except two of the 42 territories at WSMR contained 21% or more Juniper Woodland and Savanna.

Territories and non-territories did not overlap, which reduced "contamination" (Keating and Cherry 2004) when comparing used vs. available habitat. 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 at CTTA and KAFB and in 2009 at WSMR. Additional data from Rob Frei (Kirtland AFB 2005, 2006) revealed very few detections in the areas we defined as unused.

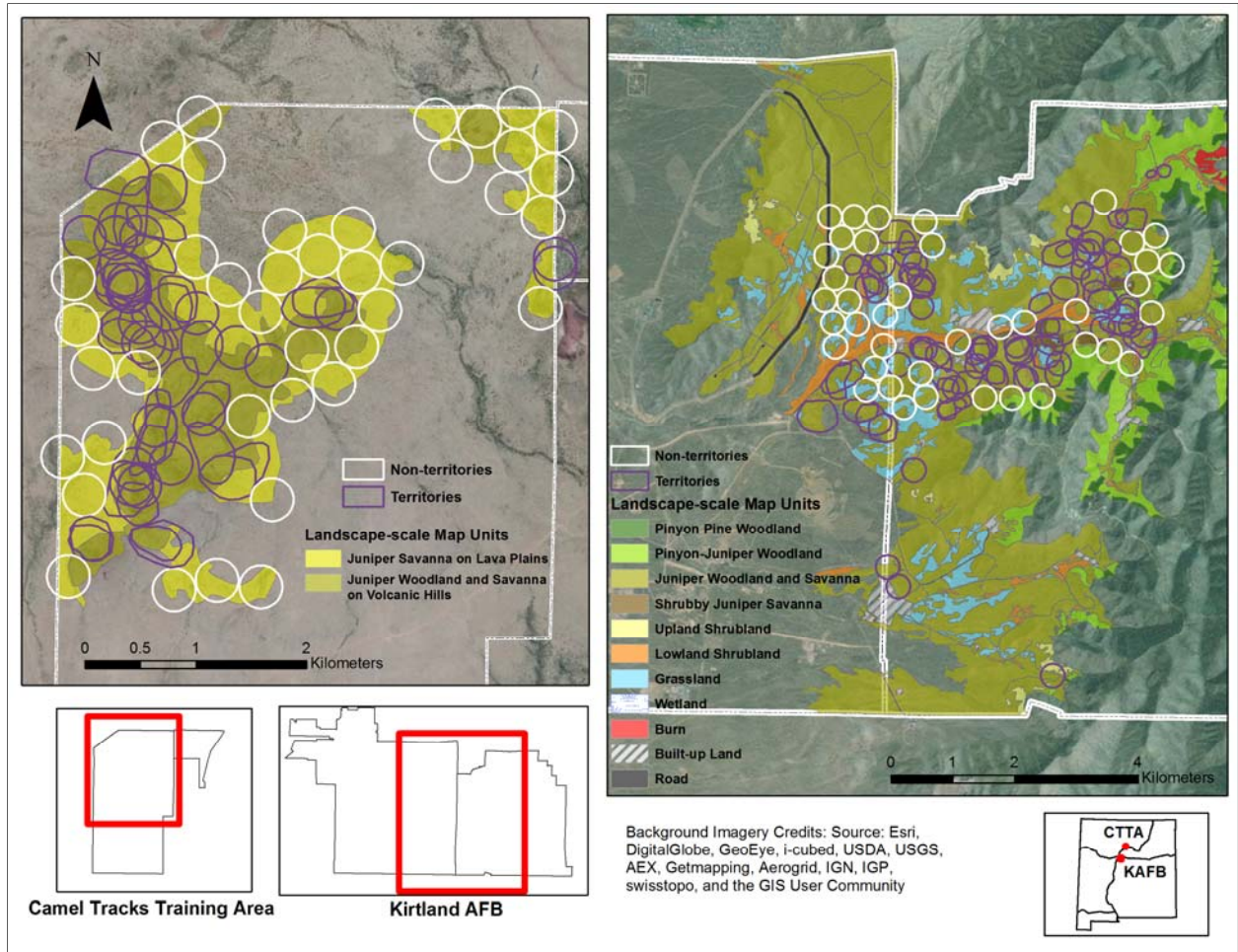


Figure 5. Gray Vireo territories and non-territories, CTTA and KAFB.



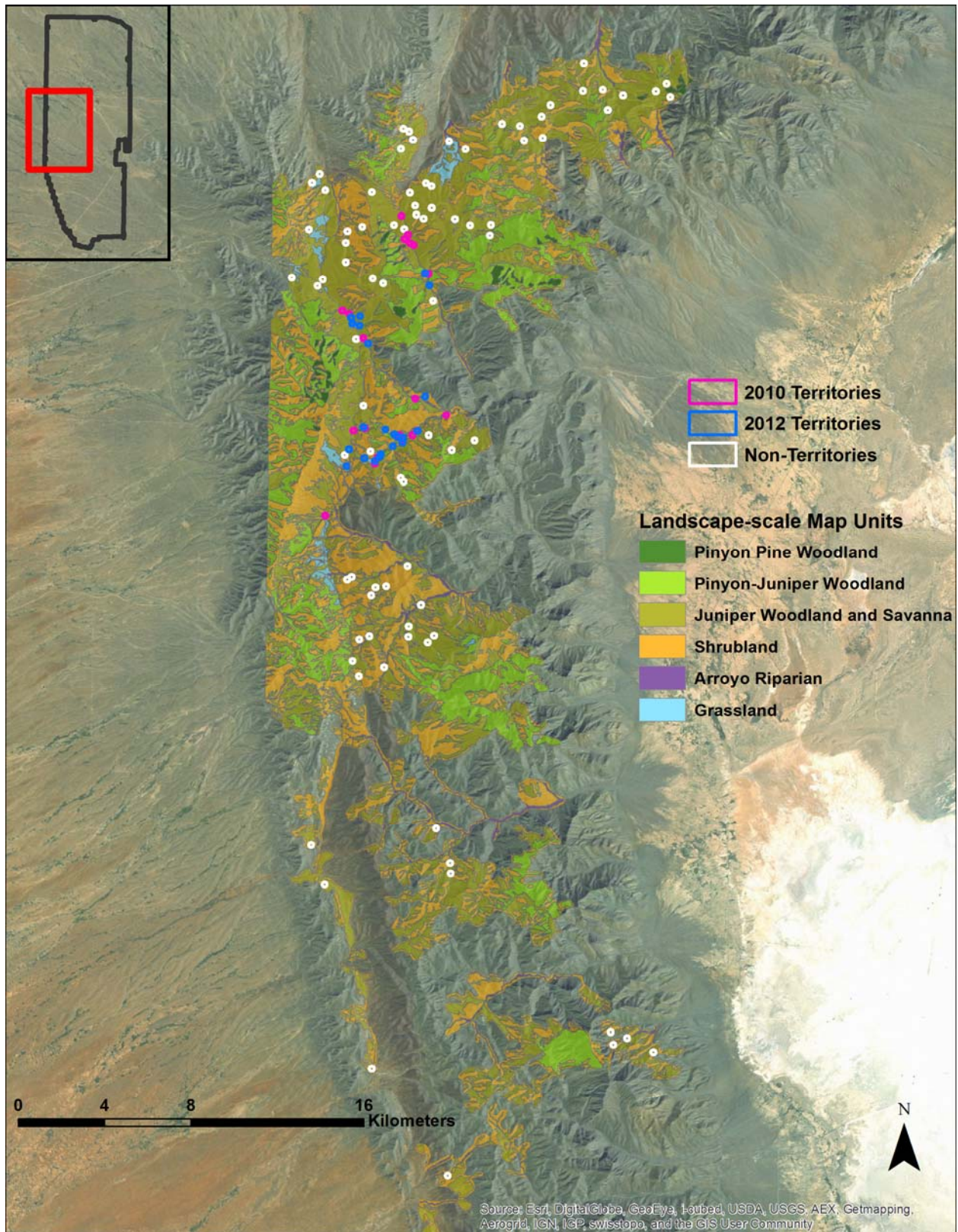


Figure 6. Gray Vireo territories and non-territories, WSMR.

*Territory Models.* We gathered GIS data from 10-m raster maps for each variable. We used a moving window that averaged values from an area of a specified size around each 10-m pixel, then assigned the averaged value to each pixel. The size of the moving window was the territory radius: 194 m for CTTA and KAFB and 115 m for WSMR. 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 sample-size adjusted Akaike Information Criterion value (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 at each site, we predicted the probability that each 10-m area of was the center of a territory. We then mapped all areas with >50% probability. We clipped this modeled area to the landscape model for all sites, and we clipped the model at WSMR again to exclude areas of Pinyon Pine Woodland. Because the territory size at WSMR (4.15 ha), and thus the radius of the moving window (115 m) was much smaller than for the other two sites (11.8 ha and 194 m), the resulting WSMR model was quite fragmented. To address this fragmentation, we buffered the model area for WSMR by the 115 m territory radius but did not buffer the validation points. For CTTA and KAFB, we buffered the validation points but not the model.

*Model Validation.* We validated territory models using independent datasets of Gray Vireo observations at KAFB (data from Rob Frei; Kirtland AFB 2005, 2006) and WSMR (Hobert et al. 2009, Natural Heritage New Mexico 2014). Independent data were not available for CTTA. For KAFB, 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 a territory radius (194 m) of a 10-m (territory center) pixel with a predicted probability  $\geq 0.5$ . Because we had previously buffered the pixels for WSMR, we determined the proportion of un-buffered validation points falling inside the predictive territory model.

### **Gray Vireo Within-territory Nest-scale Analyses**

*Field measurements.* We collected nest-scale data following a modified BBIRD protocol (Martin et al. 1997). We collected nest and random plot data at KAFB and CTTA in 2009 and 2010 and WSMR in 2010 and 2012. At the nest, we recorded nest tree species, 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 approximately 100 m from the nest tree at a random bearing within the estimated boundaries of each territory. 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 to 11 m. We also measured mean foliage width of central random plot 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 plot. In this way, vegetation and other conditions varying 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 Core Team 2013). 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 territory, we randomly selected one nest and paired random plot from each vireo pair 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 multicollinearity by ensuring no variable pairs with  $|r| > 0.6$  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 AIC value was reached.

Using variables from both the best stepwise topographic and vegetation models, we built a final candidate set of 17 models representing *a priori* hypotheses (military infrastructure models were considered separately). We considered any model with a  $AIC_C < 2$  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: RESULTS**

### **Landscape-scale Models CTTA**

#### **Banding**

We captured and banded five male Gray Vireos in 2009. In 2010, however, none of the color banded males from the previous year was observed in the study area. We therefore assumed that they did not survive during migration or over winter. In 2010, we captured and banded one new male Gray Vireo (See Johnson et al. 2011, Appendix A1, for details).

We identified 11 occupied Gray Vireo territories at CTTA in 2009 and 14 territories in 2010 (Figure 7). In 2010, we may have had as many as 17 territories, but we lacked sufficient data to delineate more than 14 with certainty. Territory size based on the MCP analysis ranged from  $<0.1$ –12.4 ha, with a mean of 2.8 ha ( $n=24$ , Appendix A2).

## Territories

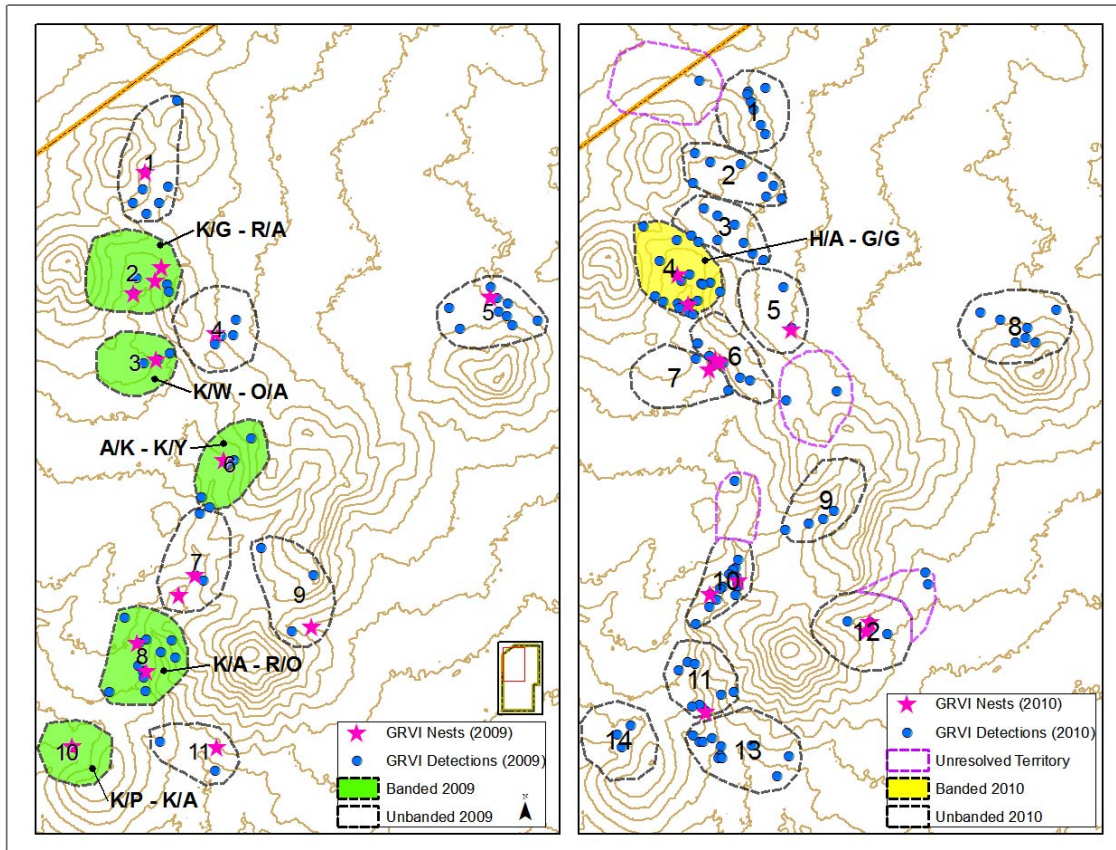
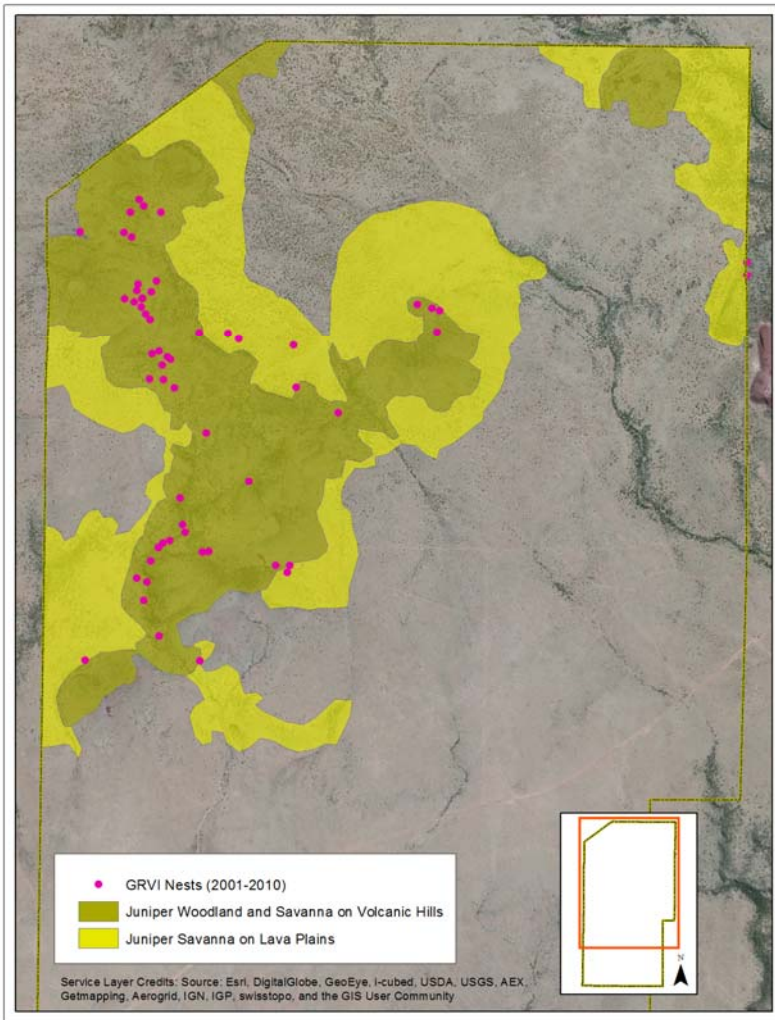


Figure 7. Gray Vireo territories at CTTA, 2009-2010. Letters indicate color band combinations. Dashed lines indicate approximate territory boundaries.

The GIS landscape model for CTTA covers approximately 797 ha of potential habitat ranging in elevation from approximately 1935- 2110 m. Two general vegetation types occur within this model, juniper upland and juniper lowland. The juniper upland vegetative type occurs at slightly higher elevation (mean=2027 m) than the lowland counterpart (mean=2001 m) and is characterized as Juniper Woodland and Savanna on Volcanic Hills (Figure 8, Appendix). The juniper lowland is classified as Juniper Savanna on Lava Plains. Over 75% of Gray Vireo detections ( $n=129$ ) and nests ( $n=20$ ) occurred within the juniper upland vegetation type, with only 35 detections and 5 nests located within juniper lowlands. Most of the territories at CTTA occurred at elevations higher than 2000 m, with the highest individual vireo detection at approximately 2070 m.

## Landscape Model



**Figure 8. Landscape-scale habitat model for Gray Vireos at CTTA. The indicated nests were used in construction of the landscape model; a subset of these was used for nest-scale modeling.**

### **Distance to Military Infrastructure and Activities**

Although the CTTA study area is used as training grounds for the New Mexico Army National Guard, no military infrastructure and no major roads occur within it. The study area is dissected by numerous unimproved, two-track roads that receive little vehicle traffic except for military training activities. The entire area is closed to military training from 15 May through 15 July annually, to protect the state threatened Gray Vireo during its peak breeding period. Therefore, the proximity of breeding habitat to military activities may not be as biologically relevant at CTTA as at KAFB and WSMR. Historically, only a few observations of Gray Vireos have occurred within the Training Area Management Units (TAMUs) on CTTA (Arbetan and Muldavin 2006).

## **Landscape-scale Models KAFB**

### **Banding**

Gray Vireo color banding has been conducted at KAFB since 2008. In 2009, seven of nine (78%) color-banded males from the previous year returned to the study area (Appendix A3), and all seven returned to the same territories they defended in 2008. By the end of the 2009 breeding season, 17 males, six females, and two birds of unknown sex were color banded in the study area (See Johnson et al. 2011, Appendix A3, for details).

In 2010, 10 (59%) color banded males and two (33%) females from the previous year returned to the study area, along with one color banded male and one female banded in 2008 but not seen in 2009. By the end of the 2010 breeding season, there were 15 males, five females, and two birds of unknown sex color banded in the study area (See Johnson et al. 2011, Appendix A3, for details).

### **Territories**

We identified 27 occupied Gray Vireo territories in 2009 and 30 in 2010 (Figure 9). Two of the territories identified in 2010 were located between approximately 550 and 750 m north of the study area boundary in Madera Canyon. Thus, the number of territories within the original study area at KAFB increased only by one from 2009 to 2010. MCP territory size ranged from <0.1–12.4 ha, with a mean of 3.2 ha ( $n=52$ ; Johnson et al. 2011, Appendix A4).

Of 82 territories monitored at CTTA and KAFB from 2009-2010, at least one bird of each annual pairing was banded in 42 territories. Twenty-two 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 few of these territories were adjacent to other territories of unbanded individuals without nests.

The GIS landscape-scale habitat model for Gray Vireo at KAFB covers approximately 4786 ha ranging in elevation from approximately 1742 to 2119 m (Figure 10). Gray Vireo habitat is primarily the Juniper Woodland and Savannah vegetation type, with only the western margins of Pinyon-Juniper Woodland occasionally used by the Gray Vireo. The Juniper Woodland and Savannah type in this model comprises approximately 3175 ha and ranges in elevation from 1742 to 2119 m. An additional 378 ha of Juniper Woodland and Savanna were mapped but not considered suitable habitat within the Gray Vireo habitat model (Appendix). In this study, 90% of Gray Vireo detections and 95% of Gray Vireo nests have occurred within the Juniper Woodland and Savannah vegetation type. Vireo territories at KAFB occurred in Juniper Woodland and Savannah habitat, on toe slopes or rolling terrain ranging in elevation from approximately 1800–1950 m. A few territories in the southwestern portion of the study area were located in this habitat between 1750 and 1800 m, and several in the south central and



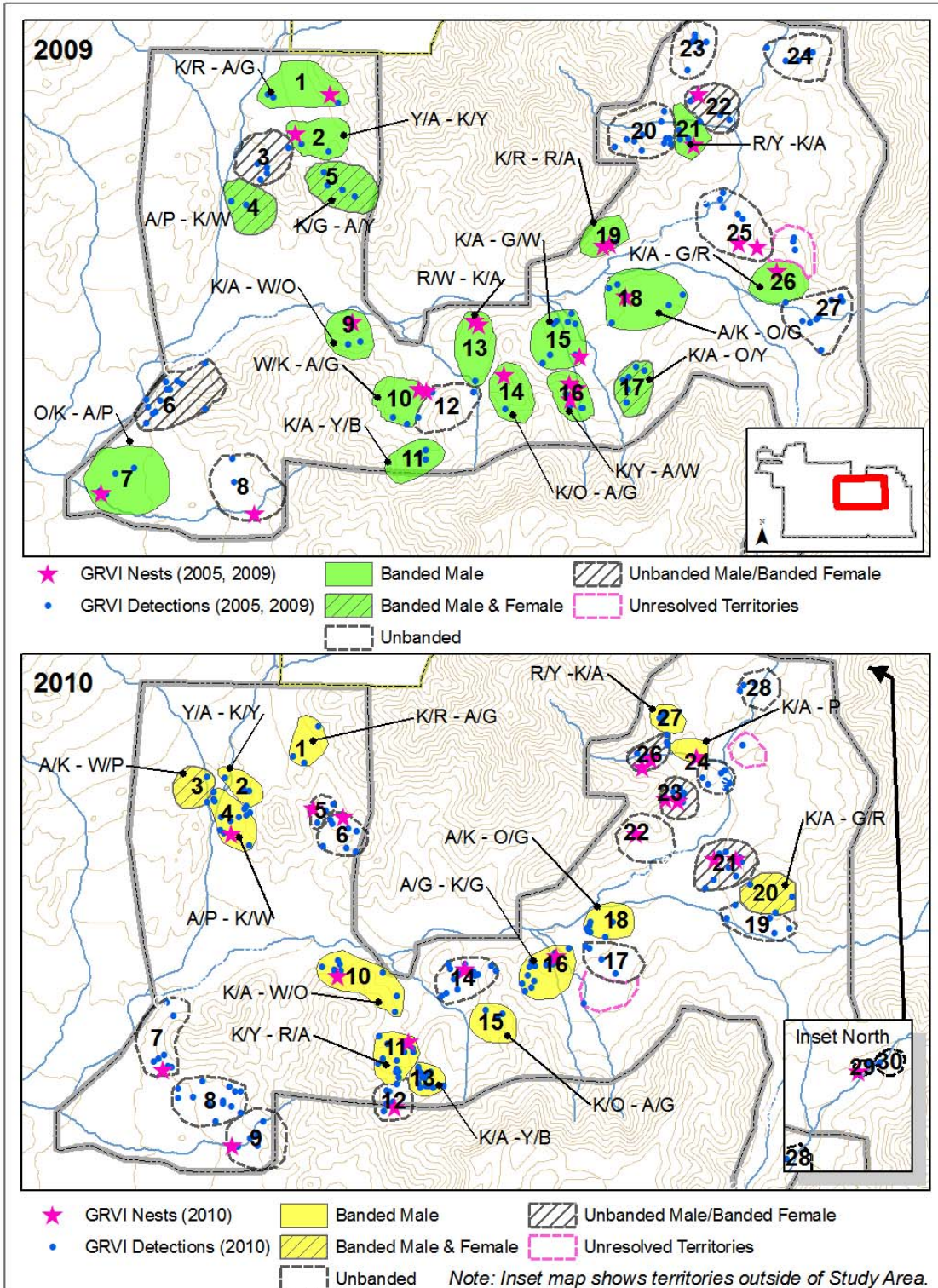


Figure 9. Gray Vireo territories, KAFB, 2009-2010. Dashed lines indicate approximate territory boundaries.



## Landscape Model

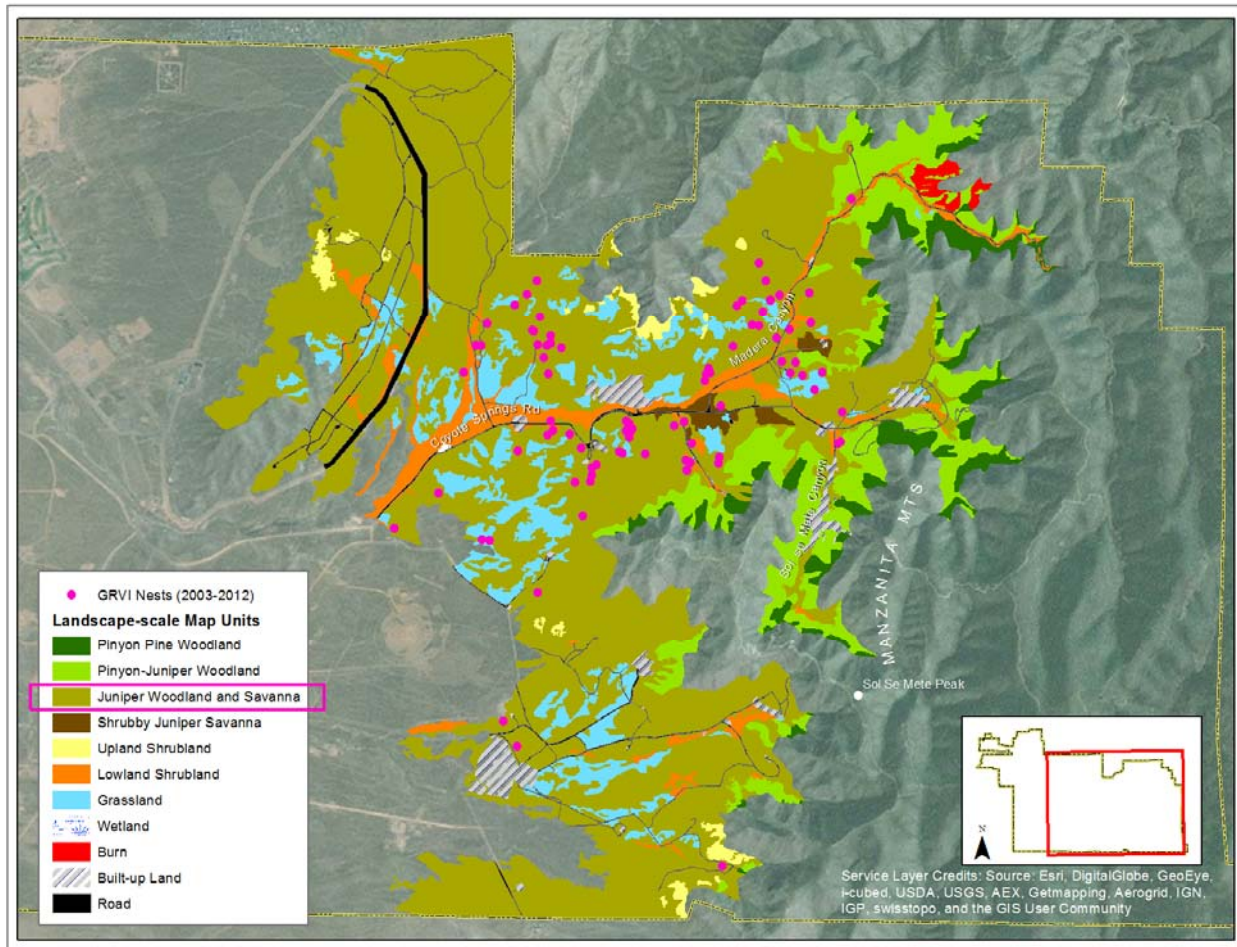


Figure 10. Landscape-scale habitat model for Gray Vireos at KAFB.

northeastern portion of the study area included areas higher than 2000 m, with the highest vireo detection at approximately 2030 m.

## Landscape-scale Models WSMR

### Territories

At WSMR, we found 38 potential territories at WSMR in 2010 and 24 in 2012 but some were based on only one or two detections. We eliminated territories based on fewer than three detections, or when three detections did not delineate a unique polygon. This left 20 acceptable territories from 2010 and 22 from 2012 for use in modeling.

### Landscape Model

The landscape-scale habitat model for Gray Vireos at WSMR covers a portion of juniper-dominated habitats on the missile range, approximately 57,873 ha in the Oscura and San Andres Mountains (Figure 11, Appendix). It ranges from 1320 to 2436 m in elevation. The landscape

habitat map units for Gray Vireo habitat include Juniper Woodland and Savanna (77% and 36% of the mapped area within the Oscura and San Andres Mountains, respectively). Arroyo Riparian occurs within the San Andres and covers approximately 2.3% of the mapped area. Both Shrubland and Pinyon-Juniper Woodland are occasionally used by the Gray Vireo at the margins of its primary habitat, and combined these units cover 20% and 60% for the Oscura and San Andres Mountains, respectively.

The areas with the highest apparent densities of Gray Vireo territories in 2009 (Hobert et al. 2009), 2010, and 2012 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 12). Shrubland comprises 41% of the landscape model, and 54% (2009 areas) and 31% (2010 and 2012 areas) of the occupied polygons we classified as having high vireo density. Juniper Woodland and Savanna comprises 35% of the landscape model and 33% (2009 high density areas) and 55% (2010 and 2012 high density areas) of the polygons occupied by vireos.

Areas of highest vireo density were not necessarily similar in vegetation composition (Figure 13, Table 1). Cottonwood Canyon was Shrubland-dominated (55%), followed by Juniper Woodland and Savanna (33%), with 7% of Pinyon-Juniper and 5% Arroyo Riparian components. Bear Den Canyon, also an area of high vireo density, had 16% Shrubland, 68% Juniper Woodland and Savanna, and 14% Pinyon-Juniper, with minor components of Pinyon Pine Woodland, Arroyo Riparian, and Road. The third high-density area, Bosque Canyon, was nearly evenly divided between Shrubland (46%) and Juniper Woodland and Savanna (43%), with a 6% Pinyon-Juniper component, followed by Arroyo Riparian, Grassland and Road (2.3%, 1.2%, 0.8%, respectively) (Figure 13, Table 1).

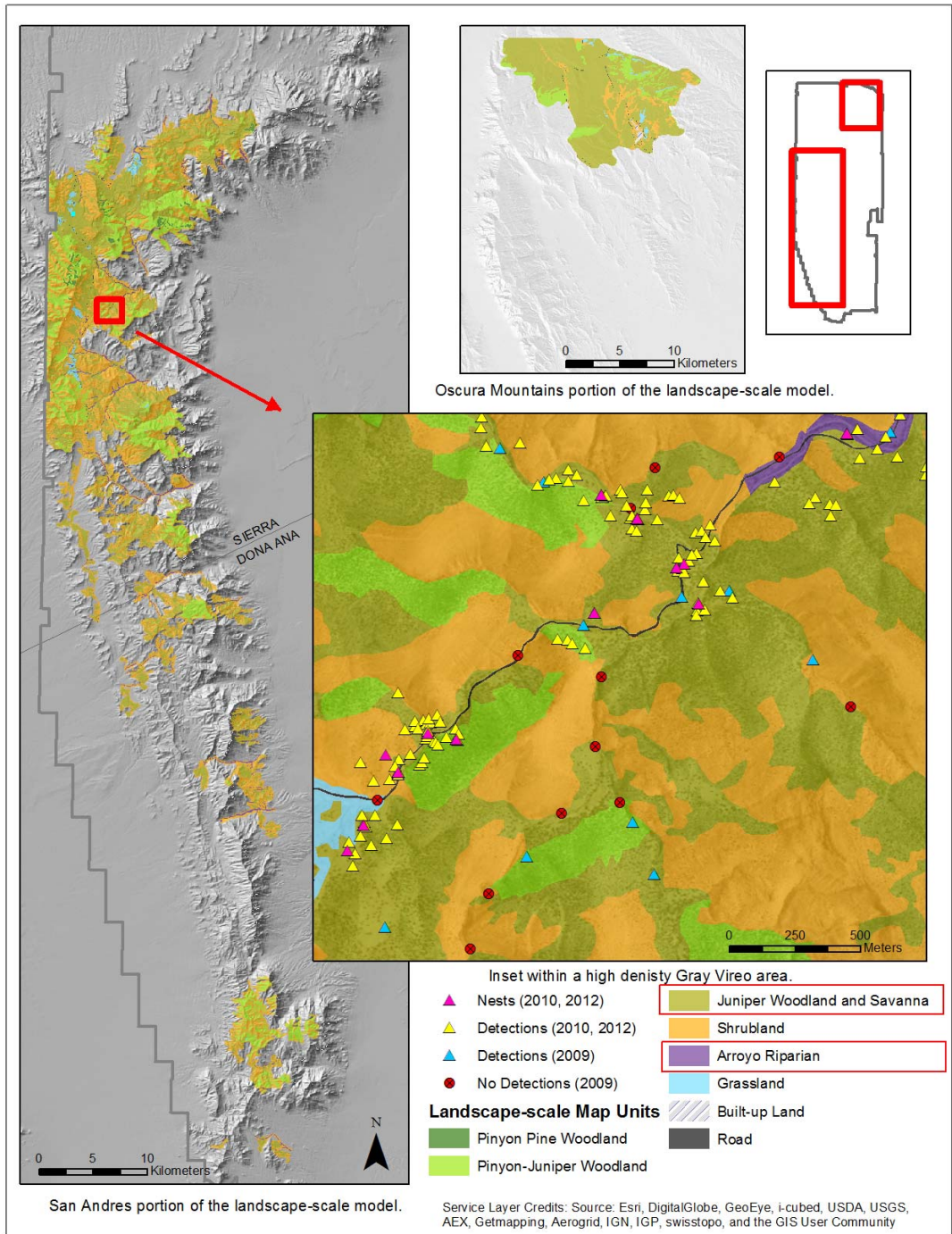
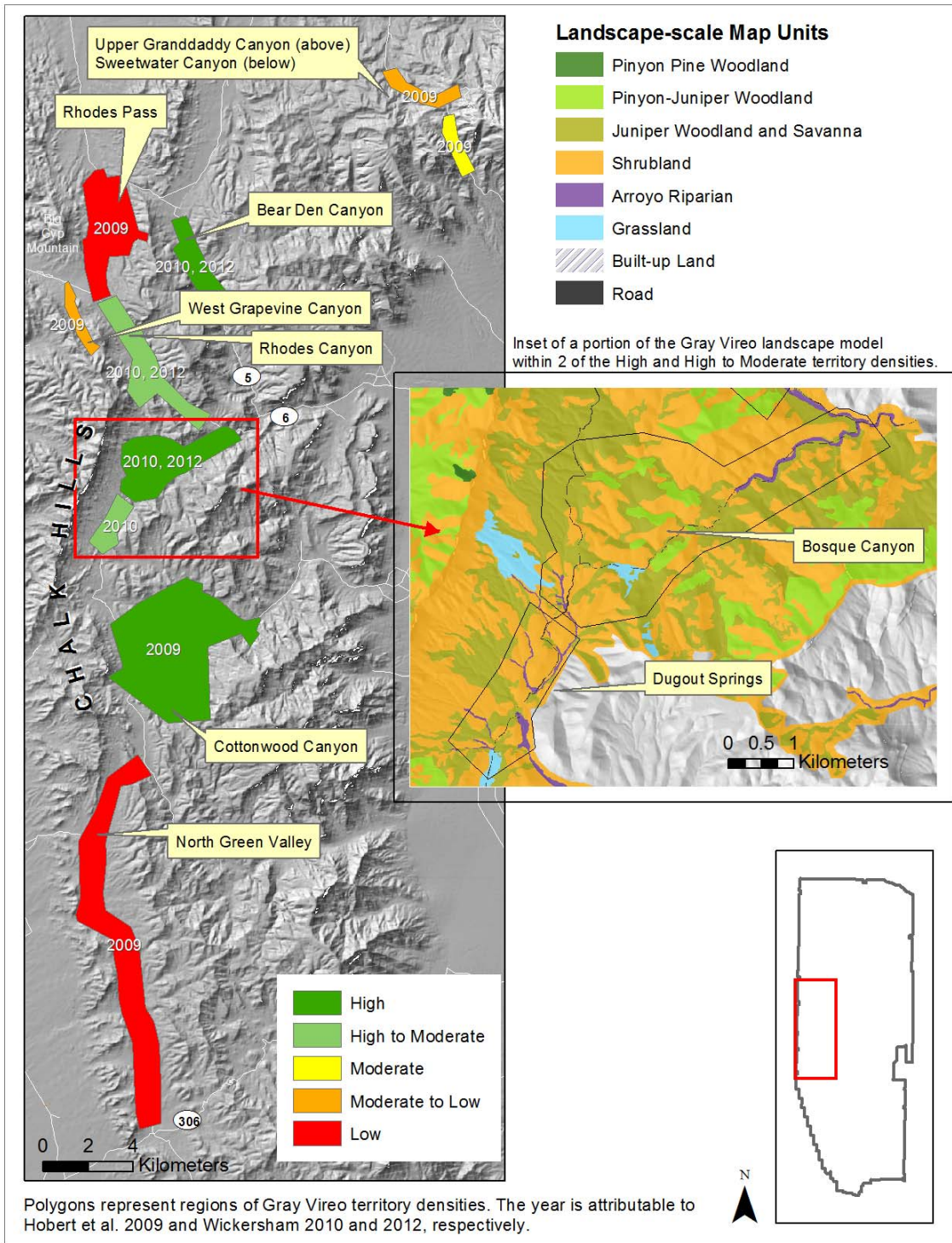


Figure 11. Landscape-scale habitat model for Gray Vireos at WSMR.

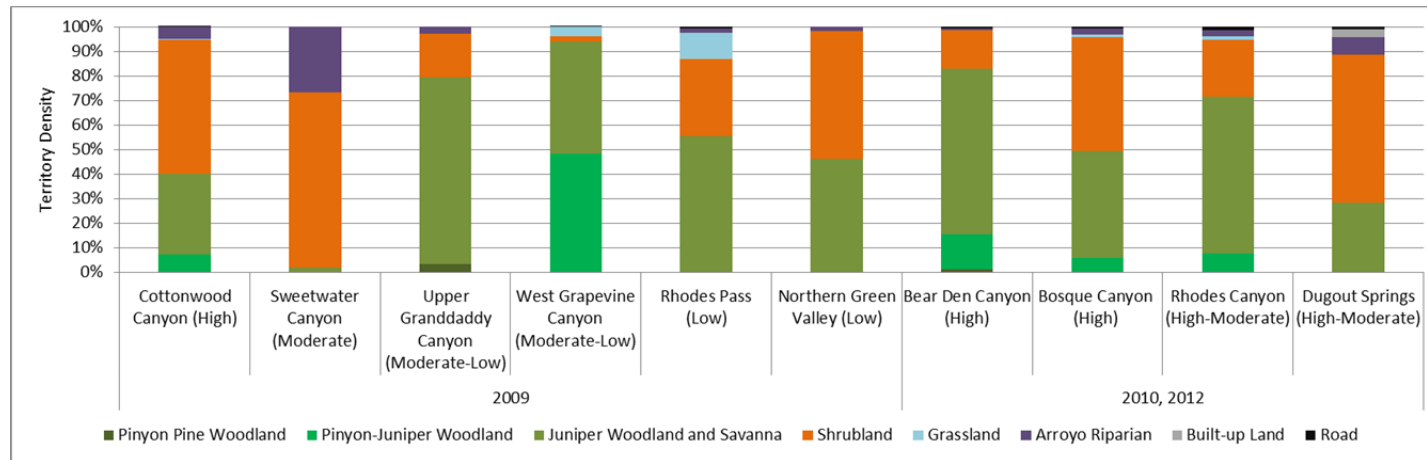




**Figure 12.** Areas of high to low Gray Vireo density at WSMR. Inset shows a portion of the landscape model in two areas of higher vireo density.

**Table 1. Relative cover of vegetation types in areas with various densities of Gray Vireo detections 2009 (Hobert et al. 2009) and 2010 (this study).**

	Cottonwood Canyon	Sweetwater Canyon	Upper Granddaddy Canyon	West Grapevine Canyon	Rhodes Pass	Northern Green Valley	Bear Den Canyon	Bosque Canyon	Rhodes Canyon	Dugout Springs
<i>Territory Density (%)</i>	<i>High</i>	<i>Moderate</i>	<i>Moderate - Low</i>	<i>Moderate - Low</i>	<i>Low</i>	<i>Low</i>	<i>High</i>	<i>High</i>	<i>High - Moderate</i>	<i>High - Moderate</i>
Pinyon Pine Woodland			3.5				1.2			
Pinyon-Juniper Woodland	7.5			48.4			14.4	6.1	7.7	
Juniper Woodland and Savanna	32.6	2.0	75.8	45.4	55.6	46.3	67.5	43.3	63.7	28.3
Shrubland	54.5	71.4	17.7	2.4	31.3	52.0	15.6	46.3	23.3	60.4
Grassland	0.3			3.7	10.7			1.2	1.5	
Arroyo Riparian	5.0	26.6	3.0		1.5	1.7	0.5	2.3	2.4	7.2
Built-up Land					0.1					2.9
Road	0.1			0.1	0.7		0.7	0.8	1.3	1.2



**Figure 13. 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 (64%:23% versus 28%:60%, respectively). The two areas of apparently low vireo density varied widely. Northern Green Valley was nearly half Juniper Woodland and Savanna and half Scrub. Rhodes Pass, in contrast, was Juniper Woodland and Savanna-dominated (56%) with a lesser Scrub component (31%) and 11% Grassland (Figure 13, Table 1).

Of the nests detected by Animas Biological Studies in 2010 and 2012, 85% were in Juniper Woodland and Savanna, with the remaining nests distributed between Pinyon-Juniper Woodland (8%), Shrubland (4%), and Arroyo Riparian (4%). The majority of detections (78%) were also in Juniper Woodland and Savanna, with 10% in Pinyon-Juniper Woodland, 9% in Shrubland, and 3% in Arroyo Riparian. In Hobert et al.'s (2009) study, 50% of detections were in Juniper Woodland and Savanna, followed by Arroyo Riparian (28%), Shrubland (13%), and Pinyon-Juniper Woodland (9%).

## **Territory-scale Models**

### **Distance to Military Infrastructure and Activities**

The Gray Vireo study area on KAFB is intersected by Coyote Springs and Madera Canyon Roads, which service numerous military buildings and the Live Firing Range. Approximately 40% of territories at KAFB were within 100 m of Coyote Springs or Madera Canyon Roads; and, in some cases, territories spanned these roads. We also identified seven territories at KAFB that occurred within 200 m of buildings. Although our study area does not include the Live Firing Range, noise from training activities at that site could be heard within the territories to the southeast, south, and southwest. This included a distance range from approximately 200–800 m, and possibly farther. Animas Biological Studies conducted a base-wide Gray Vireo survey in May and June of 2010 and identified two territorial vireos, approximately 200 m and 350 m away from the footprint of the Live Firing Range (Wickersham and Wickersham 2011).

### **Territories vs. Unused Areas**

The variables used to discriminate territories from non-territories at all study sites are shown in Table 2.

*Camel Tracks.* We identified and delineated 25 territories 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. We identified 40 unused areas 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 at CTTA included elevation, north-south aspect, degree slope (quadratic), and solar radiation (Table 3). 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 3, Figure 14). This model had an AUC of 0.940, indicating excellent discrimination between territories and non-use areas.

**Table 2. Variables used in models discriminating territories from (unused) Gray Vireo non-territories at all study sites. Mean values of each variable were calculated across all 10-m pixels within each territory. Values presented are means  $\pm$  standard errors across all territories.**

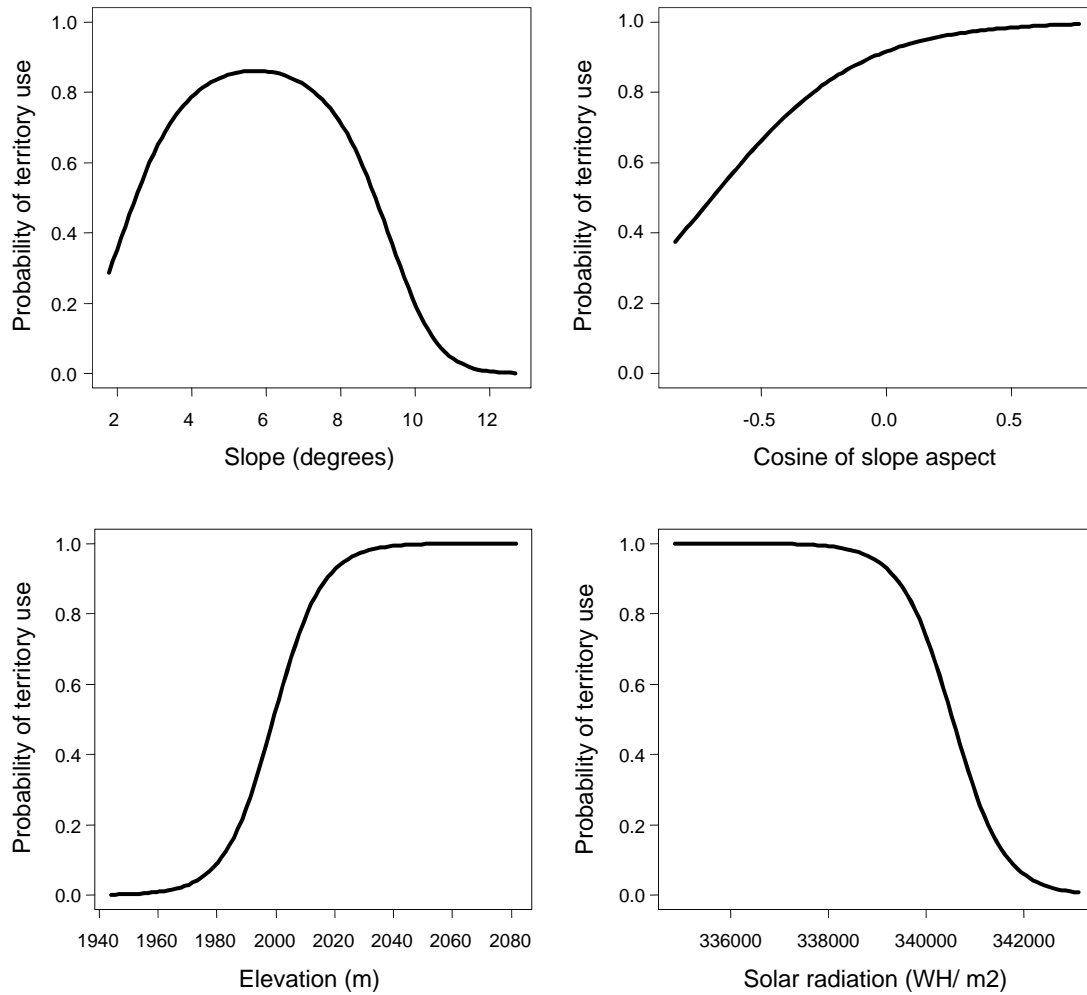
GIS variables	Explanation	CTTA		KAFB		WSMR	
		Territories	Unused areas	Territories	Unused areas	Territories	Unused areas
ELEV	Elevation calculated from 10-m digital elevation model (DEM) (m)	2,000 (5)	2,026 (5)	1,888 (9)	1,878 (4)	1,836 (11)	1,870 (15)
ASP_COS	Cosine of aspect (in degrees), from DEM. Varies between -1 (south) to 1 (north).	-0.23 (0.06)	-0.11 (0.06)	-0.14 (0.07)	0.07 (0.05)	-0.01 (0.06)	0.23 (0.04)
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)	12.9 (0.8)	13.9 (0.7)
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)	-0.176 (0.028)	-0.006 (0.018)
FLOW_ACC	The number of pixels draining into or through each pixel, from DEM (100 m <sup>2</sup> )	13.4 (1.3)	25.8 (5.2)	39.8 (6.0)	67.2 (7.3)	125.8 (21.5)	82.9 (15.1)
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 <sup>2</sup> ).	273,771 (174)	273,575 (204)	254,408 (1827)	253,227 (1124)	113,842 (1,022)	114,021 (819)
JAN_NDVI	Evergreen greenness; normalized difference vegetation index (NDVI <sup>a</sup> ) calculated from January, 2005 Landsat imagery (900 m <sup>2</sup> resampled to 100 m <sup>2</sup> ).	0.165 (0.002)	0.179 (0.002)	0.170 (0.007)	0.181 (0.003)	0.093 (0.004)	0.085 (0.004)
JAN_OCT_NDVI	Deciduous greenness; the difference in NDVI between October 2005 and January 2005 Landsat imagery (900 m <sup>2</sup> resampled to 100 m <sup>2</sup> ).	0.051 (0.002)	0.042 (0.002)	0.051 (0.003)	0.051 (0.001)	0.075 (0.003)	0.072 (0.004)

<sup>a</sup> NDVI = (raw NDVI + 1) \* 100

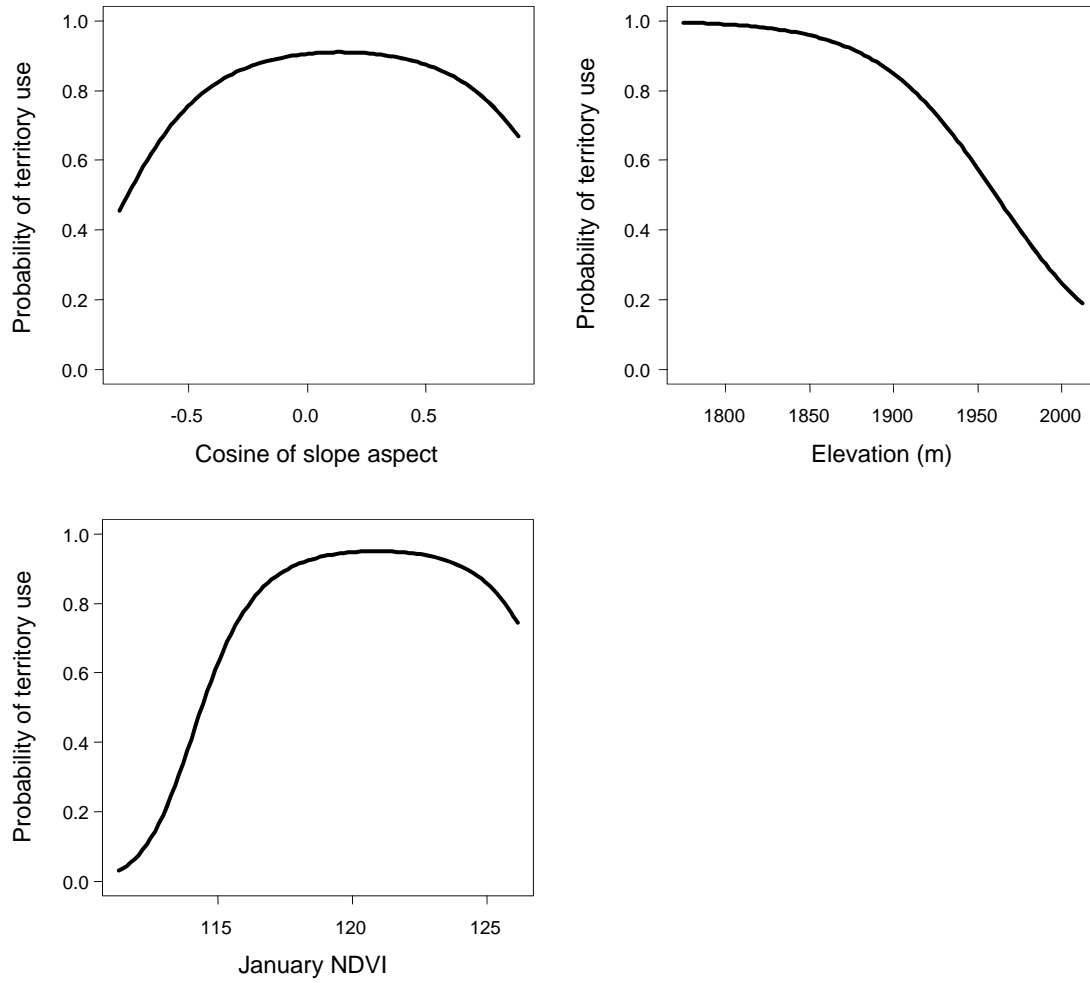
**Table 3. Parameter estimates from stepwise-selected logistic regression models discriminating territories from unused areas on CTTA, KAFB, and WSMR.**

Variable	Estimate	SE	z-value	P
<b>CTTA</b>				
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 <sup>2</sup>	-0.176	0.049	-3.628	<0.001
SOLAR	-0.002	0.001	-2.866	0.004
<b>KAFB</b>				
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 <sup>2</sup>	-2.856	1.276	-2.239	0.025
JAN_NDVI	16.582	4.731	3.505	<0.001
JAN_NDVI <sup>2</sup>	-0.069	0.020	-3.442	<0.001
<b>WSMR</b>				
Intercept	-431.476	168.134	-2.566	0.010
ELEV	0.552	0.188	2.933	0.003
ELEV <sup>2</sup>	0.000	0.000	-2.847	0.004
ASP_COS	-7.997	1.920	-4.165	<0.001
CURVE	-4.751	1.866	-2.546	0.011
SLOPE	0.234	0.284	0.822	0.411
SLOPE <sup>2</sup>	-0.028	0.012	-2.291	0.022
SOLAR	-0.001	0.000	-3.357	<0.001

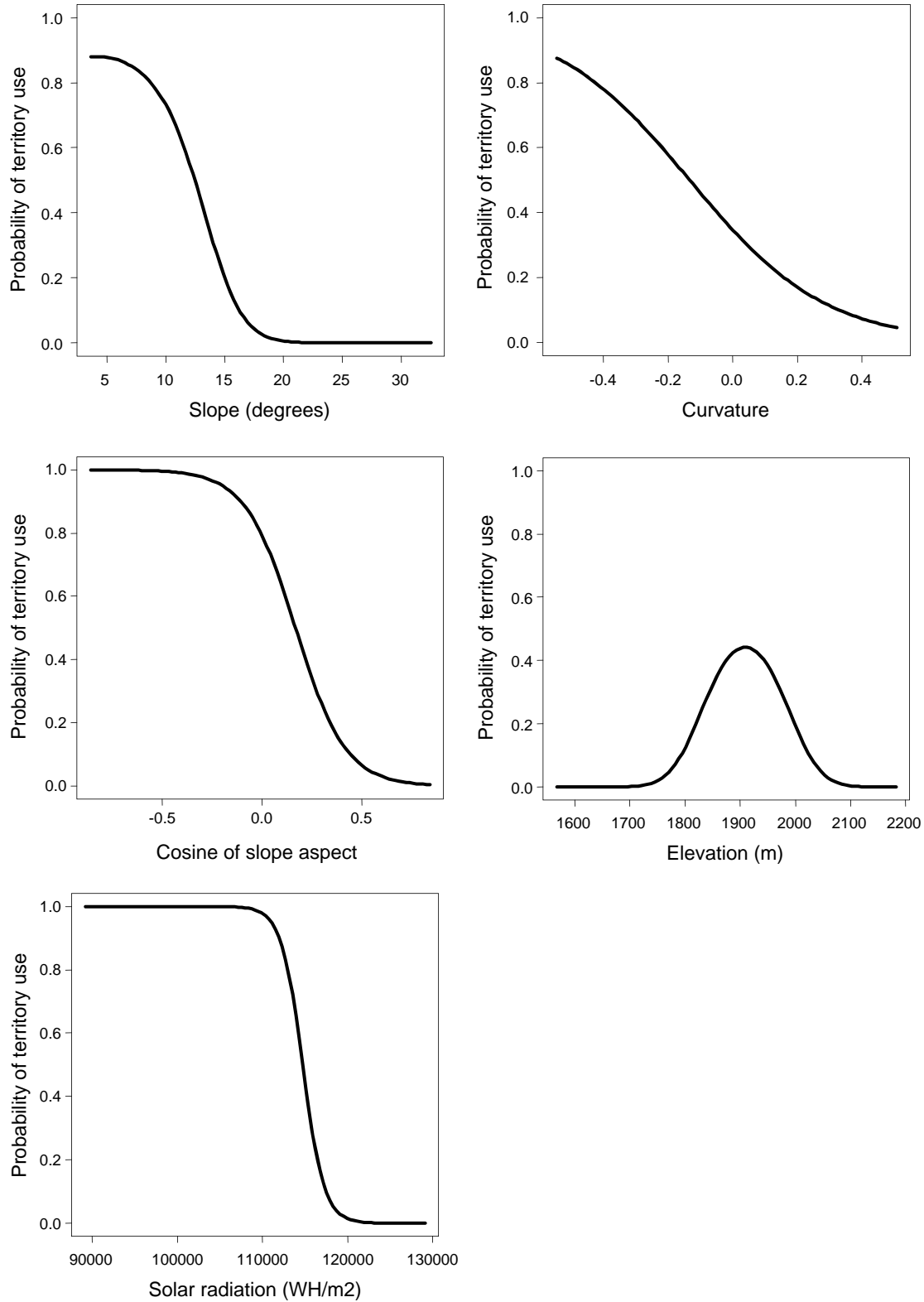




**Figure 14. Probability of Gray Vireo territory use on CTTA in relation to GIS variables in the best model discriminating occupied and unoccupied territories. Slope exhibited a quadratic relationship with selection, indicating selection for territories with intermediate slope.**



**Figure 15. 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.**



**Figure 16. Probability of Gray Vireo territory use on WSMR in relation to GIS variables discriminating occupied and unoccupied territories. Elevation and slope (degrees) exhibited quadratic relationships with selection, though selection for intermediate values was indicated only for elevation.**

*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<sub>C</sub> (138.83) and an AUC of 0.728, indicating acceptable discriminatory power between territories and non-territories. 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 at KAFB included aspect (quadratic), elevation, and evergreen greenness (quadratic). 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 3, Figure 15). This model had an AUC of 0.814, indicating good discrimination between territories and non-use areas.

*WSMR*. Forty-two territories were identified and delineated in 2010 and 2012. Eighty-four unused areas were identified in areas outside of delineated territories, at least 115 m from nests and other positive observations and within the boundaries of the area that was both searched extensively in 2009, 2010, and 2012 and was the core study area prior to 2009.

Only one competitive model emerged from the territory-scale infrastructure analysis at WSMR. The best model was a single-variable model containing distance to road. The road model had an AUC of 0.952, indicating excellent discriminatory power between territories and non-territories. The coefficient for roads was negative, meaning that territories were closer to roads at WSMR than non-territories.

The best territory model for WSMR included cosine of aspect, curvature, elevation (quadratic), slope (quadratic), and solar radiation. Territories had more southerly aspect, negative (bowl-shaped) curvature, intermediate elevation, lower slope, and lower solar radiation than non-territories (Table 3, Figure 16). This model had an AUC of 0.933, indicating excellent discrimination between territories and non-use areas.

### **Gray Vireo Model Predictions**

We applied the logistic regression models for CTTA, KAFB, and WSMR to generate maps of habitat with  $\geq 50\%$  probability of being occupied by vireos (Figures 17, 18-20). The territory models covered 428 ha, 2027 ha, and 16,120 respectively. 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 WSMR, potential habitat occurs in relatively narrow montane valleys and canyons in more diverse plant assemblages including shrubland and juniper.

### **Gray Vireo Model Validation**

Validation data collected by Rob Frei were available for 2003-2006 across approximately 31 km<sup>2</sup> 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  $\geq 0.5$  (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  $\geq 0.5$  (50%) of being the center of a territory.

At WSMR, we used 138 unbuffered positive survey locations from Hobert et al. (2009) and 15 points from NM Biotics for validation of the territory model. Ninety (58.8%) of the validation points fell within the WSMR predictive territory-scale habitat model. However, breaking the habitat model into north, the area where territories occurred, and south, the model is more successful in the north and less so in the south. In the north, 48 of 62 (77.4%) occurrences fell within the territory model (Figure 18); in the south 42 of 91 (46.2%) validation points fell within the model. Noticing that the mapped area contains much larger intact blocks in the north, we broke the south area down further into a large block in its northern section and a southern part containing smaller, more fragmented patches of habitat. In the larger southern segment, 20 of 30 (67%) of validation points fell within the model (Figure 19), while only 22 of 61 (36.1%) fell within the model in the far south (Figure 20). Hence, the model performed better farther north and in areas with larger intact habitat blocks.



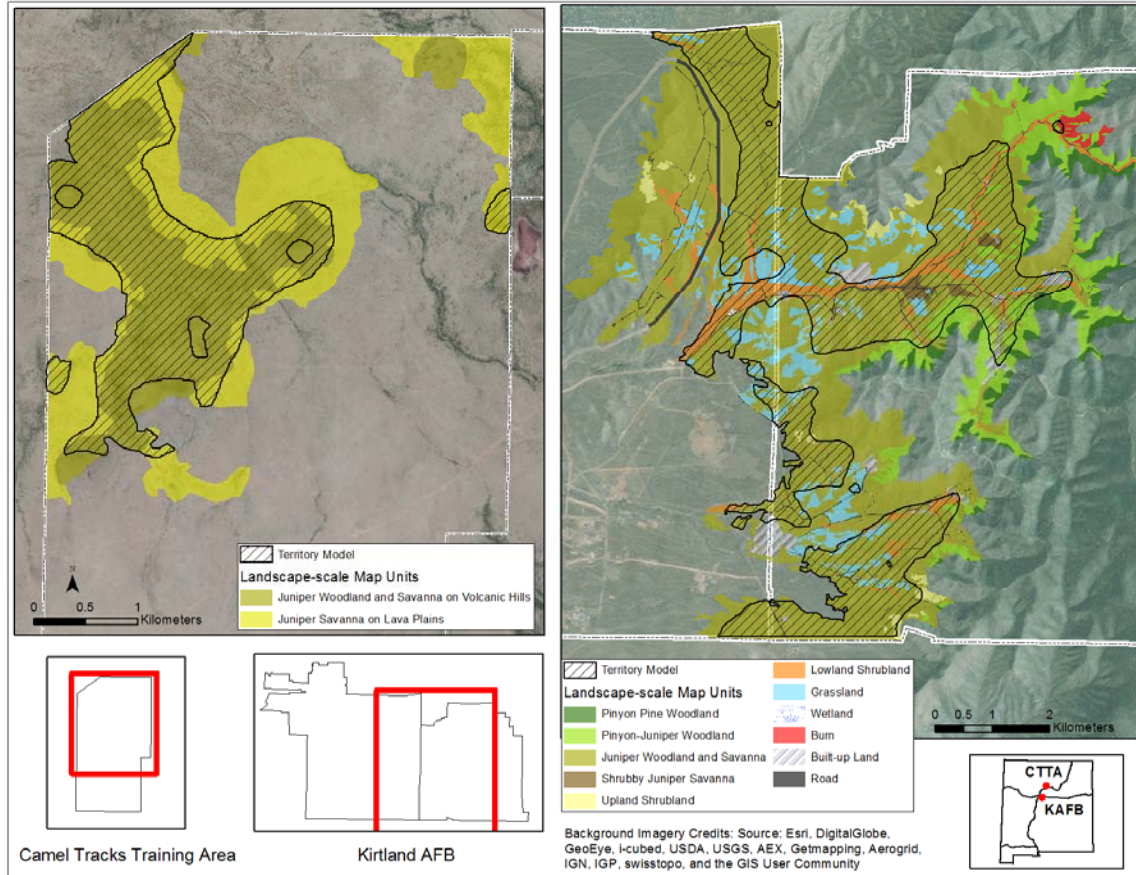


Figure 17. Predictive model of Gray Vireo territory-scale habitat at CTTA and KAFB.



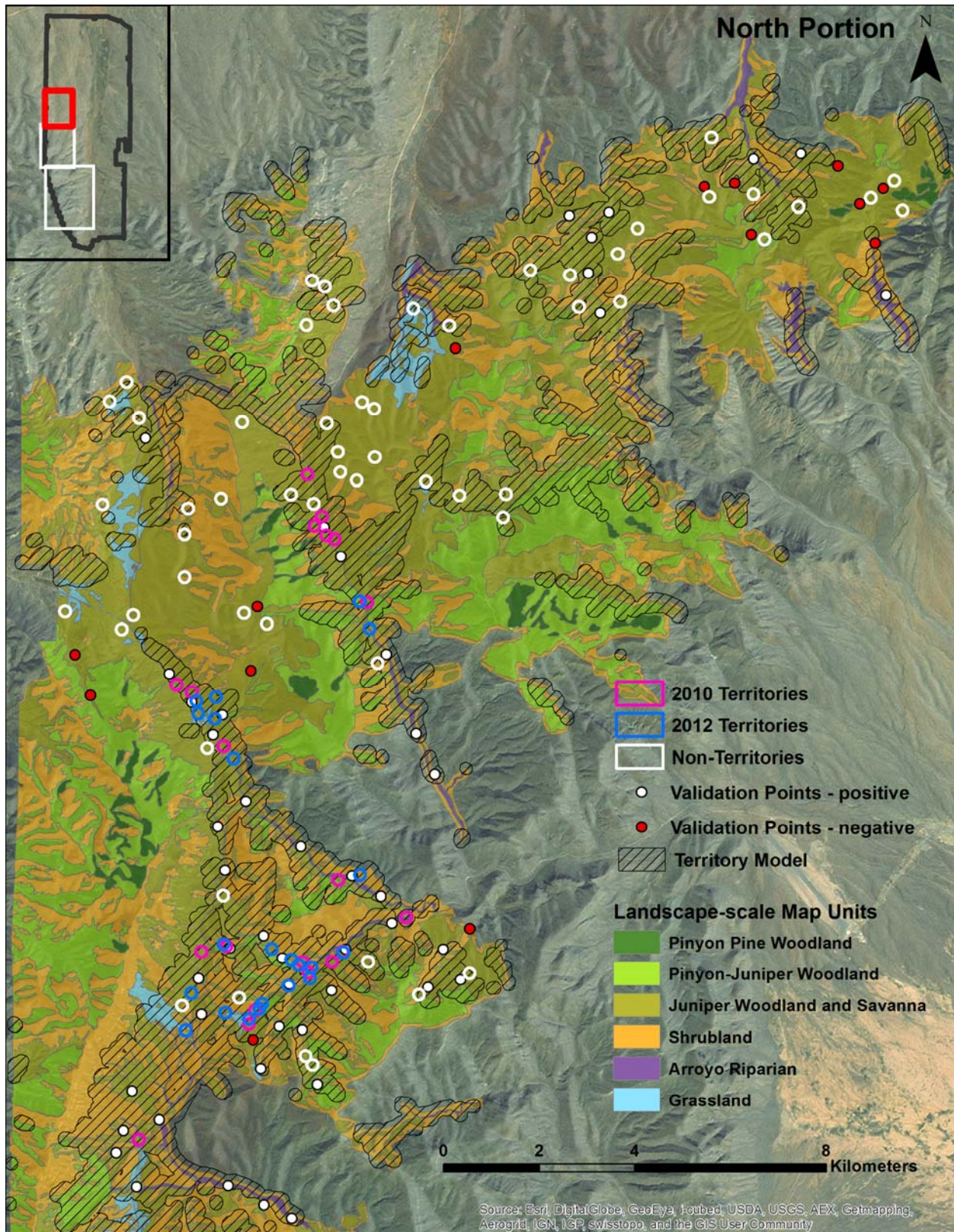


Figure 18. WSMR territory model and validation points, north portion.



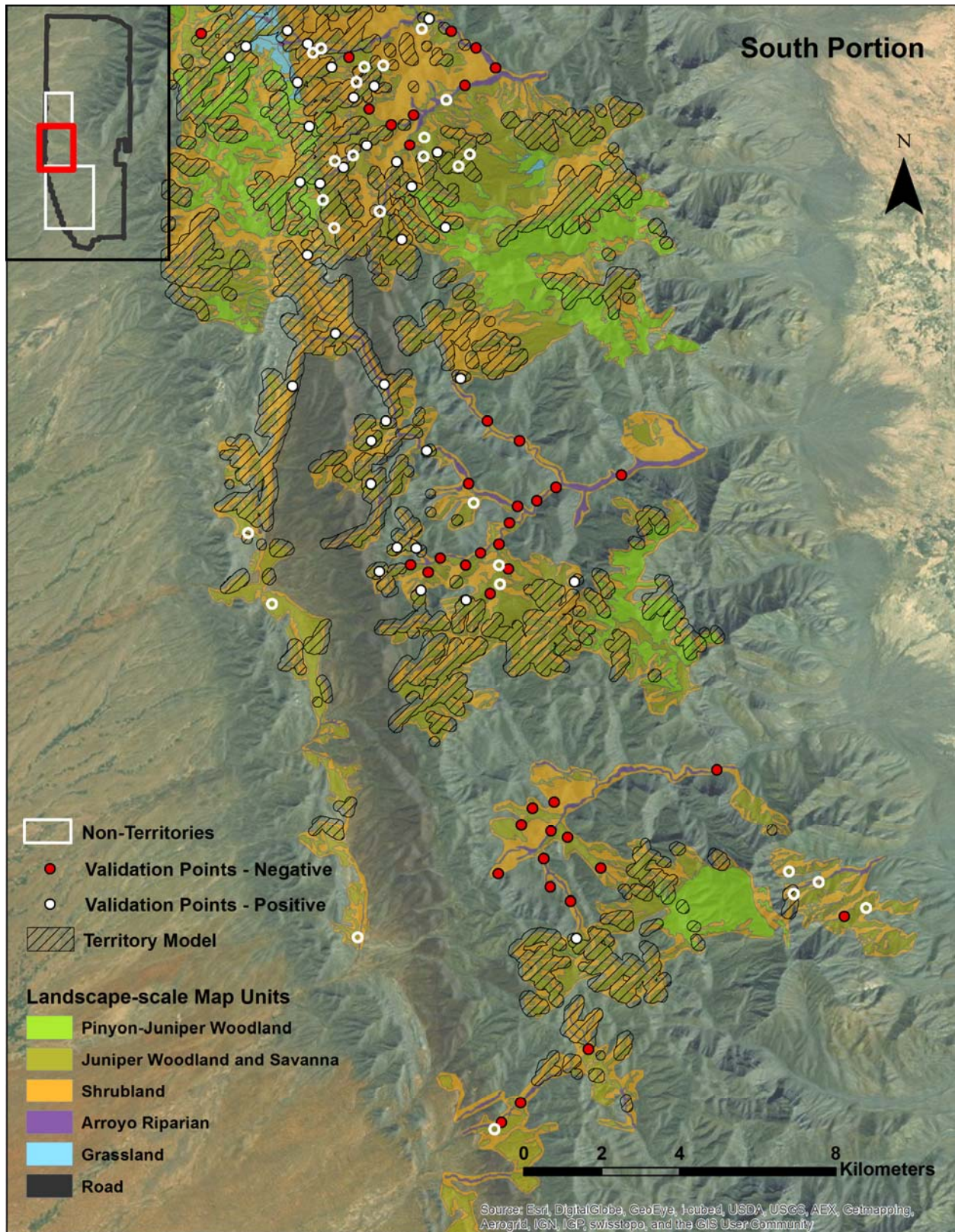


Figure 19. WSMR territory model and validation points, south portion.



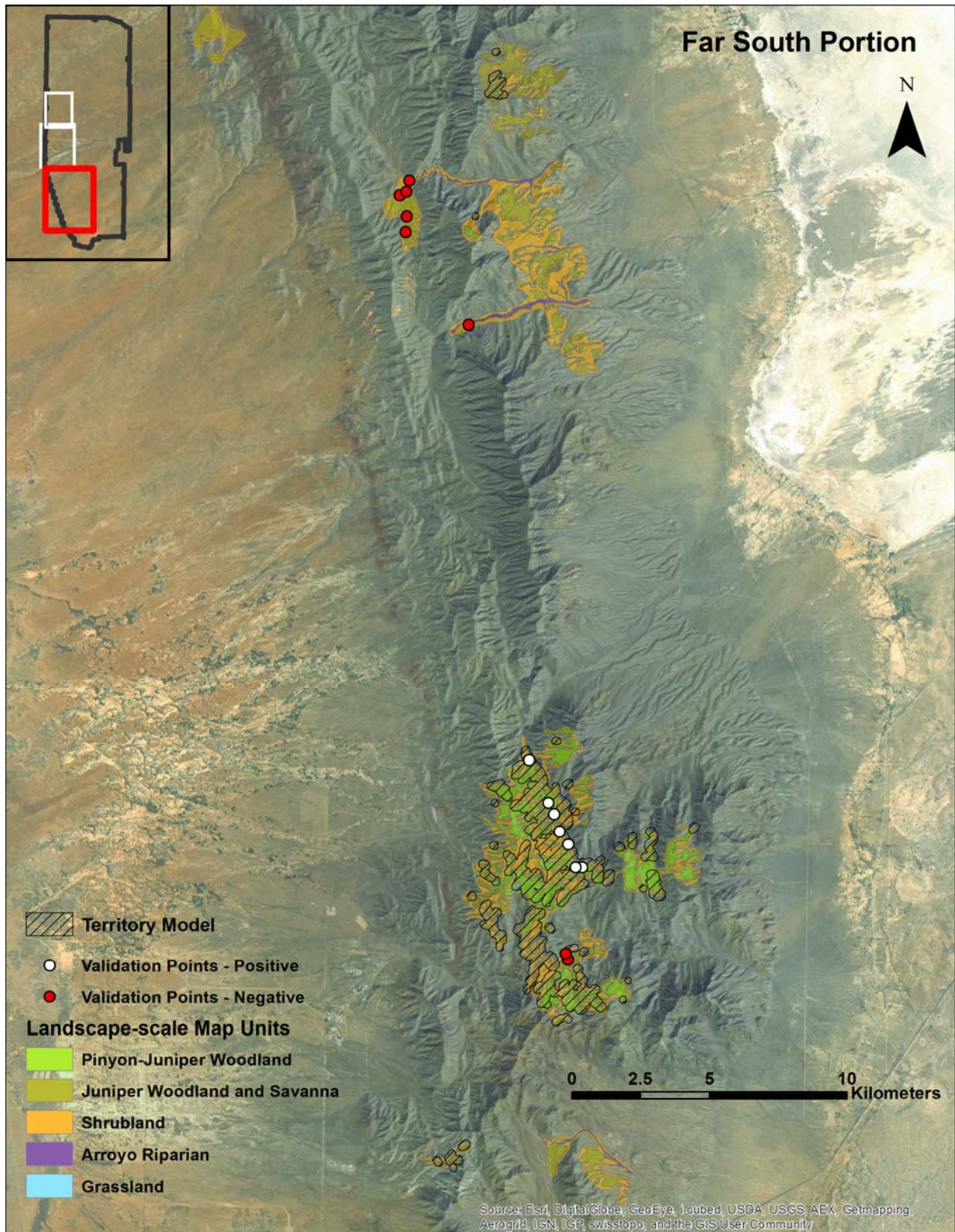


Figure 20. WSMR territory model and validation points, far south portion.

### Gray Vireo Within-territory Nest-site Selection

We found and measured vegetation attributes of 89 nests on CTTA, KAFB, and WSMR from 2009-2012. Eighteen 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 21 nests 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. Due to a more limited road network, only one road category was used for WSMR. One model (distance to building) was competitive for CTTA (Table 4) 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 5). 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 on KAFB (which also included distance to buildings) had a  $\Delta AIC_C < 2$ , but parameter estimates ( $P = 0.43$ ) indicated the distance to building was uninformative (Arnold 2010). Only one WSMR infrastructure model had a  $\Delta AIC_C < 2$  (distance to road); however, parameter estimates indicated that distance to road was uninformative ( $P = 0.40$ ).

*Topography and Vegetation.* The number of trees/ha on nest plots ranged from 25-425 (mean=113, SE=9). Most plots had 200 or fewer trees/ha (Figure 21).

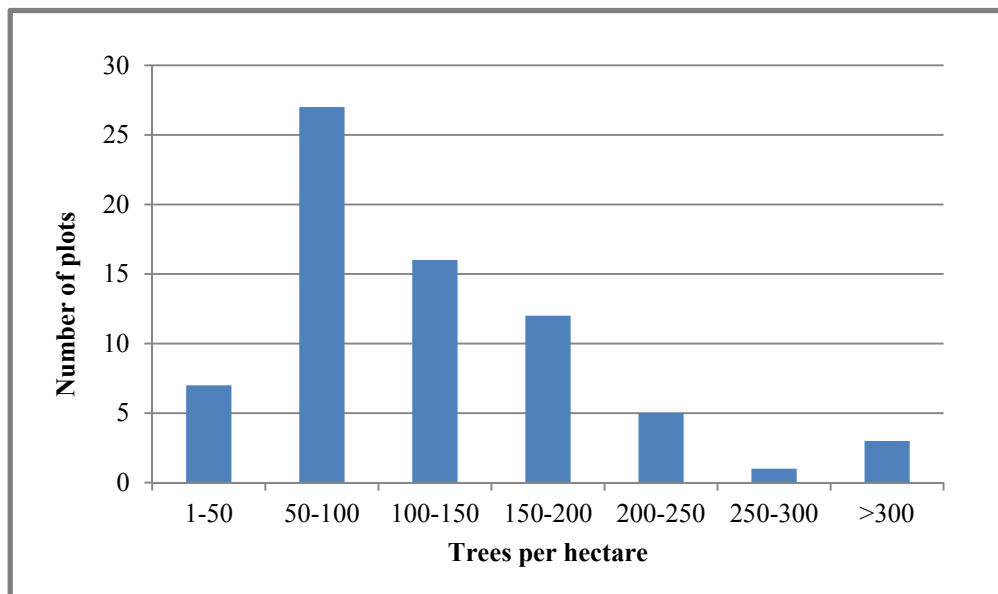


Figure 21. Distribution of tree density on Gray Vireo nest plots, 2009, 2010, and 2012.

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 mean tree height within plots would be potentially useful in discriminating nests from non-nests within territories (Table 6). Two models in the final candidate set were competitive ( $\Delta AIC_C < 2$ , Table 7). These models had a weight of 51% and 35% of the model set. Both models had an AUC value greater than 0.8, indicating good model discrimination between nests and non-nests. Parameter estimates (Table 8, Figure 22) indicated Gray Vireos selected nest sites on more southward-facing aspects having more trees and higher mean tree heights relative to non-unused random plots within each territory. While curvature was generally lower (i.e. more concave) in nest plots when compared to unused plots within territories, parameter estimates for this variable bounded zero, indicating weak directional influences (Table 8).

**Table 4. 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. Gravel and two-track roads were not discriminated on WSMR.**

Site	Model	k	LL	AIC <sub>C</sub>	$\Delta AIC_C$	$w_i$	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	-15.942	33.976	0.000	0.542	0.500
	Distance to a road	2	-15.565	35.409	1.434	0.265	0.673
	Distance to buildings	2	-15.882	36.043	2.067	0.193	0.673

**Table 5. 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 and WSMR showed no strong patterns relative to infrastructure.**

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
WSMR	Distance to a road	-0.001	0.008	-0.846	0.398



**Table 6. Variables used in models discriminating Gray Vireo nest plots from random plots within territories on CTTA and KAFB (2009-2010) and WSMR (2010 and 2012). Nest plots were 0.04-ha circles (11.3-m radius) centered on each nest and random unused locations. Values are means.**

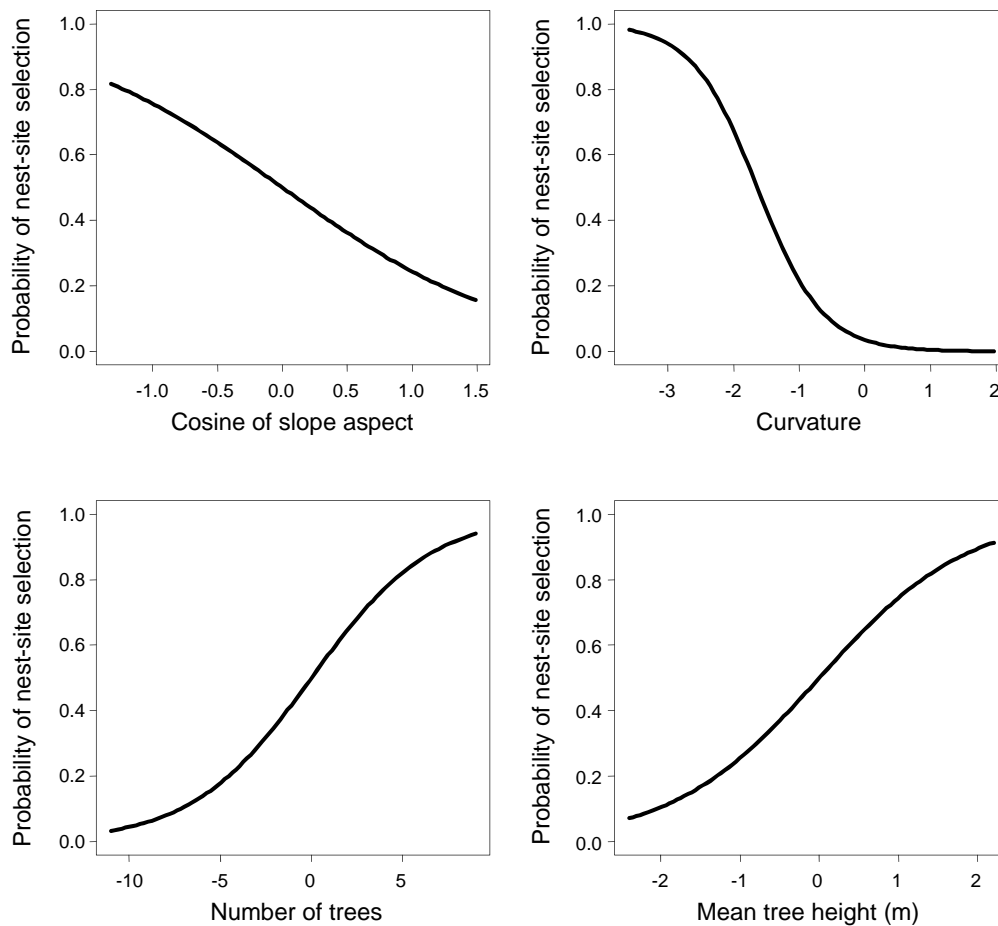
Variables	Explanation	CTTA		KAFB		WSMR	
		Nest plots	Random plots	Nest plots	Random plots	Nest plots	Random plots
<b>Topography</b>							
ELEV	Elevation of plot calculated from 10-m digital elevation model (DEM) (m)	2005 (7)	2011 (7)	1863 (7)	1865 (7)	1821 (14)	1822 (13)
ASP_COS	Cosine of plot aspect (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)	0.17 (0.14)	0.10 (0.13)
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)	12.2 (1.4)	10.9 (1.4)
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)	-0.31 (0.13)	-0.09 (0.24)
<b>Vegetation</b>							
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)	25.9 (3.4)	26.2 (3.3)
MNTREEHT	Mean height of all trees (m)	3.7 (0.2)	3.1 (0.2)	3.3 (0.1)	2.9 (0.1)	4.0 (0.2)	3.8 (0.2)
NTREES	Number of trees > 1 m in height (n)	2.9 (0.3)	2.5 (0.4)	4.1 (0.4)	3.5 (0.4)	5.9 (1.0)	4.5 (1.0)
NSHRUBS	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)	46.1 (11.7)	40.3 (7.8)
TOTAL LIVE	Mean 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)	3.1 (0.3)	3.9 (0.3)

**Table 7. 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,  $\Delta AIC_C$  is the difference between the  $AIC_C$  of each model and the model with the lowest  $AIC_C$ ,  $w_i$  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	$AIC_C$	$\Delta AIC_C$	$w_i$	AUC
ASP_COS+NTREES+MNTREEHT	4	-37.047	82.385	0.000	0.510	0.819
ASP_COS+CURVE+NTREES+MNTREEHT	6	-35.254	83.130	0.745	0.351	0.843
CURVE+NTREES+MNTREEHT	5	-37.493	85.427	3.042	0.111	0.810
CURVE+MNTREEHT	4	-41.501	91.293	8.908	0.006	0.752
ASP_COS+CURVE+MNTREEHT	5	-40.443	91.327	8.942	0.006	0.784
ASP_COS+CURVE+NTREES	5	-40.549	91.539	9.154	0.005	0.776
CURVE+NTREES	4	-42.039	92.370	9.985	0.003	0.743
MNTREEHT	2	-44.720	93.526	11.141	0.002	0.708
ASP_COS+MNTREEHT	3	-44.111	94.396	12.011	0.001	0.713
ASP_COS+NTREES	3	-44.405	94.983	12.598	0.001	0.715
NTREES	2	-45.784	95.655	13.270	0.001	0.685
CURVE	3	-44.787	95.747	13.362	0.001	0.685
ASP_COS+CURVE	4	-44.126	96.544	14.159	0.000	0.708
NTREES+MNTREEHT	4	-44.126	96.544	14.159	0.000	0.708
NULL	1	-49.213	100.455	18.070	0.000	0.500
ASP_COS	2	-48.827	101.741	19.356	0.000	0.539
ASP_COS+NTREES+MNTREEHT	4	-37.047	82.385	0.000	0.510	0.819

**Table 8. 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 (WSMR nests were located in 2010 and 2012). Odds ratios indicate the change in selection probability for each 1-unit increase in the predictor variable. For example, an odds ratio of 1.357 for NTREES indicates the probability a site was used for nesting increased 35.7% for each additional tree.**

Variable	Estimate	SE	Odds ratio		
			Lower 95% CI	Estimate	Upper 95% CI
ASP_COS	-1.132	0.569	0.106	0.322	0.983
CURVE	-0.787	0.559	0.152	0.455	1.362
CURVE <sup>2</sup>	-0.362	0.251	0.426	0.696	1.139
NTREES	0.305	0.103	1.107	1.357	1.661
MNTREEHT	1.069	0.362	1.432	2.912	5.926



**Figure 22. Probability of nest site selection relative to values of each variable in the strongest Gray Vireo nest site model.**

## GRAY VIREO: DISCUSSION

### **Territory Size and Site Fidelity**

The number of territories at CTTA increased by more than 25% from 2009 to 2010, and we also saw a slight increase in the number of territories at KAFB. The increase in territories in 2010 may be due to an extremely productive breeding year in 2009, resulting in an influx of second-year birds to both study areas. In 2009, spring precipitation was more than twice that from the previous year, which likely increased available food resources (Wickersham and Wickersham 2009).

The MCP analysis yielded a large range of territory sizes for Gray Vireos at all three installations. These results should be viewed with caution, as numerous MCPs were based on a relatively small sample of vireo locations, which would probably have caused us to underestimate territory sizes. By contrast, many of the larger MCPs used locations of color banded individuals, making those territory sizes more reliable. Therefore, our analysis probably does not overestimate the potential for some Gray Vireos to have large territories (>12 ha). In general, territory sizes for Gray Vireos in this study fall within the range reported in other studies. Gray Vireo territory sizes in the Sacramento and Organ Mountains in southern New Mexico ranged from 0.6–11.3 ha ( $n=37$ ), and 1.6–6.8 ha ( $n=14$ ), respectively (Britt and Lundblad 2009). DeLong and Cox (2005) reported a mean territory size of 8 ha for Gray Vireos in central New Mexico. In the Chisos Mountains of Texas, Barlow et al. (1999) reported Gray Vireo territories ranging in size from 2–10 ha. Hutchings and Leukering estimated a territory at 7 ha for a Gray Vireo in western Colorado (Unpublished data cited in Barlow et al. 1999).

Our data indicate that site fidelity may be relatively high for Gray Vireos. At KAFB, we observed a high percentage of color banded males returning to the study area in 2009, with fewer returning in 2010. Color banded males that returned to the study area almost always re-occupied the same territory as the previous year. Further, one male-female pair color banded in 2008 paired again in the same territory in 2010. Barlow et al. (1999) also reported high site fidelity for Gray Vireos in west Texas, with 22 of 24 birds color banded over a four year period returning to their territories. Hutchings and Leukering (unpublished data cited in Barlow et al. 1999) reported one color banded vireo returning to the same territory in Colorado National Monument for three consecutive years.

### **Landscape-scale Habitat Use**

We conclude that WSMR vireo habitat includes a more diverse assortment of vegetation types than that at CTTA or KAFB, owing largely to the lower availability of juniper-dominated habitat at WSMR and its interspersions with Shrubland, Arroyo Riparian, and Pinyon-Juniper. When viewed at the landscape scale, Gray Vireos at WSMR appear to occupy habitats containing Shrubland and Juniper Woodland and Savanna vegetation in proportion to their availability, but when viewed at the nest scale, Juniper Woodland and Savanna vegetation is strongly preferred.

Perhaps the most striking feature of Gray Vireo landscape-scale habitat use at WSMR is the proportion of Shrubland habitats. Shrubland 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 at WSMR. Only in West Grapevine Canyon and Bear Den Canyon was Shrubland not one of the two most abundant vegetation types (Figure 13, Table 1). Shrubland habitats are not a major component of the landscape models at KAFB and CTTA (6% and 0%, respectively).

Shrubland habitats within areas used by Gray Vireos at WSMR appear to be relatively prevalent in the landscape model. 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 4% of nests and 9% of detections in this study were in Shrubland habitats, and 13% of detections in the Hobert et al. (2009) study were in Shrubland habitat, considerably lower than Shrubland availability across the landscape. Hence, although shrub habitats were relatively abundant within areas occupied by Gray Vireos, the birds tended to nest and spend proportionately more time in Juniper Woodland and Savanna, while nesting and spending proportionately less time in Shrubland.

### **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, east- or west-facing slopes at KAFB, and south-facing slopes at WSMR. These differences are more likely a function of the topography in these areas than varying preferences for aspect by site. Topography in occupied vireo habitat at KAFB consists predominantly of foothills 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 is 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. At WSMR, territories are found within the relatively narrow canyons of the San Andres, often in close proximity to Arroyo Riparian vegetation.

Another contradictory variable in the territory models is elevation. Gray Vireos appear to occupy habitat at higher elevations than unused areas at CTTA, lower elevations than unused areas at KAFB, and intermediate elevation at WSMR. 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. 2011). 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. At WSMR, Gray Vireos occupy elevations between 1710-1983 m, although they have been observed in areas ranging from 1416–2119 m. Lower elevations are rare and occur within Arroyo Riparian in east-west canyons such as Hembrillo with the highest elevations occurring near Granddaddy Peak and Upper Granddaddy Canyon.

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 WSMR, slope and solar radiation were also important in territory choice. Like at CTTA, but somewhat contrary to selection for more southern-facing slopes, vireos chose territories with lower solar radiation, but they preferred intermediate slopes. Territories at WSMR were placed in more bowl-shaped areas. No vegetation indicators were included in the WSMR model.

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. A preference for intermediate greenness may also be an indication that juniper savanna, rather than juniper woodland, is preferred. Woodland should show a higher NDVI response than savanna. The between-canopy spaces of savanna would be more grass-, as opposed to shrub-covered. Some of the shrubs found in association with junipers, like *Atriplex* spp. or *Artemisia* spp., retain their leaves in winter. These could contribute to higher NDVI values, whereas grasses in January are senescent, which would lower the overall NDVI of savanna, as compared to woodland. *Yucca* spp. and *Opuntia* spp. would also contribute to higher NDVI values in January.

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.

Analysis of distance-to-infrastructure at WSMR indicated a strong pattern of territory placement near roads. We suspect this is due, in part, to the placement of roads in areas with low slopes and near canyon or valley bottoms. This is supported by the correlation of distance-to-roads with slope ( $r=0.22$ ,  $P<0.02$ ) and curvature ( $r=0.22$ ,  $P<0.02$ ), both negatively associated with territory selection. We acknowledge, however, that the areas surveyed for Gray Vireos were selected in part due to their accessibility by roads.

### **Gray Vireo Territory 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. At WMSR, the model performed well in the north, with 77.4% accuracy (Figure 18). It performed comparatively poorly in the far south (36.1% accuracy, Figure 20), where habitat was fragmented into small patches, and better in the northern segment of the south (67% accuracy, Figure 19). Model predictability at KAFB could probably be improved with the inclusion of more vireo territory data in the modeling process and the inclusion of more validation points. At WSMR, the model might be improved by including patch size or contiguity measures and more vireo territory data in the modeling process, or simply by eliminating small or disjunct patches of mapped habitat from the model area before modeling.

### **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 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 and taller 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. Taller trees provide better vantage points than shorter trees for broadcasting songs for mate selection and territory defense and may provide more foliage to hide nests.

Our best nest-site selection model also included weak preferences by Gray Vireos for areas with lower curvature (i.e., more concave or bowl-shaped) within territories. Within-territory differences in curvature were overall notable (mean=-0.21, SE=0.08); however, when included in models with other variables having larger effects, this effect was diminished.

### **Gray Vireo Habitat Requirements and Management**

On a landscape scale, Gray Vireo habitat requirements at CTTA and KAFB are fairly simple. As expected, vireos at KAFB occupied Juniper Woodland and Savanna habitat types, were not found in the Pinyon Woodlands used by Pinyon Jays, and were rarely found within Pinyon-Juniper Woodland at the margins of Juniper Woodland and Savanna. At CTTA, potential habitat for vireos was Juniper Woodland and Savanna, with no significant pinyon component. Vireos

appeared to prefer the slightly higher elevation, upland Juniper Woodland and Savanna on Volcanic Hills compared to the lowland Juniper Savanna on Lava Plains habitat at CTTA.

At KAFB, most territories occurred on slightly higher elevation toe slopes and hills, compared with the lower elevation savanna. Although the upper elevation limit for juniper habitat on KAFB was about 200 m higher than at CTTA, in general most of the territorial Gray Vireos at CTTA occupied habitat at slightly higher elevations (>2000 m) than at KAFB. In a recent study at similar elevation (1725–2228 m) in the San Juan Basin of northwestern New Mexico, Gray Vireos appeared to prefer habitat at elevations >1900 m (Wickersham and Wickersham 2007). Schlossberg (2006) also reported a relationship between elevation and Gray Vireo density in Arizona and Utah; however, in his study, density was lower at elevations greater than 1900 m, compared with habitat at lower elevations (1500–1900 m). Although habitat in Schlossberg's study was similar to Wickersham and Wickersham's (2007) study, elevation was lower in his study area (~1550–2100 m). Territories at WSMR ranged in elevation from 1677–1962 m, lower than we found at CTTA and KAFB and lower than in the San Juan Basin study, but closer to those reported by Schlossberg (2006).

To manage habitat for Gray Vireos, maintaining healthy juniper-dominated habitats occurring on hills and toe slopes appears to be essential. It is important that land managers identify and differentiate between juniper-dominated habitats and Pinyon-Juniper Woodlands. At KAFB and likely elsewhere, juniper-dominated habitats overlap in elevation considerably with Pinyon-Juniper Woodlands (1742–2319 m for juniper and 1889–2351 m for pinyon-juniper). While management of Pinyon-Juniper Woodlands has been an important issue in recent years for federally owned lands in New Mexico, land managers must also manage for Juniper Woodlands and Savannas to ensure enough habitat is available to sustain populations of Gray Vireos in the state.

Management of Gray Vireo habitat at WSMR should include areas delineated in the landscape model, particularly those areas dominated by a mix of Shrubland and Juniper Woodland and Savanna habitats. Pinyon-Juniper Woodland and Arroyo Riparian habitats should also be included, comprising up to ~9% and ~4%, respectively, of areas managed for vireos, based on high- and high-to-moderate-density vireo occupancy at WSMR.

Probably the greatest threat to Gray Vireos is habitat loss or alteration due to land management activities, such as thinning, chaining, and clearing for exurban development, biofuel production, and oil-and-gas development (Walker and Doster 2009). Tree removal by way of fire, chaining, or thinning has been implemented on public lands to combat pinyon-juniper expansion into grasslands and shrublands. These expansions have been shown to be influenced by natural processes and changing climate and thus do not necessarily represent unnatural events (Romme et al. 2009). These management practices should be avoided at all three installations.

Additionally, removal of trees for the construction of military infrastructure where Gray Vireo populations are known to occur should also be avoided.

Juniper Woodland and Savanna habitats of all three installations appeared to be in good health for the three years of this study. However, in 2013, large-scale pinyon and juniper mortality occurred at KAFB and throughout the state, in conjunction with several years of drought. Drought, coupled with increased temperatures, has increased insect mortality in pinyons; however, drought alone has been shown to cause large-scale juniper mortality (Floyd et al. 2009). With climate projections for the Southwest suggesting increases in temperature and drought conditions, climate change appears to be a significant threat to juniper, as for pinyon.

Historically, fire regimes in most Pinyon-Juniper Woodlands have been infrequent and high intensity, wiping out large stands of trees. However, data are lacking on the history of low intensity fires and their role in maintaining low tree densities of juniper savannas (Romme et al. 2009). In the absence of more information on the role of fire in structuring juniper savannas, fire is not recommended as a management strategy for maintaining healthy juniper-dominated habitats.

### **Relationship to Military Activities**

The area known as the Vireo Seasonal Restriction Area (VSRA) at CTTA is closed to military activities between 15 May and 15 July annually. Therefore, Gray Vireos at this installation are not subject to the level of disturbance that potentially affects vireos during the peak breeding period at KAFB. Further, since only a few vireo detections have occurred within the TAMUs on CTTA, it is unlikely that military activities at CTTA have a significant effect on the population of Gray Vireos.

Disturbances at KAFB are primarily associated with human presence and noise. In general, human presence within Gray Vireo territories was limited to our field biologists; however, we did rarely encounter one to two military or civilian personnel walking for recreation within or adjacent to vireo territories. In this study, Gray Vireos appeared to tolerate human presence in their territories, but they typically displayed territorial and sometime aggressive behavior in response to playbacks and target mist netting. Sometimes, but not always, Gray Vireos exhibited scolding calls and aggressive postures to field biologists in close proximity to their nests. According to Barlow et al. (1999), Gray Vireos may abandon their nests during the building or egg-laying stage if disturbed by humans, although banding adults or nestlings does not usually disrupt their activities. We observed nest abandonment during both the building and egg-laying stage at both installations during 2009 and 2010, and other factors that we have not fully examined might have affected nest abandonment (e.g., parasitism by Brown-headed Cowbird, disturbance by field biologists).

Noise disturbances in the study area are typically short-term and temporary, including noise generated by vehicles, heavy equipment, and the firing range. Occasionally, very loud, sonic boom-type noises could also be heard within the study area, although their origin was unknown. Probably the most common noise disturbance in the study area is generated by vehicles. Vehicle traffic along Coyote Springs Road is variable but may approach approximately five vehicles per

hour at times. The proximity of Gray Vireo territories to Coyote Springs Road, however, suggests that vireos are not avoiding habitats adjacent to lightly traveled roads. Noise from the firing range was considerably louder than vehicle traffic but again was relatively short-term. Although our study area did not include habitat directly adjacent to the firing range, a base-wide Gray Vireo survey conducted by Animas Biological Studies in May and June of 2010 identified two territorial vireos, approximately 200 m and 350 m away from the footprint of the firing range facility (LW unpublished data). Further, noise from the firing range could be heard well within many of the vireo territories to the southeast, south, and southwest of the facility. Therefore, the loud but short-term noise from the firing range apparently does not negatively affect territory selection by Gray Vireos.

## PINYON JAY: METHODS

### Pinyon Jay Landscape-scale

#### KAFB

During the spring and summer months from March 2009 through April 2012, we surveyed for Pinyon Jays in suitable pinyon-juniper habitats at KAFB. Initially we visited areas where Pinyon Jays had been reported by KAFB biologists, MAPS (Monitoring Avian Productivity and Survivorship) station operators, and Sandia Laboratory biologist Steve Cox. Once we had located several areas frequented by groups of jays, we focused our surveys on those sites. In 2009, we also surveyed into the winter months, to establish the winter range of the KAFB Pinyon Jays. We visited areas frequented by the birds and collected GPS points wherever we found jays. Some detections were in areas we could not access. For example, we could not enter the Live Firing Range, and we could not reach locations high on hills before the birds left the area. In those cases we placed approximate location points on a mapping GPS unit.



Figure 23. Coyote Springs Road Pinyon Jay feeder, KAFB.

In July 2009 we erected an automatic koi feeder from Super Feeder (<http://www.super-feeder.com/>) next to Coyote Springs Road (Figure 23). We set up a livestock watering tub near the feeder. The feeder was kept supplied with *P. edulis* seeds and water was kept in the tub constantly, except when deer emptied it overnight or the water evaporated on weekends.



Figure 24. Pinyon Jay walk-in trap (right foreground) at Coyote Springs Road, KAFB.

After Pinyon Jays were regularly visiting, we trapped them near the Coyote Springs Road feeder on 12 and 31 August 2009. We used a 107 x 61 x 20 cm welded wire walk-in trap designed after a standard pigeon trap (Figure 24). The trap was baited with *P. edulis* seeds. Each captured bird was banded with a USGS

numbered aluminum band and a unique combination of three plastic color bands. We recorded the following data on each captured bird: age, sex, weight, culmen length, bill height, tarsus, and wing chord. We attached 2.5 g, tail-mounted, whip antenna radio transmitters (Holohil Systems Ltd.) to three of the birds captured on 12 August. We tied each transmitter to the base of the two central rectrices with sturdy thread, and then glued the body of the transmitter to the top of the same two rectrices (Figure 25). All birds were released unharmed after processing. Pinyon Jays were captured and banded under USGS Federal Marking and Salvage Permit #22158 and New Mexico Department of Game and Fish Scientific Permit #1795.



**Figure 25. Transmitter affixed to Pinyon Jay.**

After transmitters had been attached to the birds, we used a TRX 1000S receiver from Wildlife Materials to listen for transmitter birds one to four times each week from mid-August through November and once each on two weeks in December. Each time we received a signal, we recorded our location when we heard the signal and took the compass bearing of the strongest signal. We then attempted to take a second GPS point and directional bearing from a different location, to triangulate on the bird's specific location. The success of obtaining a second bearing depended on the jays' movements. GPS coordinates for all sightings of jays and all signal bearings were recorded in an Excel spreadsheet. Using ArcGIS, we mapped the location where

we were standing when we received a signal from each bird. We then mapped the vector indicating the direction we heard the strongest radio signal. Where the vectors crossed on the map, we added a point to signify the approximate location of the bird. Each point was associated in the GIS with the following data for the observation: date, time elapsed between observations, weather, transmitter frequency, and general location. We combined all GPS coordinates of Pinyon Jay locations into a GIS layer. This included points derived from visual detection, audio detection of Pinyon Jays, and radio telemetry. We used only telemetry locations resulting from bearings taken 25 or fewer minutes apart, a total of eleven. We divided GPS point locations into breeding (1 March-31 July), nonbreeding (1 August- 28 February), and year-round (all points combined).

## **WSMR**

We visited North Oscura Peak (NOP) and vicinity at WSMR approximately once weekly from 24 March- 29 October 2009. On each trip we watched the traditional colony site at NOP to determine where Pinyon Jays were nesting. When we saw birds going in and out of an area repeatedly during March-May, we searched for nests in the area. We took GPS coordinates of any nests we found.





**Figure 26. Pinyon Jay feeder at NOP, WSMR.**

On 10 April 2009 we set up a solar-powered, battery-operated automatic feeder (Sweeney Enterprises, Boerne, TX, Figure 26) within the traditional nesting colony area at NOP. The feeder was set to deliver about two cups of pinyon seed twice a day, early morning and late afternoon. We took down the feeder after we finished trapping. On 24 and 30 June, 1 and 21 July, and 17 August 2009, we trapped jays in a modified Australian crow trap set near the feeder and baited with pinyon seed. We processed captured birds as at KAFB, above.

We attached radio transmitters to five of the captured birds, as described above at KAFB: two adults, two second-year birds, and one older hatch-year bird. We tracked birds with a TRX-1000 receiver from Wildlife Materials International, Inc. We attempted to locate the birds with radios each time we visited the study site from the time we banded them until the last transmitter batteries failed or birds left the area. We located the last transmitter, one that had fallen off the bird and was transmitting, on 29 October. We mapped locations as at KAFB, above.

### **KAFB and WSMR**

Because Pinyon Jays are highly social, we mapped and analyzed locations for the flock rather than for any single individual. Telemetry points were used to find an individual, but that individual was always with other jays. To determine home ranges, we first created MCPs for each season using Hawth's Analysis Tools for ArcGIS (Beyer 2004). The resulting MCPs showed the minimum area used by the flock in either the breeding or nonbreeding season. Because the MCPs lack detail on probability of detection/use, we followed with a fixed kernel density analysis.

For the kernel analysis we used the Hawth's Tool, Fixed Kernel Density Estimator (KDE). Kernel analysis is a nonparametric statistical method for estimating probability densities from a set of points. When used to analyze home range data, kernel density methods describe the probability of finding an animal in any one place. The KDE calculates a fixed kernel density estimate and produces contour lines representing the boundary of the area that contains a specified percent of the volume of a probability density distribution. A 95% volume contour, for example, typically contains 95% of the points used to generate the kernel density estimate. Kernel parameters were set as follows: scaling factor- 1,000,000, kernel- bivariate normal, single parameter smoothing factor (h)- 1000, raster cell size- 100, and percent volume contours- 50, 90, and 95.

## Pinyon Jay Landscape-scale Habitat Modeling

Pinyon Jay Landscape-scale habitat modeling was conducted in concert with the Gray Vireo habitat modeling (see section Gray Vireo and Pinyon Jay: Landscape-scale habitat modeling, above). Map unit descriptions and photos are included in the Appendix. We delineated the boundaries based on field data, an existing vegetation map (Muldavin et al. 2000b), and visual aerial photo interpretation of the relative density of trees to distinguish between Pinyon-Juniper Woodland and Pinyon Pine Woodland.

## Pinyon Jay Colony-scale Predictive Modeling

For this study, we monitored five Pinyon Jay nesting colonies, at the KAFB Winch Site in 2009, the KAFB South Site in 2010-2011, the Receiver and Office Sites at KAFB in 2012, and WSMR colony sites in 2009-2012 (Figure 27). 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). They moved their colony site again in 2012. These shifts provided the opportunity to investigate factors associated with choice of colony site. Second, we collected GIS measures of colony-scale variables at three colonies (South and Office at KAFB; 2009 colony at WSMR) to provide a range of these measures at the two study sites. At each study site, we created a landscape-scale classification using these variables. Then, elsewhere across the landscape, we mapped the classes we had defined within the colonies. We considered sites classified similarly to the colony sites to be potential or predicted colony sites.

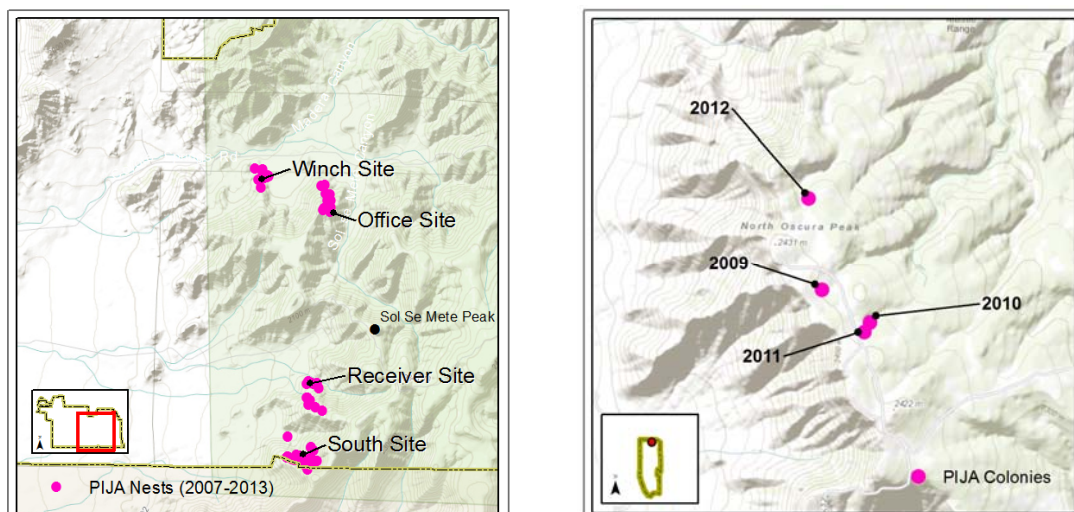


Figure 27. Pinyon Jay (PIJA) colony sites (2009-2013), KAFB on left, WSMR on right.

*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 sites in 2010, 2011, and 2012.

To investigate the hypothesis that tree vigor at the traditional, abandoned colony site declined over time, we first estimated the colony boundary using a 95% minimum convex polygon (MCP) around all nests detected in 2007-2009 via the *adehabitatHR* package (Calenge 2013) in R (R Core Team 2013). The 95% MCP excludes possible outliers to reduce over-inflation of MCPs and is often employed in radio-tracking data (White and Garrott 1990). In addition to MCP area, we added a 100 m buffer. In doing so, we assumed birds selecting nest sites within colonies considered habitat quality at multiple scales (e.g., vegetation at nest sites plus food availability in surrounding vegetation, Orians and Wittenberger 1991). This assumption was supported by observations of recently-fledged broods within this buffer area (10 broods 2005-2009; K. Johnson, pers. observ.). For the analysis reported here, we used a subset of the vigor data set, including vigor data from all transect trees that fell within the buffered colony polygons.

We ranked vigor only on standing trees, which meant that fallen dead trees were removed from the data set and replaced with standing trees, while standing dead trees remained in the data set for more than one year. Because of this inconsistency with regard to dead trees, we ensured that (1) only one tree at each point quarter was used in the time series of vigor measurements, (2) a tree was only included if its vigor was recorded in at least half the sample (i.e.,  $\geq 3$  years), and (3) once a tree died, it was removed from the analysis in subsequent years.

We modeled changes in tree vigor over time using linear mixed models (Pinheiro and Bates 2000, Zuur et al. 2009). Although vigor was a categorical index, we treated it as a continuous dependent variable because it had an approximately normal distribution. We used a baseline (null) model with three hierarchically-nested random intercepts: (1) transect, (2) plot within transect, and (3) tree within plot within transect. We used random intercepts at the transect and

plot level to account for spatial dependence of these sampling locations and random intercepts at the tree level to account for repeated (annual) sampling of individual trees. We also included a crossed random intercept of year to account for correlated measures within each year. We then built two additional models hypothesizing: (1) a linear decline of vigor that was equal across all trees, and (2) a linear decline of vigor that varied across trees (i.e., a random coefficients [random slope] model). Each model was fit via maximum likelihood (using the Laplace approximation), and we assessed the evidence for each model using the  $AIC_C$ . We averaged parameter estimates following Burnham and Anderson (2002) if multiple models were supported ( $\Delta AIC_C < 2$ ). Using the most complex model, we examined residuals for serial autocorrelation but found fewer than 4% (mean  $r_s = -0.05$ ) and 2% (mean  $r_s = -0.23$ ) of trees showed significant autocorrelation ( $P < 0.05$ ) at one-year and two-year lags, respectively. We performed all modeling in R (R Core Team 2013).

To investigate the hypothesis that trees in newly-colonized areas had higher vigor than in newly abandoned areas, we first assessed the annual movement of colonies used between 2005 and 2012. As with long-term changes in tree vigor within the historical (2005–2009) colony, we first employed a 95% MCP to identify colony boundaries in 2010–2012. We identified two years of notable movement (2010 and 2012) in which previous and current colony boundaries showed no spatial overlap. Using a 100 m buffer around these boundaries, we designated trees as being within abandoned or colonized sites during these two focal years.

We modeled colonization or abandonment as a response to tree vigor using a generalized linear model with a binomial link (logistic regression). We constructed a candidate set of three models: (1) a year-effect only to account for overall different proportions of colonized and abandoned trees in 2010 and 2012, (2) an additive model of vigor and year, and (3) a vigor  $\times$  year interaction model accounting for different vigor gradients in the two years. While we considered using a mixed model approach to this analysis by employing subject-level random effects, most trees, plots, and transects had only one state (colonized or abandoned) in the two years of major colony movements, leading to model convergence issues. As with models of vigor trend, we assessed support for models using  $AIC_C$ .

*Modeling 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).

$$\text{Eq1: NDVI} = (\text{NIR} - \text{VIR}) / (\text{NIR} + \text{VIR})$$

$$\text{Eq2: NDSVI} = (\text{MIR7} - \text{VIR}) / (\text{MIR7} + \text{VIR})$$

$$\text{Eq3: Moisture Index} = (\text{MIR5} - \text{MIR7}) / (\text{MIR5} + \text{MIR7})$$

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.

*Colony-scale modeling.* 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. 2011) using a minimum-distance decision rule classifier in an unsupervised classification.

For our initial colony-scale modeling effort at KAFB (Johnson et al. 2012a), 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 unsupervised classification applied to the entire study area, we selected the classes that overlay Pinyon Jay nests within the South Site colony as a subset and analyzed each class with regard to biophysical characteristics such as dense-to-sparse tree cover, slope ranges, and presence of a nest from one of the two colony sites. The 20 classes were combined into three meaningful groups, based on spatial contiguity and landscape position. We then combined the grouped classification results with the landscape model vegetation type. We ran a diversity focal analysis (32 x 32 matrix) on these, approximating the smallest colony size (10 ha). Our resulting nine biophysical classes represent landscape position and dominant vegetation map unit. These classes range from high to moderate to low slopes for Pinyon Pine Woodland, Pinyon-Juniper Woodland, and Juniper Woodland and Savanna. 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 (see Johnson et al. 2012a for details).

*Second iteration of Pinyon Jay colony-scale model.* After finding two additional colonies in the 2012 field season using the aforementioned colony model, we recreated the colony-scale model. We also acquired a new statistical software tool to group our initial classification results (ESRI Grouping Analysis, ArcGIS 10.2), where we had previously used graphical displays of the data to determine groups similar to the South Site. Also, after creating the initial colony model, we revised the landscape model, which resolves elements of the landscape at a finer scale. We felt that the additional tool and data inputs justified a second modeling effort.

In 2013, for our second iteration, we combined the South Site colony with one of the new colony sites (Office Site), again selecting those polygons with the largest diversity indices. Small, disjunct areas were removed ( $n=18$ ), leaving 963 polygons to group. Using the ArcGIS 10.2 Grouping Analysis tool, we evaluated the polygons ( $n=963$ ) for the optimal number of groups, finding seven groups (F-statistic=33.35) would be optimal. Polygons were evaluated for grouping based on percent cover of Pinyon Woodland, Pinyon-Juniper Woodland, Juniper Woodland and Savanna, and “no value.” No value represents percent of area covered in non-target map classes such as Shrubland.

*Validation of Colony Models.* In 2012, we found two new colony sites at KAFB, and the Pinyon Jays at WSMR moved their colony again. We used the Office Colony as additional input to the second modeling effort, which revised the Pinyon Jay colony-scale predictive model for KAFB (see above). In April 2013, we field surveyed the colony site polygons at KAFB predicted by the first model. We walked through each polygon, listening and watching for Pinyon Jays, with sufficient coverage to hear jays within 200m. We found eight old Pinyon Jay nests during these surveys. For validation of the revised colony-scale model, we used 12 nests from the Receiver

Site and the eight old nests. For validation of the WSMR colony-scale model, we used the 12 nests from the new 2012 colony site.

### **Pinyon Jay Within-colony Nest-scale Analyses**

*Field measurements.* In 2010, 2011, and 2012, we captured Pinyon Jays at feeders at both study sites. In 2010, Pinyon Jays nested at the KAFB Winch Site, for one year only. Also in 2010, we switched our KAFB trapping site to the SOR guard house, where Pinyon Jays frequent feeders maintained by the security guard. In 2010, we followed transmitter birds to a nesting colony in a canyon near the KAFB south boundary (the South Colony). The jays nested at that site again in 2011. We collected nest plot data at the South Site in 2010 and 2011; jays did not nest at the South Colony site in 2012. In 2012, we followed transmitter birds to a new colony site near, but to the northeast of the 2010-2011 South Colony and collected nest plot data at the new site, which we called the Receiver Colony. In 2011 and 2012 (but not 2010), we trapped and banded WSMR birds at the same location as for the (2009) landscape modeling aspect of the study. We did not attach transmitters at WSMR after 2009 because the WSMR colony always returned to the same general area. We found WSMR colony sites and nests by observing courtship, nesting, and nestling-care behaviors.

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 for all 2010-2012 nests at all colonies. 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 Core Team 2013).

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  $|r| > 0.6$  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<sub>c</sub> 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 six models representing *a priori* hypotheses. We considered any model with an AIC<sub>c</sub> < 2 units above that of the lowest AIC<sub>c</sub> 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: RESULTS**

### **Landscape-scale Habitat Models KAFB**

#### **Banding/Transmitters**

We captured and banded seven Pinyon Jays on 12 August 2009 and 11 on 31 August 2009. Ten of these were after-hatch-year birds and eight were hatch-year birds. The presence of hatch-year birds indicates that the jays at KAFB nested successfully in 2009. We attached transmitters to three birds, all after-hatch-year birds.

One transmitter was detectable only until 23 October. This was well within the expected battery life of the transmitter, which suggests that the bird left the area. A second transmitter stopped

moving on 11 November, which suggests that the bird died or the transmitter fell off. We were unable to triangulate on this transmitter, and we failed to find it. We continued to receive moving signals from the third transmitter until 28 December, when the battery presumably died. The third transmitter provided several flock locations through the fall and into the winter.

### **Flock Size**

We have 54 records of Pinyon Jays at KAFB where we noted flock size, excluding observations at the feeder. For these 54, the mean number of birds was 18.2 (range 1-135). Most observations were of groups of birds. Only nine observations were of a single bird. Over half (29) of the observations were of groups of six or more individuals. For these larger groups, the mean group size was 31.7. On seven occasions we counted or estimated 50 or more birds in a flock. These observations occurred in June ( $n=4$ ), July ( $n=2$ ), and October ( $n=1$ ). These data suggest that the flock in the north area has up to 135 members but that the flock typically breaks up into smaller groups for nesting, foraging, caching, etc.

During the study, we found four separate breeding groups of Pinyon Jays at KAFB, which we call the Winch, South, Receiver, and Office Colonies (Figure 27). The Winch Colony was found in juniper-dominated woodland at low elevation (1859-1945 m). The South Colony was in higher-elevation pinyon-dominated woodland (2117-2144 m). The Receiver Colony was east of SOR near the Receiver Site in Pinyon-Juniper Woodland and Pinyon Woodland (1977-2165 m). The Office Colony was just over a small ridge to the east of the Winch Colony, in Pinyon-Juniper Woodland and Pinyon Woodland habitat (1972-2135m). These breeding groups were small relative to the sizes of the large flocks we observed in the nonbreeding season. We found nine active nests and four inactive nests (which could have been from previous years) at the Winch Colony in 2010, which suggests that no more than 13 pairs nested there in 2010. We found nine and 13 nests of the year at the South Colony in 2010 and 2011, respectively. In 2012, we found 12 nests of the year at the Receiver Colony and 10 at the Office Colony. In any one year, nesting pairs together with their fledglings could have numbered around 100 birds. This suggests that a large winter flock at KAFB may split into two smaller breeding groups.

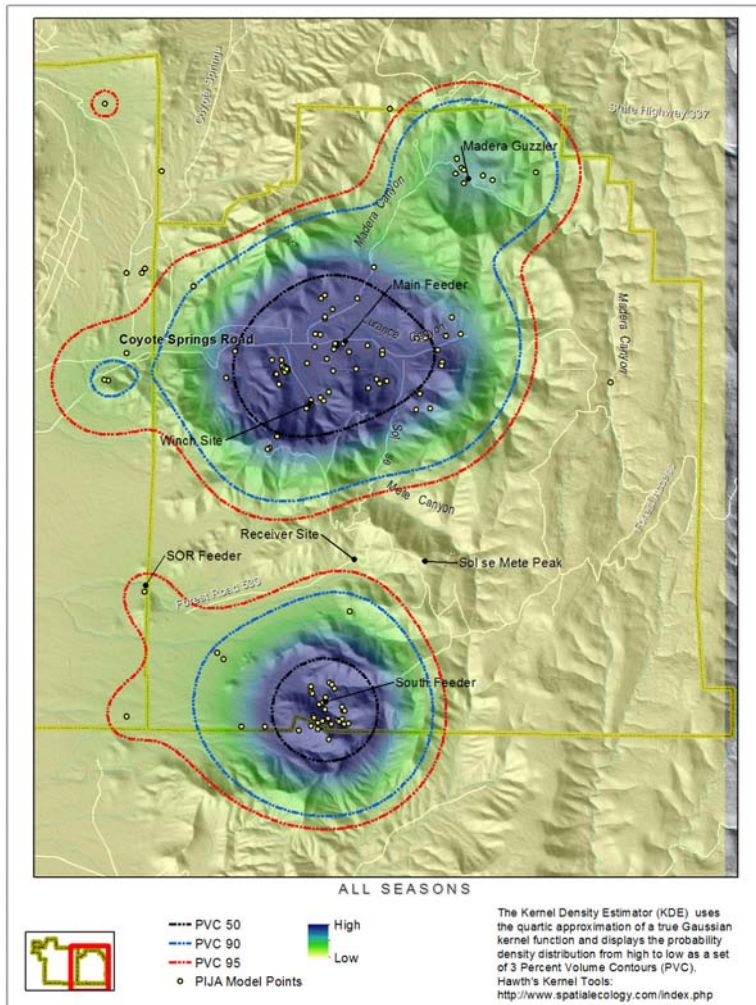


Figure 28. Kernel Density Estimator (KDE) for Pinyon Jays, all seasons, KAFB.

### Home Ranges

From the transmitters, we obtained 23 useful overlapping bearings that resulted in 11 point locations in the GIS. Ground surveys yielded 112 additional point locations. The kernel density map depicts the 50, 90, and 95% kernel density polygons for all Pinyon Jays detected in 2009 and nest sites from 2010 (Figure 28). This map provides a reasonably good prediction of where Pinyon Jays could be found at KAFB between March and December 2009 and March through June 2010.

### Breeding

The breeding season home range of the Winch Colony birds centered around the slopes of the Winch Site and Sol Se Mete Canyon, extending north to a caching area in Juniper Woodland and Savanna habitat inside the Live Firing Range. Another, smaller center of activity occurred on a hill to the northeast of the Burn Site near the Madera Guzzler (Figure 29). Birds were detected in the north area on 2-10 days each month from 22 March through 28 December 2009 and nested at the Winch Site in March and April 2010.

The South Colony was present near the south KAFB boundary in steep terrain of pinyon-dominated vegetation from May through late August 2009 and nested in the area from late March into May 2010. We did not hear or see jays in the south area in June or July 2010 when we were in the area on several occasions collecting nest plot data, but a large flock re-appeared in the area on 20 August 2010 so was likely in the area all summer.

In February 2010, we learned of a group of Pinyon Jays that was frequenting a feeder at SOR, between the summer ranges of the Winch and South Colonies. Based on the appearance of fledglings at the feeder starting 22 April 2010, we believed this group nested on the east side of the Receiver Site, an area of frequent testing and limited access (Figure 29). We found this Receiver Colony in 2012.

The 95% breeding season kernel for both breeding areas covers 4305.3 ha. The 95% breeding kernel for the north area was 2638.3 ha in area, which includes the single observation in the northwest, and the 95% breeding season kernel for the south area was 1666.9 ha (Figure 29). The breeding season MCP including both north and south areas covers 4509.4 ha (Figure 30) and does not distinguish a north-south area, as does the more statistically rigorous kernel density estimator.

The new colonies we discovered in 2012 serve as validation points for the breeding season KDE model. All 10 Office Colony nests and all 12 Receiver Colony nests, or 100% of validation points, fell within the breeding season KDE model.

#### *Nonbreeding*

Jays left the south area by the beginning of August 2009 and were gone by 20 May 2010, but they returned on 20 August 2010. Although at least one radio was transmitting through 28 December 2009, we never detected a radio signal or found the flock in the south area after August in 2009. The nonbreeding MCP covers 2554.1 ha (Figure 30), and the nonbreeding 95% kernel model covers 3951.9 ha (Figure 29).

#### *Combined Breeding and Nonbreeding*

The MCP polygon, including breeding and nonbreeding areas north, south, and everything in between, covers 5027.4 ha (Figure 30). The 95% kernel model for both north and south breeding areas and both seasons covers 5741.7 ha and shows the persistent area of activity during both the breeding and nonbreeding seasons in red (Figure 31). The most spatially extensive use occurred in the north, with distinct breeding season centers of activity.

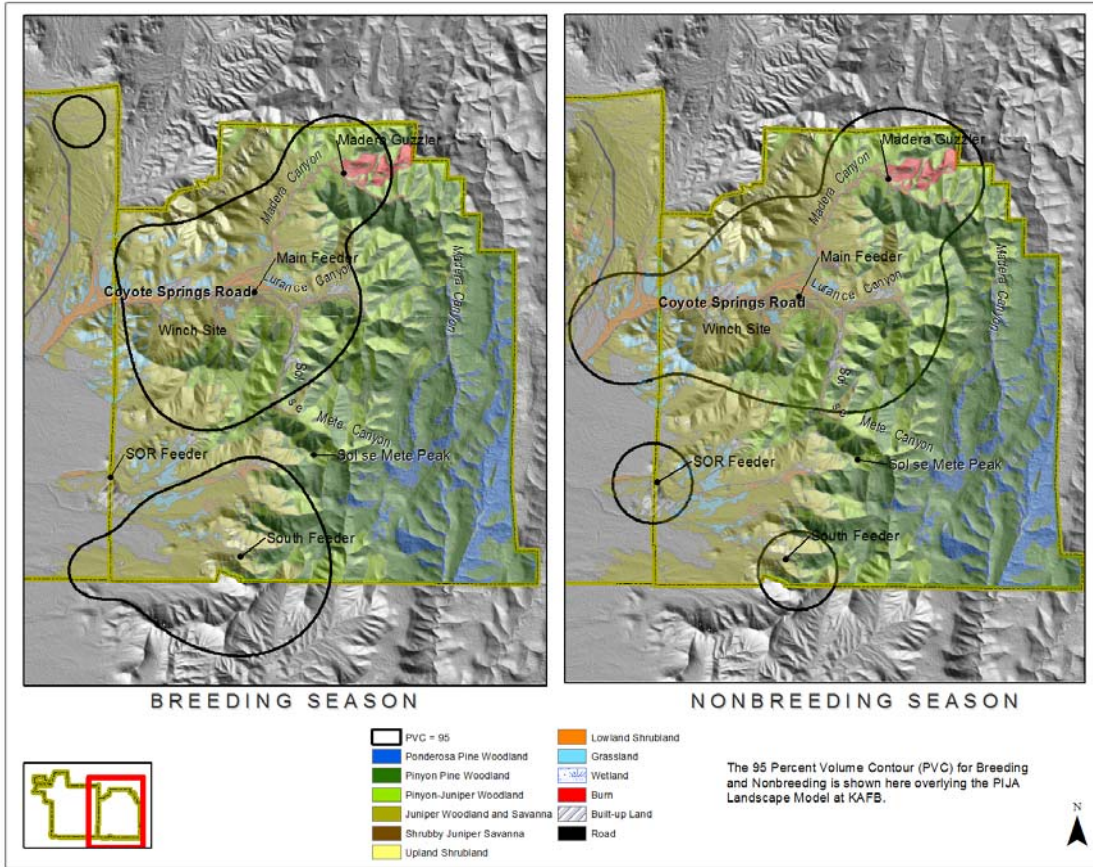


Figure 29. Pinyon Jay breeding and nonbreeding season 95% KDE, KAFB.



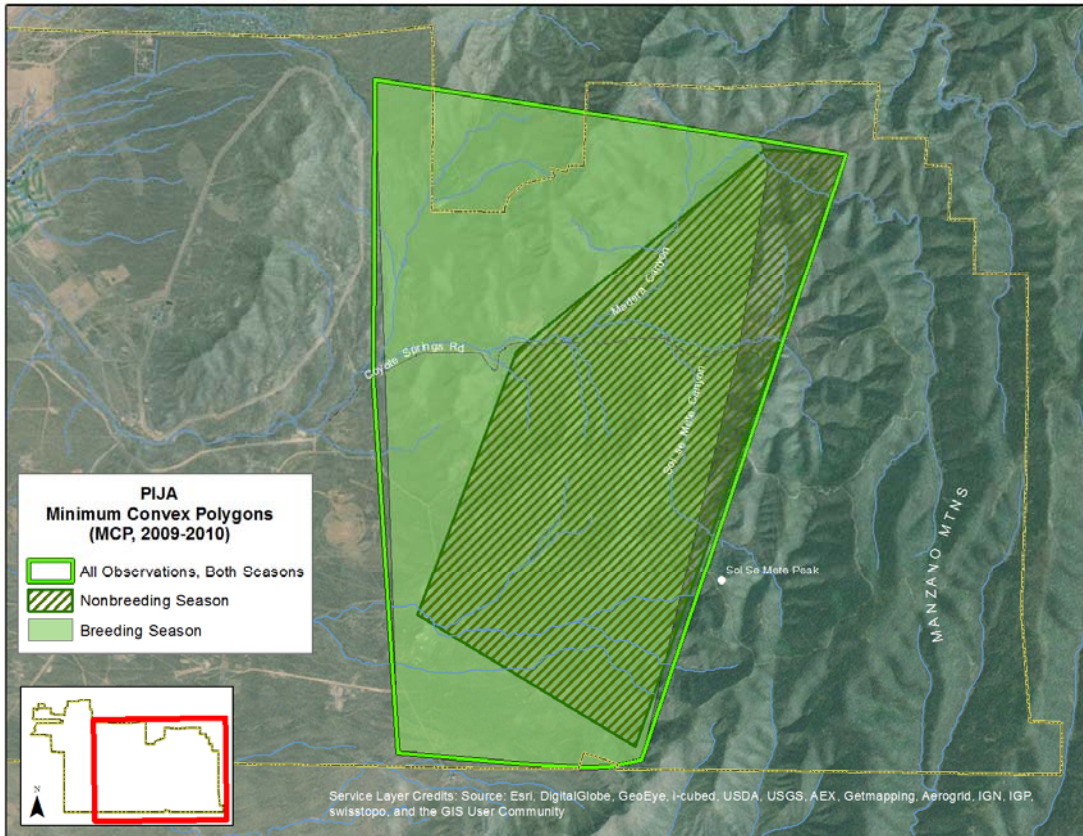
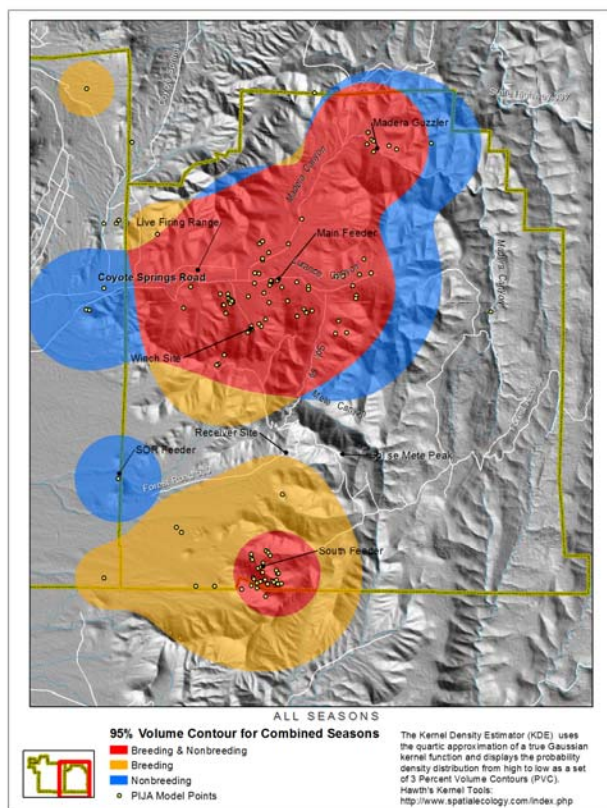


Figure 30. Pinyon Jay minimum convex polygons for all seasons, KAFB.



**Figure 31. Kernels showing areas of maximum use by Pinyon Jay, KAFB, all seasons.**

## Caching Areas

Only two activity polygons were clearly in caching areas. One, at the top of a hill near the Madera Canyon guzzler, was in a burned area. We observed birds in this area in early spring of 2009 apparently retrieving caches. These birds may have been retrieving seeds collected from the nearby woodland and cached in late 2008. We found several pinyon seedlings near the top of this hill, which was relatively free of trees and shrubs. The presence of seedlings on top of a hill suggests that avian seed dispersers cached there in previous years.

The main caching area, used in both breeding and nonbreeding seasons, was a mostly south-facing, 18 ha, gentle hill slope within the Live Firing Range (Figure 31). The lower hill slope is moderately sparse, dominated by

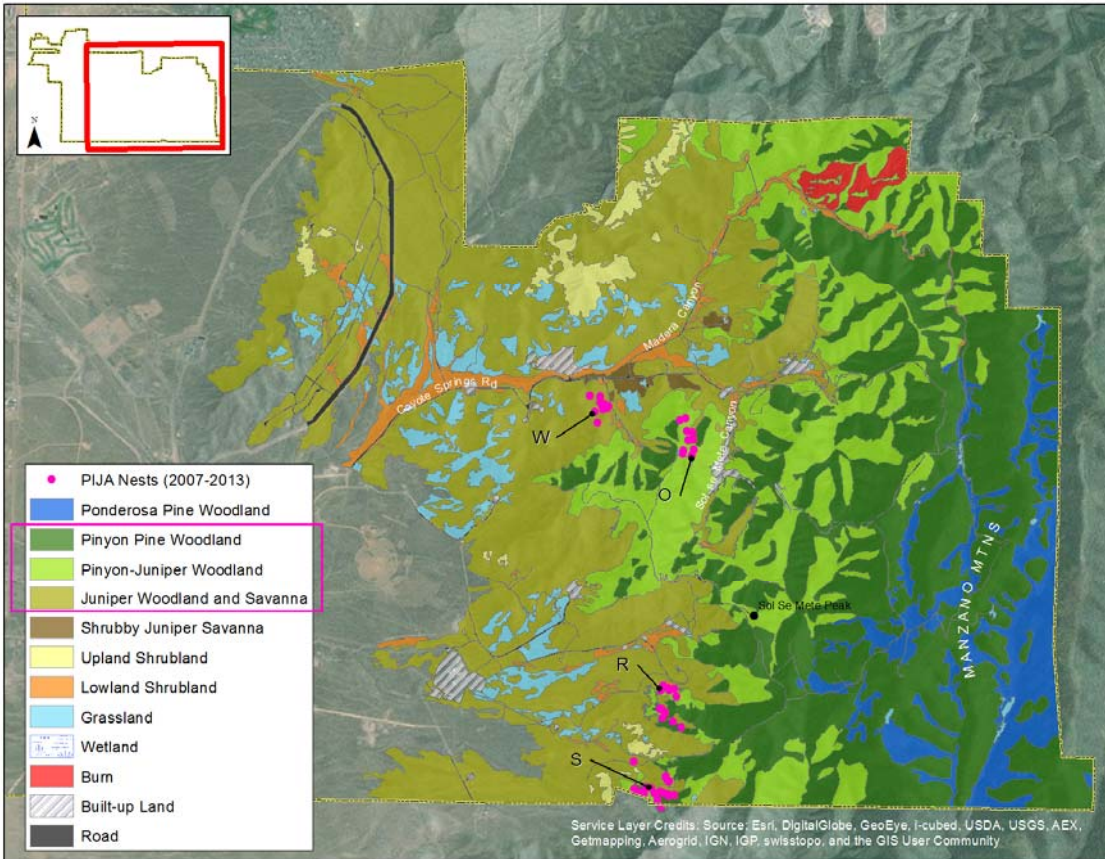
grasses and shrubs with very scattered juniper. Higher slopes and hill slope drainages have more shrubs and juniper,

transitioning to gently sloping juniper scrub mix in open woodland and juniper with fourwing saltbush in drainages. We frequently observed jays walking on the ground in this area, apparently caching and/or retrieving caches. Birds probably cached seeds from the feeder there, but they might have also had caches there from the cone crop in the fall of 2008. We observed jays in this area on nine occasions, between August and December 2009. We noted that in January and February when deep snow was present on north-facing slopes, the caching area was free of snow. Soon after we put up the feeder in February 2010, jays began frequenting this caching area again.

## Landscape Model

The GIS landscape-scale habitat model for KAFB covers 9424 ha of potential habitat ranging in elevation from approximately 1742 m to 2439 m. The vegetation types within this map include Ponderosa Pine Woodland, Pinyon Pine Woodland, Pinyon-Juniper Woodland, Juniper Woodland and Savanna, Shrubby Juniper Savanna, Upland Shrubland, Lowland Shrubland, Grassland, Wetland, Burn, Built-up Land, and Road (Figure 32, see Appendix for map unit details). A subset of the landscape-scale map units is considered habitat for Pinyon Jays at KAFB. These include: Pinyon Pine Woodland, Pinyon-Juniper Woodland, and Juniper





**Figure 32. Pinyon Jay landscape habitat model, KAFB. Vegetation types within the pink box were used by Pinyon Jays at KAFB. Pinyon Jay nesting colony sites used over the study include Winch (W), Office (O), Receiver (R), and South (S).**

Woodland and Savanna. Pinyon Jays occur rarely in the Ponderosa Pine Woodland in the eastern portion of KAFB. However, we do not include Ponderosa Pine in this model, because we had no data indicating that Pinyon Jays from the KAFB flock ranged higher into the ponderosa.

The majority of Pinyon Jay nests and observations at KAFB (2009-2013) are from Juniper Woodland and Savanna ( $n=77$ ), Pinyon-Juniper Woodland ( $n=48$ ), and Pinyon Pine Woodland ( $n=28$ ). The remaining observations ( $n=18$ ) are spread across map units with totals not exceeding five in any map unit. Comparing breeding and non-breeding use by landscape map unit, the landscape types used do not change between seasons (Figure 33), but the proportions of use differed between seasons.

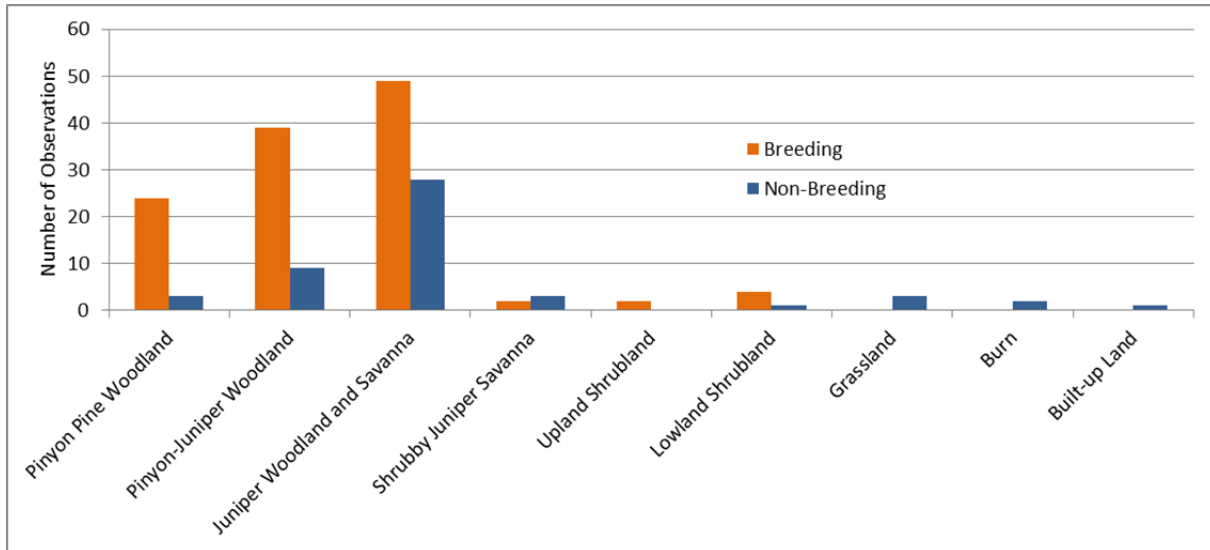


Figure 33. Observations of Pinyon Jays by season and habitat type for 2009-2010.

Comparing vegetation types within delineated breeding and nonbreeding season home ranges, higher-elevation Pinyon Pine Woodland and Pinyon-Juniper Woodland were more heavily used within the breeding range (20% and 32.5%, versus 6% and 18%, respectively). Conversely, Juniper Woodland and Savanna occupied only 41% of the breeding range and covered 56% of non-breeding home range (Figure 34).

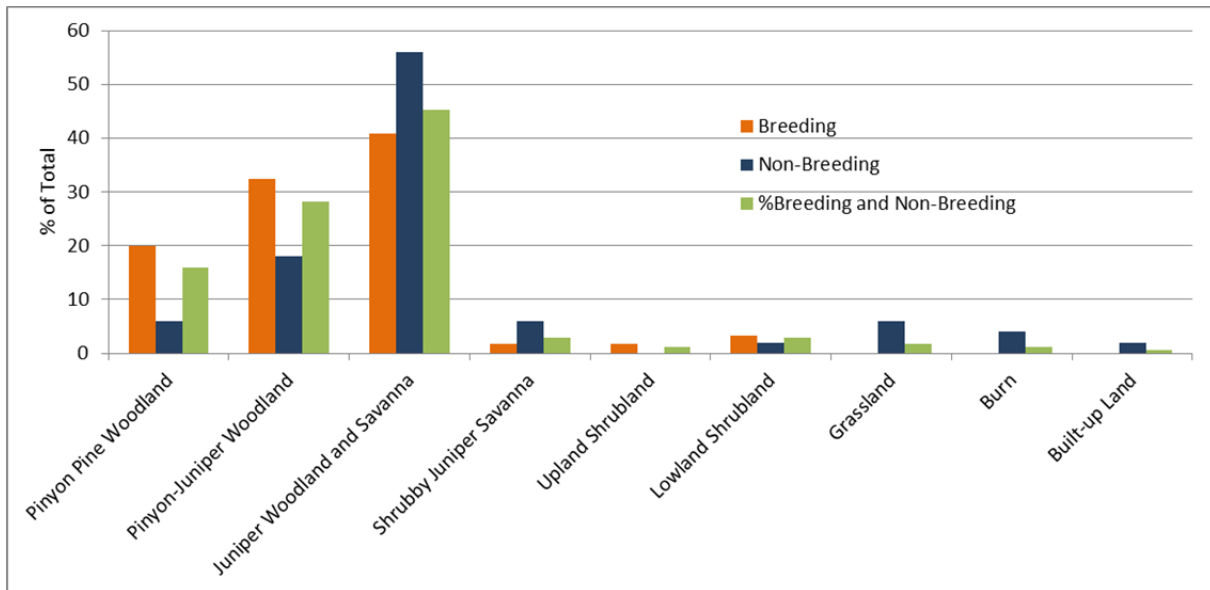


Figure 34. Percent of landscape-scale map unit within breeding and non-breeding home ranges for 2009-2010.

### Distance to Military Infrastructure and Activities

The type of infrastructure differs near the two principal breeding colonies of the north and south. The Winch Colony lay within 380 m of Coyote Springs Road, a secondary east-west trending

road, and only 60 m from a less used tertiary road (Winch Site Road, FR 24e). The area is relatively flat with the infrastructure lying essentially at the same elevation as the nest sites. The principal impacts are vehicle noise and dust, as both roads are unpaved. Additionally, a firing range lies within 850 m of the Winch Colony and live firing can be easily heard at the nest sites. The South Colony lies in relative isolation from impacts, approximately 130 m from the south boundary of the installation bordering the Pueblo of Isleta. It is in a less-utilized area of the installation and is accessible by only two tertiary roads and a ~30-minute hike. One nest tree was adjacent to the tertiary road, while the remaining breeding colony was upslope 160-180 m and 370-600 m from the nearest road.

## **Landscape-scale Habitat Models WSMR**

### **Banding**

At WSMR in 2009, we trapped and banded 24 new Pinyon Jays and re-captured three banded birds from previous years. Including all birds captured for the first time in 2009, 15 were after-hatch-year birds and 12 were hatch-year birds. The number of hatch year birds captured indicates that the NOP flock fledged young in 2009, although relative numbers of hatch-year and after-hatch-year birds captured suggests that 2009 was not a highly successful breeding season. The year 2009 was apparently also a transition year for the location of the colony. We found no nests in the traditional colony site in 2010 and only three in 2009. It is likely that the birds were in the process of moving the colony site in 2009 but we did not find the new site until 2010. Some of the nests we found at the new colony site in 2010 were inactive and could have been constructed in 2009.

### **Flock Size**

We recorded flock sizes on five occasions at WSMR on 30 June, 30 September, and 29 October 2009. Flocks ranged from 10 to over 100, with a mean flock size of 38.4. We observed the flock of >100 on 30 September. This flock was larger than the group of jays that nested at NOP and was likely an aggregate of more than one breeding group, but we have not located a breeding colony outside of NOP at WSMR.

### **Location Data**

From the transmitters, we obtained 79 bearings in 2009 that resulted in 17 point locations in the GIS. Ground surveys in 2009 and 2010 yielded 38 additional point locations. We included 47 locations from 2005, 2007, and 2008 in the KDE analysis. All points from previous years fell within the 95% kernel boundaries. We used 102 point locations from all sources in the kernel analyses. The kernel density maps depict the 95% kernel density polygons for all Pinyon Jays detected in 2005 and 2007-2010.

## Home Ranges

The combined KDE model provides a reasonably good depiction of where Pinyon Jays could be found at or near NOP between 24 March and 29 October 2009. Jays left NOP the last week of September 2009. We saw a flock of over 100 birds northeast of NOP in the Garden Spring Canyon area on 30 September and heard transmitters in lower-elevation juniper habitat to the east of there. We detected a few birds in low-elevation juniper habitat on 29 October. The NOP flock left NOP after the breeding season every year from 2005 to 2011, and we have never found the flock after October. We suspect that they winter in lower-elevation juniper savanna habitat and probably wander widely in the nonbreeding season.

### *Breeding*

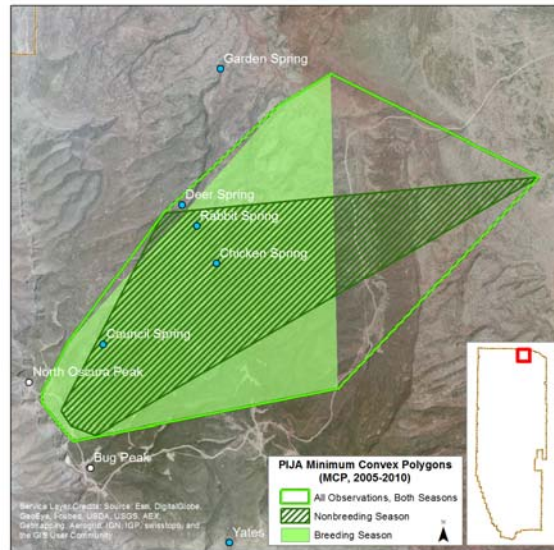
The NOP breeding season MCP covered 2161.8 ha (Figure 35), and the 95% KDE model for the breeding season at NOP covered 2550.9 ha (Figure 36).

### *Nonbreeding*

The nonbreeding MCP covered 1635.9 ha (Figure 35), and the nonbreeding KDE model covered 2720.9 ha (Figure 36).

### *Combined Breeding and Nonbreeding*

The combined breeding and nonbreeding MCP covered 3415.7 ha (Figure 35), and the combined 95% kernel covered 3486.8 ha, with the greatest amount of activity occurring in all seasons shown in red (Figure 37). Seasonal activities overlap 51% of the time, with the remaining breeding and nonbreeding areas fairly disjunct.



**Figure 35. Pinyon Jay minimum convex polygons for all seasons, Oscura Mtns., WSMR.**

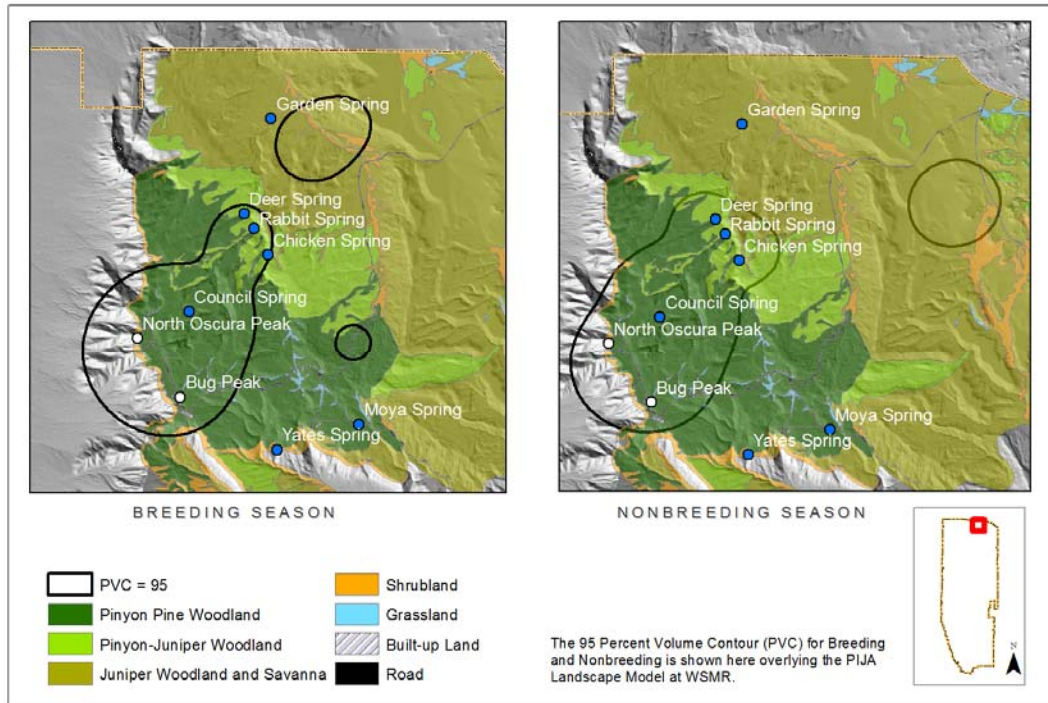


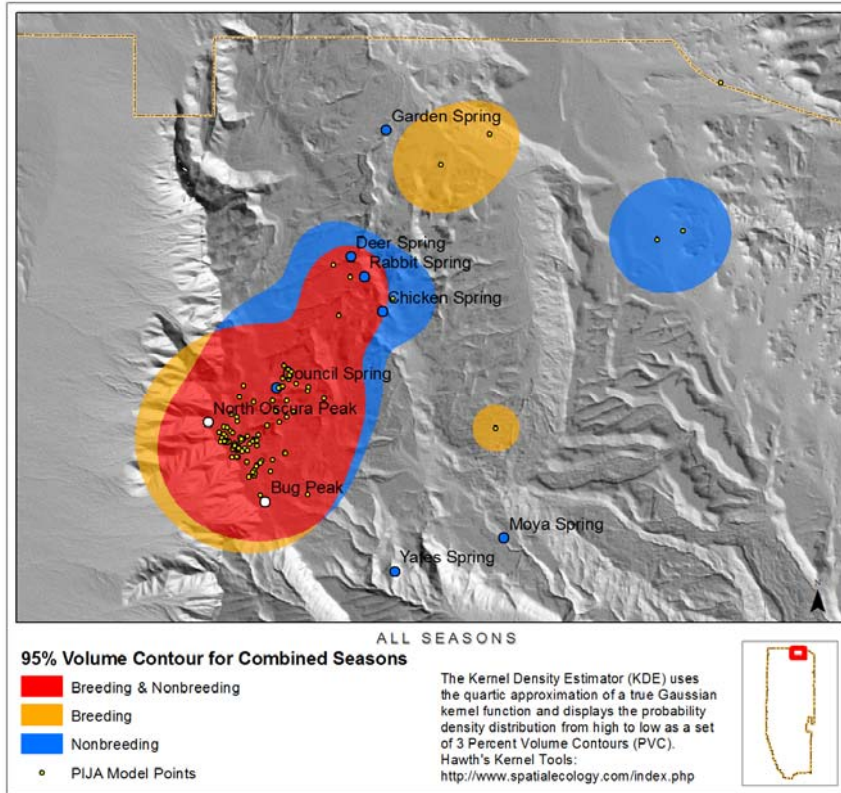
Figure 36. Pinyon Jay KDE model, Oscura Mtns., WSMR.

### Landscape Model

The landscape model for Pinyon Jays in the Oscura Mountains at WSMR covers 23,066 ha of potential habitat ranging in elevation from approximately 1678-2632 m. The habitat types in this map are Pinyon Pine Woodland, Pinyon-Juniper Woodland, Juniper Woodland and Savanna, Shrubland, Grassland, Built-up Land, and Road. Only Pinyon Pine Woodland, Pinyon-Juniper Woodland, and Juniper Woodland and Savanna are included in the landscape habitat model for Pinyon Jays at WSMR (Figure 38). At WSMR, we found fewer transitions from Pinyon Pine Woodland to Pinyon-Juniper Woodland than at KAFB. This may be due to abrupt changes in elevation, particularly along the western border, or changes in lithology.

Since 2005, Pinyon Jays at NOP have established a breeding colony in Pinyon Pine Woodland at elevations up to about 2400 m. This vegetation type at NOP contains some very old trees, some approaching 400 years of age (Muldavin et al. 2003), in what has been called “persistent woodlands” (Romme et al. 2009). The colony location has shifted within this habitat type among years, but at WSMR we have never found jays nesting in lower-elevation Pinyon-Juniper Woodland or Juniper Woodland and Savanna.





**Figure 37. Pinyon Jay activity, all seasons, WSMR.**

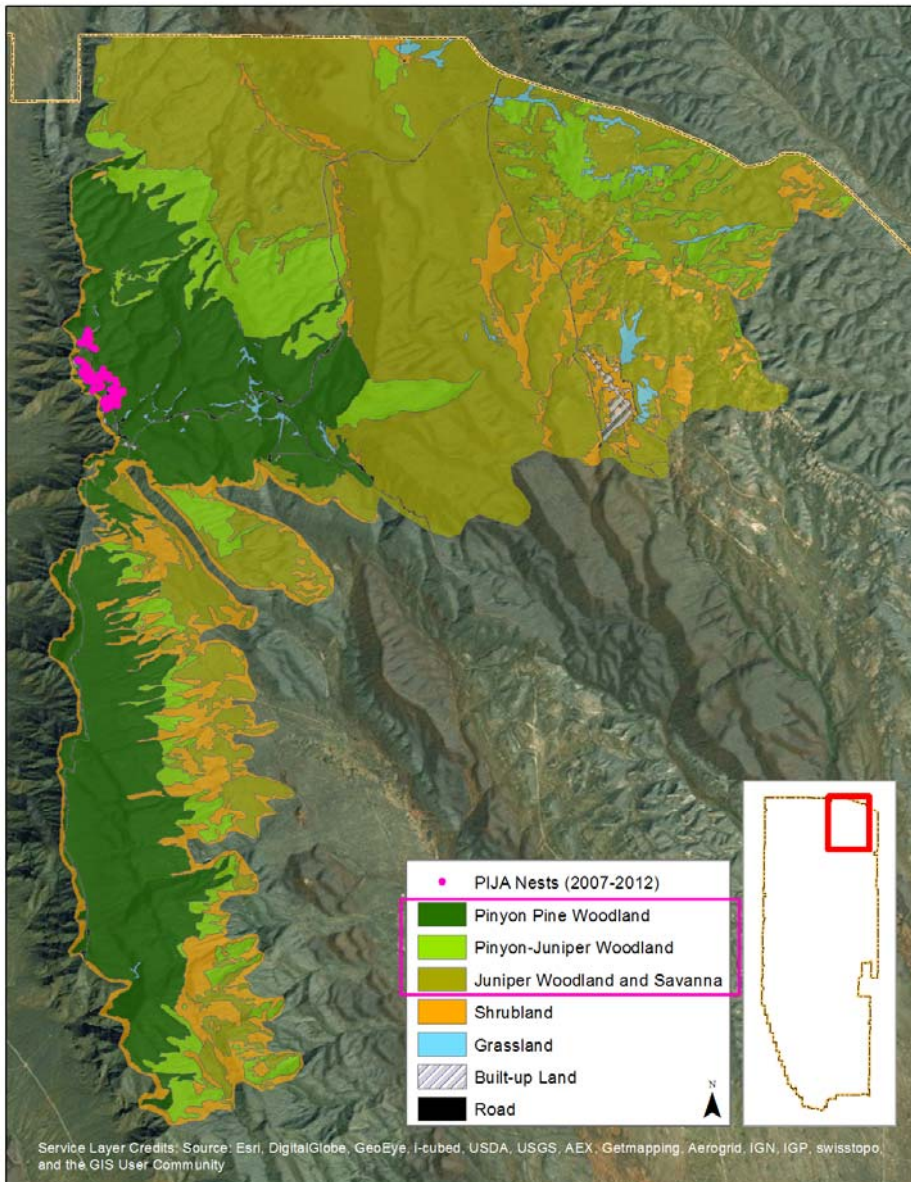
After fledglings are capable of strong flight, the flock moves widely, including to lower elevation Juniper Woodland and Savanna habitats. During these movements they pass over or through mid-elevation, mixed pinyon-juniper habitats.

The breeding season home range of the NOP flock contains a slightly higher percentage than the nonbreeding season home range of Pinyon Pine Woodland (62% vs. 58%). Conversely, the nonbreeding season home range model contains slightly more Pinyon-Juniper Woodland (14.8% vs. 8.8%). Other vegetation types are comparable between seasons (within 1% of each other) with the exception of Shrubland, having approximately 2% greater cover in the breeding season home range. However, the actual differences in habitat use between seasons could be much larger than indicated here, due to the incompleteness of our spatial data for wintering Pinyon Jays at WSMR. Because the birds leave NOP during the winter and we have found them in Juniper Woodland and Savanna habitats in the fall, we suspect that they spend relatively more time in Juniper Woodland and Savanna and less time in Pinyon Pine Woodlands during the nonbreeding season.

### **Distance to Military Infrastructure and Activities**

The breeding colony tracked since 2007 has centered nesting activities around NOP within Pinyon Pine Woodland on either side of a major north-south road (332), with some nests situated less than 15 m from the center of the unimproved road. Traffic along the road that runs through

the colony site varies, depending on contractor presence at NOP facilities, but at busy times, 10 or more vehicles may pass through the colony site per day. Several nests have been situated less than 100 m from regularly occupied buildings. Extremely loud sonic booms can be heard almost daily at NOP. The Red Rio bombing site is located approximately 12 km to the east of the NOP breeding colony, but sound from there does not typically carry to NOP.



**Figure 38. Pinyon Jay landscape-scale habitat model, Oscura Mountains and portions of Chupadera Mesa, WSMR. Vegetation types outlined by the pink box were used by Pinyon Jays at WSMR.**

## Colony-scale Model KAFB

### *Characteristics of occupied colony sites KAFB.*

Nine classes were defined by combining the landscape model (Johnson et al. 2011) and the unsupervised classification results in an intuitive classification indicative of the heterogeneous PIJA south colony site. The classes describe the floristic and topographic diversity within the KAFB South Colony site (E, Figure 39) and range from low to high slopes of areas dominated by either pinyon, pinyon-juniper, or juniper vegetation. 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 39. Together, these 12 regions delineating potential colony sites cover only 7.6% (593 ha) of the available Pinyon Woodland, Pinyon-Juniper, and Juniper Woodland and Savanna map units of the KAFB Pinyon Jay landscape model.

The original KAFB Pinyon Jay colony-scale model predicted 11 colony sites, aside from the South Colony which was used to construct the model. The mean elevation for all sites was 2107.57 m (range=1938.88-2347.15, SD=76.19). The mean slope was 24.85°, range= 0.14-74.21, SD=8.5). The mean cosine aspect was 0.21 (range=-1.0-1.0, SD=0.64).

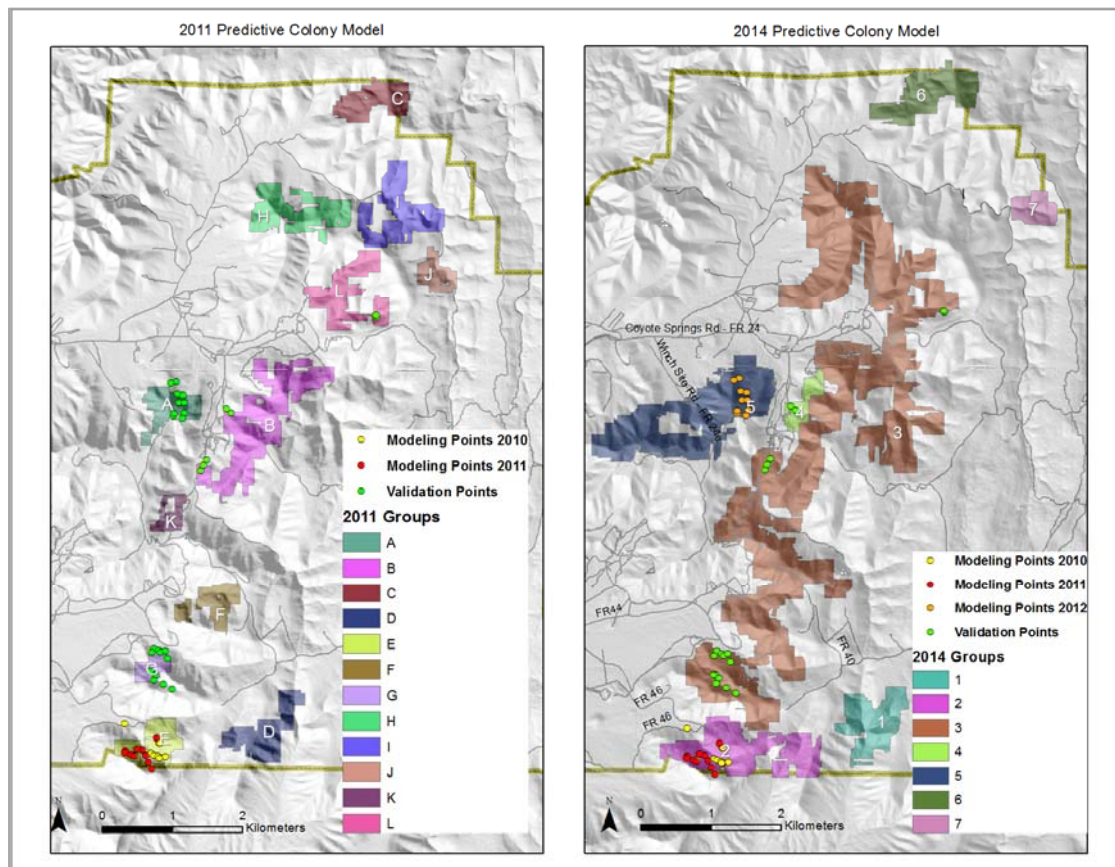


Figure 39. Colony-scale predictive habitat models for Pinyon Jay colonies at KAFB, showing nests. KAFB Receiver (polygon G) and KAFB Office (polygon A) Colonies, were predicted by the 2011 colony-scale predictive habitat model, with 56.7% of validation nests predicted by the 2011 model. The revised (2014) predictive model was more successful at predicting nests, with 90% success.



The second Pinyon Jay colony-scale model consisting of seven groups (Figure 39) covers 1304 ha over 16 % of available Pinyon Woodland, Pinyon-Juniper, and Juniper Woodland and Savanna available within the KAFB Pinyon Jay landscape model. The mean elevation for all sites was 2104.4 m (range=1901.9-2333.6, SD=78). The mean slope was 22.7°, range=0.11-76.1, SD=3.2). The mean cosine aspect was 0.129 (range=-1.0-1, SD=.22). The 2014 model includes more than twice the area of the 2011 model, likely due to the input of data from two colonies in the model construction, as well as use of the Grouping Analysis tool.

### **Colony-scale Model WSMR**

*Abandoned versus new colony sites.* We modeled vigor change from 2005-2009 at the traditional NOP colony site. A total of 77 trees, among 21 plots, and on two transects, fell within buffered 95% MCP boundaries of the historical (2005–2009) colony. Vigor of each tree was measured for an average 5.9 years. Vigor declined from an average 3.81 ( $\pm 0.65$  SD,  $n=71$ ) in 2005 to 3.09 ( $\pm 0.71$  SD,  $n=77$ ) in 2010 (Table 9), or 81% of initial vigor. The overwhelmingly supported model of vigor decline was a random-slopes model (Table 10). Parameter estimates of this model indicated the index of vigor declined 0.12 units per year (Table 11). Variation in annual vigor decline was greatest at the level of the individual tree (Table 11).

We identified 117 and 64 trees in 2010 and 2012, respectively, falling within boundaries of either abandoned or newly colonized sites. Mean vigor was overall higher among trees in colonized areas than in abandoned areas in both 2010 and 2012 (Table 10). The most supported model of colonization and abandonment was the vigor  $\times$  year interaction model (Table 10), which indicated both higher vigor in colonized vs. abandoned areas and differences between 2010 and 2012 in the relationship predicting the status of trees as abandoned or colonized (Table 11). This difference indicated a clearer discrimination of colonized and abandoned trees in 2012 (among trees with vigor between 3 and 4) than in 2010.

*Characteristics of occupied colony sites at WSMR.* 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 because 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.

**Table 9. Mean vigor ranks of pinyon trees in abandoned Pinyon Jay colony, 2005-2011.**

Year	<i>n</i>	Mean Vigor Rank	SD
2005	71	3.81	0.65
2006	75	3.51	0.53
2007	76	3.42	0.59
2008	77	3.32	0.52
2009	77	3.30	0.65
2010	77	3.09	0.71

**Table 10. Candidate models of (1) tree vigor decline during 2005-2010 in the historical (2005-2009) colony and (2) tree vigor differences among colonies abandoned or colonized during 2010 and 2012. Tables indicate the number of parameters (*K*), the model log-likelihood (LL), the sample-adjusted Akaike Information Criteria (AIC<sub>C</sub>), the difference between the given and best (lowest) model's AIC<sub>C</sub> (ΔAIC<sub>C</sub>), and the Akaike weight associated with each model given the model set (*w<sub>i</sub>*).**

Model	<i>K</i>	LL	AIC <sub>C</sub>	ΔAIC <sub>C</sub>	<i>w<sub>i</sub></i>
Vigor decline					
Year (random slopes)	13	-294.598	616.024	0.000	1.000
Year	7	-315.896	646.043	30.018	<0.001
Null (no trend)	6	-322.521	657.231	41.207	<0.001
Abandonment and Colonization					
Vigor × Year	4	-95.840	199.908	0.000	0.865
Vigor + Year	3	-98.740	203.616	3.708	0.135
Year	2	-114.557	233.182	33.274	<0.001



**Table 11. Parameter estimates from competitive models ( $\Delta AICC < 2$ ) of tree vigor decline (2005-2010) and tree vigor differences among colonies abandoned or colonized (2010 and 2012) on NOP, New Mexico. Standard deviation in vigor decline models is an indication of variation (from a random-slopes mixed-effects model) in the linear vigor-year relationship at three levels of sampling. Odds ratios for abandonment and colonization parameters indicate changes in the probability of colonization for each unit increase in the variable. For example, the probability of a tree being in a colonized vs. abandoned colony increased over 300% (95% CI = 81–832%) for each 1-unit increase in the tree vigor index.**

Vigor Decline					
			SD		
Variable	Estimate	SE	Transect	Plot	Tree
Year	-0.119	0.028	0.021	0.051	0.052
Abandonment and Colonization					
			Odds Ratio		
Variable	Estimate	SE	Lower 95% CI	$\bar{x}$	Upper 95% CI
Year	0.430	0.418	0.660	1.537	3.575
Vigor	1.414	0.431	1.814	4.114	9.328
Vigor $\times$ Year	2.404	1.096	1.292	11.066	94.787

Further, we were unable to evaluate the signatures using the JM formula due to a 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 concluded that the entire area similar to the colony sites should be classified as one colony-scale region (Figure 40). This region occupies 2307 ha (40%) of the Pinyon Woodland unit of the landscape model (Johnson et al. 2011) and shows little variation in the GIS measures we used in modeling (slope, aspect, elevation, NDVI, etc.). Of the Pinyon Jay colony model,

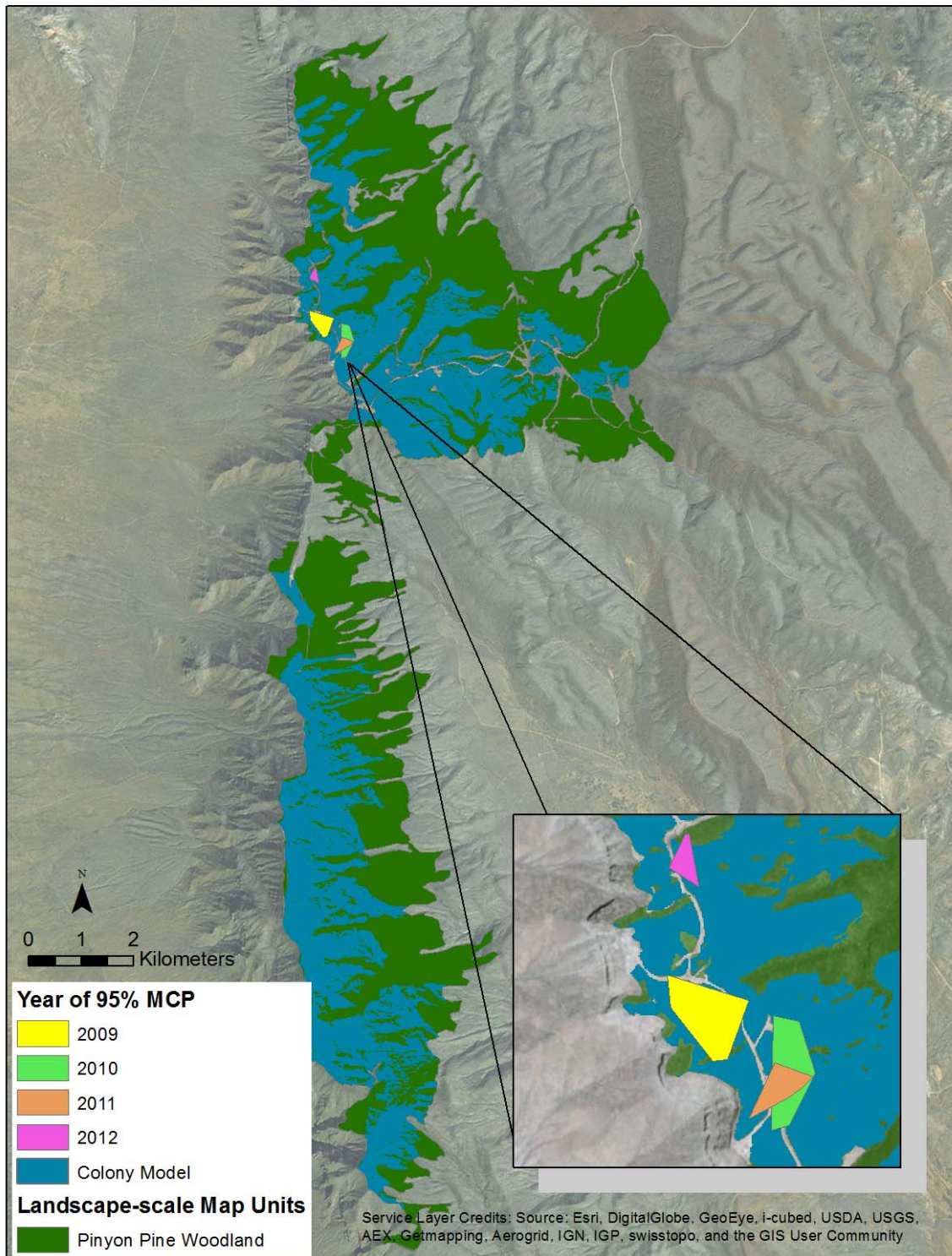


Figure 40. Colony-scale predictive habitat model for Pinyon Jays at WSMR. Inset: in 2010, Pinyon Jays moved nests from the traditional colony site to the 2010-2011 site. They moved again in 2012, to a site farther north.

which comprises mainly Pinyon Woodland, Pinyon-Juniper Woodland, and Juniper Woodland and Savanna, Pinyon Woodland covers 11.7%.

The WSMR Pinyon Jay colony-scale model included areas with mean elevation of 2346.73 m (range=2086.06-2632.82, SD=102.15 m). The mean slope was 11.62° (range=0.01-51.11, SD=5.57). The mean cosine of aspect was -0.04 (range=-1.0-1.0, SD=0.56).

### **Validation of Pinyon Jay Colony-scale Models**

New results reported here are for the revised KAFB colony-scale model and its validation. We also summarize validation results for the first colony model (see Johnson et al. 2012a for the first colony-scale model).

We used 30 points for validation of the first KAFB colony-scale model: 12 at Receiver, 10 at Office, and 5 old nests found during 2013 surveys (Johnson et al. 2012a). Of these 30 nests, 17 (56.7%) fell within the original colony-scale predictive model. The mean distance from outlier nests to the edge of model polygons was 65.08 m (SD=63.91).

For validation of the revised KAFB colony-scale model, we used 12 nests from Receiver and 8 old nests. Of these 20 points, 18 (90%) fell within the revised predictive colony model, indicating that the revised model was much more accurate than the original. The mean distance from the two outlier points to a model polygon was 10.5 m (SD=13.43).

The new colony site at WSMR also fell partially within the WSMR colony-scale habitat model (Figure 40). We found six nests that we classified as definitely new in 2012, based on attendance by Pinyon Jays, and we classified six nests as probably older than 2012, based on structure and lining. Four of the 2012 nests and four of the older nests (8 of 12 total, or 67%) fell within the boundaries of the colony-scale model for WSMR. In summary, all three new colonies we found in 2012 were at sites predicted by the colony-scale habitat models. The second modeling effort at KAFB was especially successful (90%) at predicting new colonies and old nests.

### **Pinyon Jay Within-colony Nest-site Selection**

We found and measured 57 Pinyon Jay nests at KAFB and 40 nests at WSMR. 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. Distances to infrastructure and buildings 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 the null model (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=965.1/ha, SE=97.88/ha). The most common species/size class was medium-sized pinyon trees (mean/ha=306.96, Table 12), and the least common class was small junipers (mean/ha=32.22, Table 12).

Models containing variables describing vegetation were the most useful, while neither topographic models nor military infrastructure models discriminated between nest and random plots. Of the ground-cover variables, litter proved useful (Table 13). Only one of the final six-model set was competitive. The best model had an AIC of 198.803. The second-best model had an AIC of 201.348 and a  $\Delta AIC_C=2.546$ , making it non-competitive (Table 14). The best model had a weight of 71.65% of the model set and included three variables related to the size of nest tree, canopy cover at nest tree, and litter cover under the nest tree.

**Table 12. Summary statistics for trees on 11.3m-radius Pinyon Jay nest plots, KAFB and WSMR.**

Tree category	Min	Min/ha	Max	Max/ha	Mean	Mean/ha	SE	SE/ha
All trees	1	25	109	2725	38.60	965.10	3.92	97.88
All small	0	0	64	1600	11.36	284.11	1.15	28.81
All medium	0	0	51	1275	14.45	361.34	1.47	36.65
All large	0	0	34	850	13.09	327.32	1.33	33.20
Jumo-s	0	0	14	350	1.29	32.22	0.13	3.27
Jumo-m	0	0	16	400	2.18	54.38	0.22	5.52
Jumo-l	0	0	27	675	6.71	167.78	0.68	17.02
Pied-s	0	0	64	1600	10.06	251.56	1.02	25.51
Pied-m	0	0	47	1175	12.28	306.96	1.25	31.13
Pied-l	0	0	20	500	6.38	159.54	0.65	16.18
Snags	0	0	17	425	2.86	71.39	0.29	7.24

The evidence ratio (ratio of model probabilities) between the highest- and second-highest-weighted model was 3.562, and between the highest- and third-highest-weighted models was 12.294. These ratios provide support for the first model. The model comparisons suggest that the second-best model is significantly improved by adding litter cover. The AUC for the best model is 0.772, indicating acceptable discrimination between nest and non-nest plots (Table 14). Parameter estimates (Table 15, Figure 41) indicated that Pinyon Jays nested where total canopy cover was higher, in trees with larger root crown diameters, and where litter cover on the ground within 5 m of the nest was higher, relative to non-nest trees within the colony. These variables are all direct or indirect indicators of cover at and near the nest. Litter accumulation is correlated with canopy cover and indicates a history of dense foliage. The same variables entered the model in the Year 2 report; hence, addition of 2012 nests confirmed our preliminary model from 2011.

**Table 13. Variables used in models discriminating Pinyon Jay nest plots from unused plots in colonies at KAFB and WSMR, 2009-2012. Values are means followed by SDs.**

Site	KAFB Winch	KAFB Winch	KAFB Office	KAFB Office	KAFB Receiver	KAFB Receiver	KAFB South	KAFB South	NOP	NOP
Plot Type	Nest	Random	Nest	Random	Nest	Random	Nest	Random	Nest	Random
Elevation	1873.62	1870.69	2048.30	2042.30	2048.58	2069.33	2121.14	2118.86	2403.65	2395.10
SD	20.97	11.23	61.20	60.73	62.78	81.38	34.94	48.36	51.57	18.37
Slope	4.08	5.46	20.00	22.20	23.75	19.00	19.77	20.91	8.65	8.35
SD	4.87	7.04	11.29	6.43	6.89	8.67	11.43	10.46	6.62	4.58
Aspect	0.80	0.84	0.61	0.65	0.80	0.64	0.81	0.56	0.40	0.45
SD	0.22	0.19	0.33	0.26	0.33	0.47	0.24	0.55	0.58	0.60
Tree RCD	79.41	46.29	27.14	24.45	21.32	23.93	33.66	36.23	29.79	23.96
SD	11.05	24.36	14.86	15.10	13.66	13.90	24.80	26.58	9.81	9.16
Height	4.12	3.34	4.22	3.87	4.34	4.11	4.03	4.03	6.11	4.62
SD	0.65	1.05	1.12	0.64	1.49	1.41	1.01	1.32	1.48	2.07
Canopy	10.00	6.38	8.60	8.20	11.00	7.25	9.45	7.05	12.25	9.35
SD	1.73	3.75	2.59	1.23	3.05	3.33	4.19	3.80	2.33	4.02
Forb	2.92	2.85	3.50	3.70	2.92	3.92	2.18	2.82	2.75	3.23
SD	1.55	1.68	0.71	0.48	1.31	0.29	1.68	1.30	1.55	1.56
Shrub	1.69	2.85	3.60	4.30	2.42	3.17	2.50	3.00	4.23	5.28
SD	1.60	1.28	0.70	2.79	1.73	1.34	1.47	2.29	2.11	3.06
Litter	14.23	8.08	17.40	19.30	20.92	17.33	18.14	12.05	17.38	13.53
SD	6.92	6.47	6.24	4.69	4.10	6.17	7.32	5.08	7.16	7.69
No. Trees Large Plot	5.69	4.69	37.50	42.90	48.92	32.83	40.68	24.05	45.88	40.35
SD	3.30	2.50	17.70	17.57	22.40	21.05	27.73	19.71	22.38	19.10
No. Trees Small Plot	0.69	0.38	8.60	8.90	13.17	6.83	7.64	3.41	8.65	7.28
SD	0.85	0.51	4.62	6.03	8.18	4.91	5.77	3.80	5.78	5.01
Edge	136.85	113.46	686.10	635.10	118.33	94.33	264.68	267.32	64.95	89.08
SD	119.75	117.05	154.37	144.46	49.13	78.01	170.58	142.38	68.78	96.64
Road	124.31	96.85	223.50	261.20	332.58	334.83	374.23	348.68	100.50	122.98
SD	86.74	82.71	177.58	164.25	192.08	229.06	117.51	123.05	83.70	107.88
Building	721.54	750.46	786.70	790.50	553.42	571.33	1743.95	1712.41	362.70	367.58
SD	90.24	106.76	59.15	63.81	203.17	248.74	279.09	175.00	214.64	228.09
Military	721.54	750.46	613.10	644.20	942.50	969.42	1743.95	1712.41	362.70	367.58
SD	90.24	106.76	156.32	138.05	215.23	240.74	279.09	175.00	214.64	228.09

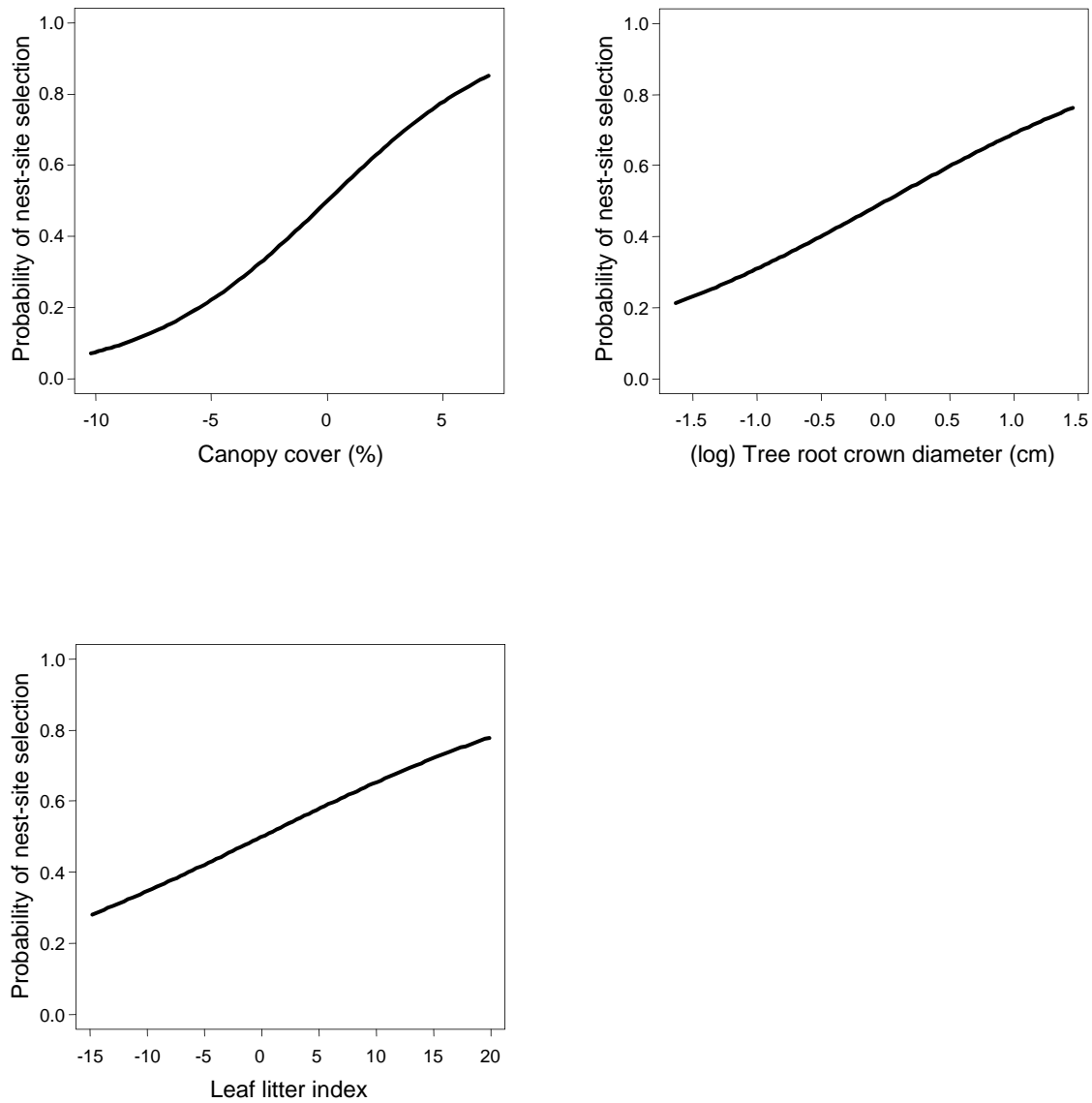


**Table 14. Candidate model set of conditional logistic regression models discriminating Pinyon Jay nest plots from unused plots at KAFB and WSMR, 2009-2012. k= number parameters in model, including a stratification term, -LL= negative log-likelihood of the model, AIC<sub>c</sub> = small sample adjusted Akaike's information criterion value of the model, ΔAIC<sub>c</sub> = difference in AIC<sub>c</sub> between models with lowest and higher values, w<sub>i</sub> = 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 <sub>c</sub>	ΔAIC <sub>c</sub>	w <sub>i</sub>	AUC
6	canopy+logtreeRCD+litter	4	-95.296	198.803	0.000	0.716	0.772
5	canopy+logtreeRCD	3	-97.611	201.348	2.546	0.201	0.744
4	canopy+logtreeRCD+height	4	-97.463	203.138	4.335	0.082	0.745
1	forb+forb <sup>2</sup> +shrub+shrub <sup>2</sup> +litter+litter <sup>2</sup> +canopy+canopy <sup>2</sup> +logtreeRCD+logtreeRCD <sup>2</sup> +height+height <sup>2</sup> +smtrees+smtrees <sup>2</sup> +lgtrees+lgtrees <sup>2</sup>	17	-87.450	212.377	13.574	0.001	0.808
2	allshrub+allforb+alllitter	4	-102.960	214.132	15.330	0.000	0.718
3	smtrees+lgtrees	3	-112.355	230.837	32.035	0.000	0.624

**Table 15. Parameter estimates from best candidate conditional logistic regression model discriminating Pinyon Jay nest plots from unused plots at KAFB and WSMR, 2009-2012. Tree RCD was log-transformed prior to modeling.**

Variable	Estimate	SE	95% CI	
			Lower	Upper
Cancov	0.251	0.066	0.122	0.380
logtreeRCD	0.799	0.328	0.156	1.442
litter	0.063	0.030	0.004	0.122



**Figure 41. 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: DISCUSSION**

### **Pinyon Jay Landscape-scale Habitat Models**

#### **Home Ranges**

Pinyon Jay flock home ranges reported in the literature vary widely: 1600 ha (Balda 2002), 2300 ha (Marzluff and Balda 1992), 2890 ha (Ligon 1971), and 6400 ha (Balda 2002). The KAFB breeding, nonbreeding, and year-round 95% kernel models fall within these ranges, but the combined MCP for KAFB is larger than all except an estimated home range of one flock that Balda (2002) reported as having a home range of 8 x 8 km. At WSMR, breeding and nonbreeding season ranges are also comparable to these reported ranges, but we have likely under-estimated the area of the nonbreeding range for the WSMR flock (see below).

We have studied Pinyon Jays at WSMR since 2005, with varying degrees of effort, depending on funding. We know both more and less about the NOP flock than about the KAFB flock. The WSMR flock has returned to the area to nest every year from 2005-2012. We have found active nests, banded hatch-year birds, and/or observed young fledglings in each of these years. However, the landscape model for WSMR is less complete for the nonbreeding season than for KAFB, because the NOP flock typically leaves the nesting colony area in September or October each year, and we have no location data for WSMR jays from November through February. We assume the flock wanders widely over a much larger area than the summer range. Our fall location data suggest that this range includes more lower-elevation, juniper-dominated habitat than the summer range. However, because they leave the area each winter, we have not identified the boundaries of the area they use in the winter months. Our models are based on location data from March through October.

Radio telemetry enabled us to collect a substantial number of point locations for the Pinyon Jays at WSMR and KAFB over four months, including points we would not have collected without the radios. However, on several occasions at KAFB, especially in winter, we were unable to locate any jays, even when we knew transmitters were functional. Our inability to find jays at these times could be due to the birds' mobility, their large home ranges, or the limitations of telemetry equipment in rough terrain. The home range we modeled for KAFB therefore may also be conservative, particularly in winter when the species is known to wander widely (Marzluff and Balda 1992).

Our home range models may also under-represent the higher-elevation vegetation types, particularly Pinyon Pine Woodland, because even with telemetry, it is difficult to cover the higher-elevation habitats where roads are sparse or nonexistent. It is also important to note that the kernel models were created in years with no pinyon mast crop. In a mast year, Pinyon Jays would be expected to be harvesting seeds in pinyon-dominated woodland until most seeds were harvested, which could take months in the case of a large crop. This would result in the inclusion of more Pinyon Pine Woodland in the nonbreeding home ranges, and those ranges would

presumably be smaller than in years with no cone crop. Nonetheless, the main caching area in the north at KAFB was in Juniper Woodland and Savanna, which would also be visited frequently during a mast year and might partially balance additional time spent in Pinyon Pine Woodland in a mast year.

### *Breeding*

Pinyon Jays in this study nested in two general habitat types, Juniper Woodland and Savanna (KAFB) and Pinyon Pine Woodland (KAFB and WSMR). Although the South Colony at KAFB and the NOP Colony at WSMR both nested in habitat classified as Pinyon Pine Woodland, we detected differences in the age and stand structure of the two colony sites. At NOP, some stands contain very large trees approaching 400 years of age (Muldavin et al. 2003). The Pinyon Jay breeding season home range at WSMR contains more large trees and denser stands of trees than the nesting areas at KAFB, and we have not observed the huge, ancient trees that occur at WSMR (Johnson et al. 2012b).

The Winch Colony at KAFB nested in relatively flat juniper woodland, in habitat that appeared similar to that favored by Gray Vireos. We found a Pinyon Jay nest 120 m from the nearest Gray Vireo nest. Although in close proximity with scattered junipers, the Gray Vireo nest was adjacent to a meandering dry wash, in contrast to the landscape position of the Pinyon Jay nest. Although we believe breeders from the two KAFB colonies are likely members of the same wintering flock, the Winch Colony nested about two weeks earlier in 2010 than the South Colony birds. Seven of the nine Winch Colony nests that we were able to monitor failed after late winter weather occurred in the area, and we believe that most of them were abandoned. Early-nesting birds can potentially produce young that will be older and better able to survive when winter comes, but by nesting in March, early-nesters are gambling with poor weather and limited food, and the risk of failure is therefore higher (Marzluff and Balda 1992). These risks can be ameliorated in years following a pinyon crop, when cached seeds provide reliable food (Ligon 1978, Marzluff and Balda 1992).

### *Caching*

We have located two caching areas at KAFB, both within the north area of the breeding home range. Both have sparse vegetation, which is consistent with other descriptions of Pinyon Jay caching sites (Ligon 1978, Marzluff and Balda 1992, Balda 2002). The main site is located on south-facing slopes in juniper woodland and savanna habitat. This area was free of snow in January and February 2012, when north-facing slopes and tree-covered areas were covered in snow up to a meter deep. Caching in open, south-facing areas allows the jays to find caches when deep snow is present elsewhere in the study area. Marzluff and Balda (1992) also report that caching sites are often snow-free in winter. The second caching site is on a previously burned hill with extremely sparse tree cover.

### *Nonbreeding*

When we visited the KAFB northern area in December, January, and February, the birds were often nowhere to be seen. Out of seven visits to the study area during these months, we detected jays only twice. Although the difficulty in finding the birds in winter might suggest that they leave the area entirely, we believe the KAFB flock remains in the area. A large flock appeared at the feeder within six days of the feeder being set up in February, which indicates that they were not far from this activity center of their home range.

### **Pinyon Jay Colony-scale Selection**

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 than other nearby transects, 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 may have declined due to competition among densely-packed trees and more large trees, which appeared to be more vulnerable to hydrological stress than smaller trees.

The greater topographic variation at the KAFB south site probably influenced the initial colony-scale modeling process, such that only the most diverse sites, having variable aspect, elevation, slope, and vegetation were selected. We believe the first modeling effort was overly restrictive in attempting to identify sites that approximated too closely the highly variable south site. Also, the new grouping tool required a quantitative approach that was less conservative. As a result, the first model was overly conservative and predicted only 56.7% of our validation points. The second effort used input data from two widespread KAFB colonies, and the resulting model performed much better (90% of validation points fell within the predicted model).

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. 2011). The WSMR colonies were in Pinyon Woodland habitat (Johnson et al. 2011). The colony-scale classification process varied between KAFB and WSMR, likely a result of the much greater variability at the colonies we used for modeling at KAFB. The KAFB south site in particular 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 revised KAFB colony-scale classification contains more classes and allowed delineation of seven potential classes similar to the South and Office Colony sites. 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 at WSMR.



The KAFB model appears to model Pinyon Jay colony-scale habit for KAFB only. The WSMR model failed to predict potential colony-size sites within the Pinyon Woodland habitat, instead indicating a landscape of continuous suitable habitat. Although each model applies only to the installation for which it was created, we have confidence in the usefulness of the modeling process for other sites. In addition, 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.

A Pinyon Jay colony is used almost exclusively for nesting, and parents typically range widely outside the colony to forage, hence the emphasis on the nest tree in the nest-scale model. At the nest scale, the total number of trees on a plot and the number of large trees were correlated with tree RCD, a variable in the strongest model. Due to this correlation, tree number was not included in the model, but number of trees is likely also important for Pinyon Jay nest site selection. 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 matter of finding an area containing enough trees of appropriate size and canopy thickness to provide the flock good nest cover. 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. If that is the case, colony-scale habitat selection may not be the most appropriate concept for Pinyon Jays. In summary, there is weaker evidence that Pinyon Jays choose colony sites based on colony-scale variables, than for Gray Vireos 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 Pinyon Jays often return to old nesting areas (Marzluff and Balda 1992). At WSMR during this study, Pinyon Jays nested at three 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, 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 pioneer new, available habitat. If so, the potential conservation implications of colony site fidelity warrant further investigation.

### **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 and canopy cover are the features of greatest 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=595-887 m) at the Winch Colony and 1712.4 m (range=1431-2723 m) at the South Colony. 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=103-816 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 observations.

*Vegetation.* The best model to emerge from the conditional logistic regression analyses contained three variables: tree root crown diameter, canopy cover, and litter cover on the 5 m nest plot. Nest trees had larger root crown diameters than trees on random 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 plots, 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. Litter comprised mainly needles from the nest tree and was highly correlated with canopy cover, suggesting more needles produced in previous years.

The jays probably placed nests in trees with dense canopies to hide their nests from 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 flying 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 high in large trees to access nests.

### **Habitat Requirements and Management**

Perhaps the most striking feature of Pinyon Jay habitat use at the landscape scale is the size of a flock's home range. We consider the year-round home range sizes reported here to be minimum estimates, because we were often unable to locate flocks within these ranges, even with transmitters shown to be detectable over distances of 5 km or more. In addition, Pinyon Jay flocks are known to wander far outside their core home ranges in search of winter food (Ligon 1978, Balda 2002).

The second notable result of the landscape-level model is the variety of elevations and vegetation types where colonies were established. Within the landscapes modeled at KAFB and WSMR, we found Pinyon Jay flocks ranging over elevations from 1803-2420 m and in vegetation types from Juniper Woodland and Savanna to persistent, old-growth Pinyon Pine Woodland, and Pinyon-Juniper Woodland in between.

Hence, the proper scale of habitat management for a single flock of Pinyon Jays is the large landscape, including pinyon, juniper, and pinyon-juniper habitat types. A single flock can range over areas as large as half of an entire small mountain range such as the Ocuras. It is important to provide lower-elevation Juniper Woodland and Savanna for wintering, caching, and potential early spring breeding. Pinyon Pine Woodland is crucial for Pinyon Jays, not only because it is used for nesting, but more importantly because it is a major source of the pinyon seeds that strongly influence Pinyon Jay population viability. Because the production of pinyon mast crops is highly variable over years and to a lesser extent over landscapes (Ligon 1978, Forcella 1981, Zlotin and Parmenter 2008), Pinyon Jays need very large landscapes, in the thousands of hectares, of Pinyon Pine Woodland and/or Pinyon-Juniper Woodland. Most years are not mast years for *P. edulis* (Forcella 1981). In lean years when pinyon seeds are not available for caching, Pinyon Jays may move hundreds or even thousands of kilometers in search of pinyon seeds or other winter foods (Balda 2002). Only managers with jurisdiction over the very largest stands of pinyon and juniper can practically manage for Pinyon Jays at a scale necessary to positively impact their populations; thus DoD lands could be crucial to the future of this at-risk species.

In considering how to manage habitat for Pinyon Jays, the first rule of thumb is that clearing of juniper and pinyon trees should be avoided when possible. Pinyon-dominated habitats, especially those with many mature, un-crowded pinyon trees, are areas of greatest seed production (Johnson and Smith 2006, 2007). Pinyon seeds provide food not only for Pinyon Jays but also for other wildlife, including sensitive species such as the Oscura Mountains chipmunk and Juniper Titmouse; and these woodlands, especially their large, mast-producing trees, should be retained. Research at NOP suggests that seed production is relatively lower in areas where trees are most dense (Johnson and Smith 2006, 2007). However, tree densities at NOP are quite high, >2000 trees/ha in places. To foster health of the most productive trees, some selective thinning may be useful. The range of tree densities observed in this study can provide guidelines as to acceptable tree densities. Most importantly, research is needed on the usefulness of thinning in maintaining the productivity and health of pinyon-dominated woodlands, and thinning should only be initiated after careful consideration of current science and in the context of a pilot research program.

Persistent woodlands have always experienced fires infrequently, and, in fact, surface fires historically had a very limited role in structuring stands in most pinyon and juniper woodlands (Romme et al. 2009). In many pinyon and juniper woodlands, stand dynamics are driven more by climate, insects, and disease than by fire (Romme et al. 2009). Thus, fire is not recommended as a generally appropriate management tool in these woodlands. It should be added that Pinyon Jays play a crucial and likely under-appreciated role in establishing pinyon woodlands and determining stand structure (Lanner 1996).

### **Relationship to Military Activities**

Nest monitoring was not an objective for this study; hence, our nest success data are not complete enough to allow analysis of nesting success relative to military infrastructure and activities. However, Pinyon Jays showed no apparent aversion to nesting near roads, buildings, or occasional loud noises. We have observed Pinyon Jays nesting within 10 m of roads and 50 m of buildings. At times, several vehicles per hour pass along Coyote Springs Road at KAFB and along the NOP road (332) at WSMR. In addition, the Winch Colony at KAFB is 850 m from the Live Firing Range, and loud gunfire can be heard from the colony site. At WSMR, extremely loud sonic booms occur almost daily over the NOP colony, and aircraft noise is common at both sites. The south KAFB colony is more isolated, and vehicle noise and explosions are not typically heard there. All of these noises occur occasionally and are not constant. Hence, our suggestion that Pinyon Jays tolerate noise disturbance does not mean that they can tolerate constant noise, which could be much more disruptive than occasional, very short-duration noises. Constant noise would likely impact intra-flock communication such as alarm, begging, contact, and courtship calls.

## **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 higher mean tree heights than random plots. However, territories at KAFB had intermediate greenness relative to non-territories; and, when nest samples were more heavily weighted toward KAFB (Johnson et al. 2012a), intermediate mean tree heights were more predictive in models. This suggests 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 always the very largest or most dense at some sites. Juniper density on Gray Vireo territories ranged from 25-425/ha, with a mean density of 113 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. 2011). In one study at 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 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 than at random sites within nesting colonies; a decline in tree health was associated with abandoning a colony; and 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 nesting habitat for Pinyon Jays should include maintaining tree 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 more pinyon seeds. Productivity declines in extremely large, old ( $\geq 300$  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 Jays in this study moved to lower-elevation juniper habitats outside the breeding season. The Juniper Woodland and Savanna vegetation type is used for foraging in winter and seed caching in fall. Patches of this vegetation type close to Pinyon-Juniper Woodland or Pinyon Woodland are especially important to conserve.

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 ( $\geq 2000$  trees/ha), 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, on average, farther from buildings than random plots at CTTA. Vireo territories at CTTA were farther from infrastructure than non-territories, while vireo territories at KAFB and WSMR were closer to two-track roads and buildings and respectively, 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, or due to correlations with other topographic variables. 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 2 km of traditional or active Pinyon Jay colony sites between March and July. In most years, ground training should not be conducted within 2 km 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 2 km of a nesting colony. No activities that carry high potential for wildfires should be conducted within a flock's breeding home range.

### **Summary of Pinyon-Juniper Management for Gray Vireo and Pinyon Jay**

We summarize management recommendations in pinyon-juniper habitats at DoD installations as follows:

1. Retain large juniper trees in Gray Vireo nesting areas.
2. Maintain juniper trees in potential and actual nesting areas at densities similar to those on our Gray Vireo nest plots (from 25-425/ha, mean density ~99 trees/ha).
3. Continue to restrict training activities in the Gray Vireo nesting areas during the breeding season at KAFB and CTTA.
4. Construct no new infrastructure such as buildings, power lines, or shooting ranges closer to Gray Vireo territories than infrastructure that is currently present.
5. In Pinyon-Juniper and Pinyon Woodlands occupied by Pinyon Jays, maintain tree densities similar to those reported here, with most areas dominated by pinyon trees.
6. Allow no net loss of mature, healthy pinyon stands, to retain pinyon seed production areas and options for new Pinyon Jay colonies.
7. Construct no new roads or infrastructure closer to traditional Pinyon Jay colonies than what is currently present.
8. Conduct no ground training activities within 2 km of traditional or active Pinyon Jay colony sites between March and July. In most years, conduct no ground training within 2

km 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.

9. Conduct no activities that create loud noises or destroy habitat (such as bombing) within 2 km of a Pinyon Jay nesting colony.
10. Conduct no activities that carry high potential for wildfires within a Pinyon Jay flock's breeding home range.
11. Fire is not recommended as a management tool in pinyon-juniper habitats occupied by either Gray Vireos or Pinyon Jays.

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## APPENDIX: 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 Woodland Alliance (*Pinus edulis*) 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 (*Juniperus* spp.), having a variety of sub-canopy shrubs and grasses. Our target species are woodland, versus grassland, because Pinyon Jays (*Gymnorhinus cyanocephalus*) and Gray Vireos (*Vireo vicinior*) are found infrequently in shrubland and grassland. Thus, we use more general categories of the Land Cover Class of shrubland and grassland where these types dominate.

The extents and delineations of the map units are based on generalized plant associations, community structure, and differential habitat use of the Gray Vireo and Pinyon Jay within the study area. To avoid redundancy in mapping habitat for these two species, we have created three maps for the three installations and have extracted a subset of these maps for each bird species, while keeping contiguous landscapes intact. For example, within the Oscura Mountains at White Sands Missile Range (WSMR), we have excluded much of the mapped range west of Range Road 9 for the Oscura Gray Vireo model because this area is dominated by Pinyon-Juniper Woodland, a map unit that is not associated with Gray Vireo use. Whereas we have included the entire mapped area of the Oscura Mountains for the Pinyon Jay landscape model because the Pinyon Jay has been observed within the Pinyon-Juniper Woodland of Chupadera Mesa at the eastern boundary of the Range. As such, the Oscura Gray Vireo model is a subset of the Oscura Pinyon Jay model. We did not initially map the Oscura

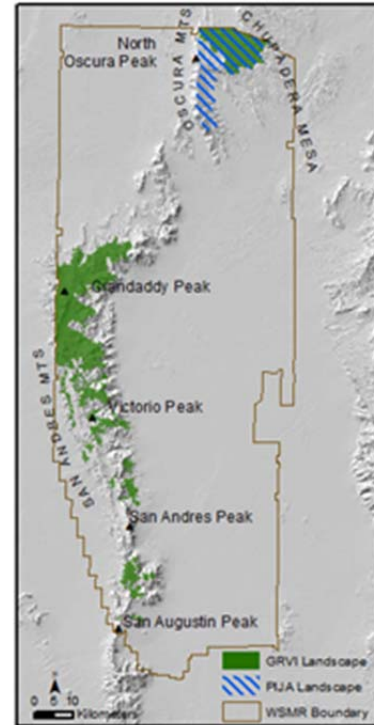


Figure A1. Gray Vireo and Pinyon Jay landscape model extents at WSMR.

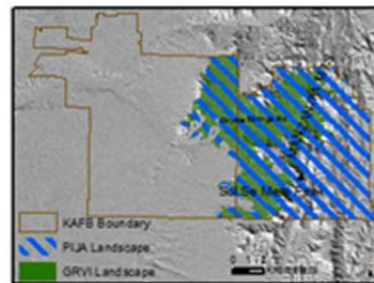


Figure A2. Gray Vireo and Pinyon Jay landscape model extents at KAFB.

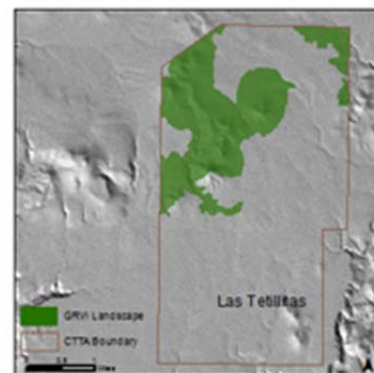


Figure A3. Gray Vireo landscape model extent at CTTA.

**Table A1. Percent cover and area (ha) for each map unit by bird species within a range is provided.**

Appendix Number	Map Unit Name	Pinyon Jay Landscape Models		Gray Vireo Landscape Models			
		Oscura % (ha)	Kirtland % (ha)	Oscura % (ha)	San Andres % (ha)	Camel Tracks % (ha)	Kirtland % (ha)
1	Ponderosa Pine Woodland	-	5.9 (553.9)	-	-	-	-
2	Pinyon Pine Woodland	25.0 (5755.3)	27.6 (2605.3)	0.0 (0.1)	0.7 (311.6)	-	3.8 (180.0)
3	Pinyon-Juniper Woodland	12.7 (2939.5)	16.7 (1574.8)	11.7 (1451.9)	18.9 (8619.8)	-	10.3 (494.2)
4	Juniper Woodland & Savanna	47.3 (10,903.8)	37.7 (3553.4)	77.2 (9534.5)	35.5 (16,150.5)	-	66.3 (3175.0)
4a	Juniper Woodland & Savanna on Volcanic Hills	-	-	-	-	46.8 (372.9)	-
4b	Juniper Savanna on Lava Plains	-	-	-	-	53.2 (424.2)	-
4c	Shrubby Juniper Savanna	-	0.4 (33.9)	-	-	-	0.7 (33.9)
5	Shrubland	13.1 (3020.0)	-	8.7 (1073.5)	41.4 (18,862.3)	-	-
5a	Lowland Shrubland	-	2.5 (237.7)	-	-	-	4.9 (233.0)
5b	Upland Shrubland	-	1.8 (171.4)	-	-	-	1.3 (61.8)
6	Grassland	1.1 (250.4)	4.3 (401.0)	1.5 (186.9)	1.1 (487.2)	-	8.0 (387.2)
7	Arroyo Riparian	-	-	-	2.3 (1036.8)	-	-
8	Wetland	-	0.0 (1.0)	-	-	-	0.0 (1.04)
9	Burn	-	0.7 (66.2)	-	-	-	0.5 (22.4)
10	Built-up Land	0.3 (78.9)	1.1 (101.9)	0.5 (66.1)	0.0 (1.2)	-	2.1 (99.6)
11	Road	0.5 (118.0)	1.3 (124.1)	0.4 (43.4)	0.1 (46.5)	-	2.1 (98.4)

portion of Gray Vireo habitat because we did not have data on their occurrence within this range. Additionally, unmapped Gray Vireo habitat may occur to the southeast within Chupadera Mesa. Figure A1 illustrates the partitioning of the landscapes model for the two species within WSMR. At Kirtland Air Force Base (KAFB) we mapped the western extent of juniper within the base and completed the mapping east to the boundary of KAFB (Figure A2), including all map units for the Pinyon Jay, such that the Gray Vireo KAFB landscape model is a subset of the mapped area. We used the maximum elevation detected for Gray Vireo (2040 m) to delimit the Gray Vireo landscape model.

Our minimum map unit is 0.10 ha. The models include most of the woodland patches found within these ranges; however, smaller, isolated patches were excluded. Within the San Andres Mountains of WSMR our target species was the Gray Vireo. Pinyon Jay has been observed within the San Andres, but we have no records of nesting colonies in the San Andres. We have excluded Salinas Peak and eastward within the San Andres Gray Vireo landscape model, but if we were to consider potential habitat for the Pinyon Jay within this range, we would add this area and subset from the San Andres Gray Vireo model a portion suitable for the Pinyon Jay.

Table A1 shows the percent of total cover and area (hectares) within each species' model by map unit. The map unit descriptions following the table are arranged by map unit with separate descriptions for each range, irrespective of species model. The map unit descriptions capture plant species dominance and habitat use by the two species.

## 1. Ponderosa Pine Woodland

This unit is dominated by ponderosa pine (*Pinus ponderosa*) and, although mapped, is not currently included in any landscape models for either bird species.



### **KAFB**

This unit occurs within Madera Canyon and Otero Canyon and along the eastern boundary within the Manzano Mountains. The woodland ranges from open to nearly closed canopies with sparse grass understories and deep accumulations of pine needles. Scattered understory trees may include Rocky Mountain juniper (*Juniperus scopulorum*), alligator juniper (*Juniperus*



*deppeana*), Gambel's oak (*Quercus gambelii*), and pinyon pine. It occupies narrow, mesic canyons and high elevations with northerly aspects. Elevations range from 2123- 2433 m and cover approximately 554 ha (5.8%) of the mapped area. Pinyon Jays are known to use Ponderosa Pine Woodland habitats east of KAFB, but we have no verified locations of the species in this habitat at KAFB.

### **WSMR – San Andres Mountains**

Ponderosa Pine Woodland occurs in a few small patches (~14 ha) at Salinas Peak and Silver Top Mountain and is not included within the extent of the landscape model for the Gray Vireo.

## **2. Pinyon Pine Woodland**

These woodlands are dominated by pinyon pine but can co-occur with juniper in nearly closed canopies. The cover of pinyon pine relative to juniper exceeds 50% in this unit. This map unit provides important foraging and nesting habitat for the Pinyon Jay. The Gray Vireo has not been detected within this map unit.



### **KAFB**

This woodland typically occurs on steep slopes and continues to the mountain summits between Pinyon-Juniper Woodland within the more mesic canyons and narrow, upland drainages. Oneseed juniper (*Juniperus monosperma*) is found scattered throughout, but alligator juniper and Rocky Mountain juniper also occur within this unit. The understory is relatively sparsely vegetated with scattered mountain mahogany (*Cercocarpus montanus*), Gambel's oak, and grama (*Bouteloua* spp.) grasses. This unit covers approximately 2605 ha (28%) and ranges in elevation from 1931- 2439 m.

### **WSMR – Oscura Mountains**

This woodland dominates North Oscura Peak (NOP) and continues along the crest of the Oscura Mountains to the south. These older, closed-to-open pinyon stands have well-developed, diverse and structurally complex understories of shrubs and grasses that include wavyleaf oak (*Quercus x pauciloba*), mountain mahogany, banana yucca (*Yucca baccata*), and Gambel's oak. Grasses include Scribner's needlegrass (*Achnatherum scribneri*) and grama grasses. A discussion of plant

associations of the Pinyon Pine Alliance at WSMR can be found in Muldavin et al. (2000) and Muldavin et al. (2003). Elevations range from 1816-2632 m and cover 25% of the Pinyon Jay landscape model within the Oscura Mountains. This unit is peripheral to the landscape model of the Gray Vireo.

### **WSMR – San Andres Mountains**

Within the San Andres Mountains, the height of pinyon pine stands do not reach those representative of the Oscura Mountains but tend to be closed-to-open pinyon stands with a diverse understory of shrubs and grasses, including mountain mahogany, banana yucca, wavyleaf oak, Scribner’s needlegrass, and New Mexico muhly (*Muhlenbergia pauciflora*). Stands are more extensive in the Oscura Mountains and become more fragmented moving south through the San Andres Mountains. These woodlands are not used by vireos but represent a minor component surrounded by Gray Vireo habitat 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 (0.7%). Elevation ranges from 1868- 2430 m.

### **3. Pinyon-Juniper Woodland**

The definition of Pinyon-Juniper Woodland is debated, with some classifying a few scattered pinyons 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  $\geq 50\%$  we assigned the unit to Pinyon Pine Woodland. This map unit provides important foraging, seasonal, and nesting habitat for the Pinyon Jay. Gray Vireos occasionally nest where this map unit meets juniper-dominated areas.



### **KAFB**

Pinyon-Juniper Woodland typically occurs on slopes in transition between juniper-dominated landscapes below and pinyon pine dominated slopes above. At higher elevations, Pinyon-Juniper Woodland will replace Pinyon Pine Woodland on drier, more southerly and westerly slopes. Understory species composition is similar to the Pinyon Pine Woodland, with transitions toward

more open canopies. The Gambel's oak shrub of the Pinyon Pine Woodland is typically replaced by wavyleaf oak within this unit. These woodlands cover approximately 1575 ha (17%) of the mapped area within KAFB.

#### **WSMR – Oscura Mountains**

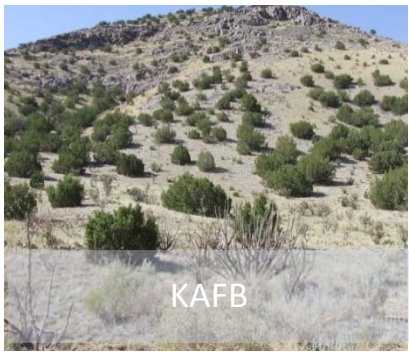
Approximately 2939 ha (13%) of Pinyon-Juniper Woodland occurs in a narrow band on east- to northeast-facing slopes at the lower elevation margins of the Pinyon Pine Woodland of NOP and on slopes within the less mesic, lower-elevation ranges along the eastern boundary within the Chupadera Mesa. Species composition within the understory is similar and as diverse as the Pinyon Pine Woodland but canopies typically are more open.

#### **WSMR – San Andres Mountains**

Pinyon-Juniper Woodland covers 8620 ha (19%) of the mapped area. This open-to-moderately-closed woodland is found in larger patches on northerly-facing slopes of named peaks within this range, such as Mount Baldy, Skillet Knob, Granddaddy Peak, Loma Vista, Pilot Knob and Black Top Mountain. Elevation ranges are higher than in juniper-dominated areas, ranging from 1677-2428 m. Species composition within the understory varies between dry and mesic slopes. The dominant understory shrubs may include wavyleaf oak and mountain mahogany. Grass cover is generally low with New Mexico muhly, Scribner's needlegrass, or blue grama as dominants.

### **4. Juniper Woodland and Savanna**

Juniper Woodland and Savanna occurs at all three installations. At Camel Tracks Training Area (CTTA), we use landscape position and surface geology to identify sub units of Juniper Woodland and Savanna: Juniper Woodland and Savanna on Volcanic Hills (4a) and Juniper Woodland and Savanna on Lava Plains (4b). On KAFB, we identify a sub-unit, Shrubby Juniper Woodland (4c), based on fire history. Within the Oscura and San Andres Mountains, we have not identified sub units (see Muldavin et al. 2000 for details). Oneseed juniper covers a broad range of topographic positions at mid-elevations, within drainages to broad valleys and small hills to steep slopes along canyon walls. Pinyon pine can be scattered throughout this landscape but typically comprises less than 25% cover relative to juniper. The Pinyon Jay may on occasion nest at the ecotone of this map unit and the Pinyon-Juniper Woodland and has been detected caching seeds in the Juniper Woodland and Savanna. This map unit is the primary habitat for the Gray Vireo, and oneseed juniper is the most common nest tree.



### **KAFB**

This unit covers 3552 ha (37.7%) of the mapped area and has the broadest elevation range of the mapped units, covering distal foothills to steep slopes reaching 2319 m in elevation. Shrubs can dominate the inter-canopy spaces, with either fourwing saltbush (*Atriplex canescens*) or mountain mahogany well represented. Mountain mahogany tends to establish on rocky slopes, replaced by fourwing saltbush near drainages and on alluvial surfaces with deeper soil horizons. Tree cholla (*Cylindropuntia imbricata*) appears throughout this map unit, often at densities greater than other shrubs. Grama grasses are found throughout this unit and can be more abundant than shrubs. Tobosagrass (*Pleuraphis mutica*) or needle and thread grasses (*Hesperostipa* spp.) can be locally abundant but rarely dominate the inter-canopy spaces.

### **WSMR – Oscura Mountains**

Juniper Woodland and Savanna covers approximately 10,904 ha (47%) of the mapped area and supports a diverse understory of shrubs and grasses. However, grasses rather than shrubs are typically more representative within the inter-canopy spaces and include blue grama (*Bouteloua gracilis*), black grama (*B. eriopoda*), hairy grama (*B. hirsuta*), sideoats grama (*B. curtipendula*), and curlyleaf muhly (*Muhlenbergia setifolia*).

### **WSMR – San Andres Mountains**

Oneseed juniper occurs in open to very open tree canopies having a diverse understory of shrubs and grasses. This unit covers 16,150 ha (35%) of the mapped area in the San Andres and ranges from 1324-2365 m. Shrubs such as hairy mountain mahogany (*Cerocarpus breviflorus*), banana yucca (*Yucca baccata*), tree cholla or sacahuista (*Nolina microcarpa*) often occur in the inter-canopy spaces. Grama grasses, New Mexico muhly (*Muhlenbergia pauciflora*), and New Mexico feathergrass (*Hesperostipa neomexicana*) are found throughout this unit and can be more abundant than shrubs.

#### 4a. Juniper Woodland and Savanna on Volcanic Hills



##### **CTTA**

Oneseed juniper with an understory of grasses dominates relatively steep conical volcanic hills of Pliocene age. Hills range in elevation from 1960- 2100 m, comprising approximately 373 ha (46.7%) of the mapped area. Juniper is most often associated with grasses such as sideoats grama, black grama, blue grama and needle and thread grass (*Hesperostipa comata*). Pinyon pine can be scattered throughout but typically comprises less than 10% cover relative to juniper. This is the principal map unit for Gray Vireo nests and territories at CTTA.

#### 4b. Juniper Savanna on Lava Plains



##### **CTTA**

Oneseed juniper with an understory of grasses dominates eolian and alluvial plains derived from basalt. The Juniper Savanna on Lava Plains unit is characterized by low slopes and incised drainages, exposing the basalt, with open to very open juniper savannas. The same grass species as on the volcanic hills dominate the understory; however, tree cholla, broom snakeweed (*Gutierrezia sarothrae*) and rubber rabbitbrush (*Ericameria nauseosa*) can be locally dominant within this unit, which covers approximately 424 ha (53.2%) of the mapped area. The Gray Vireo occupies, but rarely nests within, this map unit.



#### 4c. Shrubby Juniper Savanna

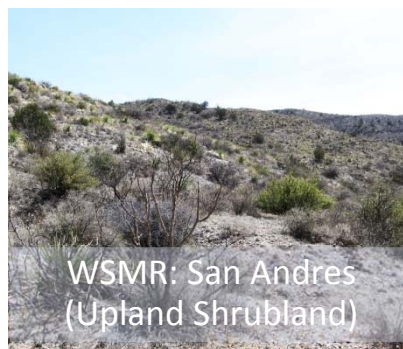
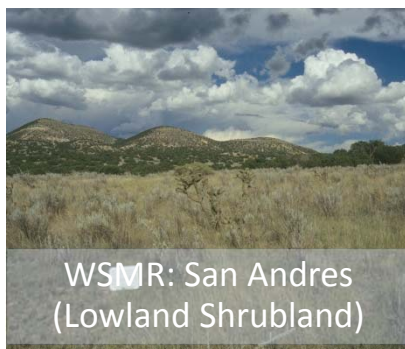


#### KAFB

This unit consists of small-stature juniper and very scattered pinyon on relatively flat slopes adjacent to lowland shrubland. The open woodland occurs along Coyote Springs Road south and east of the live firing range and a small, disjunct area just east of the Madera Canyon Road. The immature trees are not used for nesting by Gray Vireos and may indicate sites that are recovering from burns. This unit occupies 34 ha (0.4%) of the landscape, ranging from 1826- 1918 m.

### 5. Shrubland

The Shrubland map unit is used to indicate relatively large areas dominated by shrubs. At KAFB we differentiate between lowland (5a) and upland shrubland (5b). We do not delineate these two shrubland types at WSMR (see Muldavin et al. 2000 for details). Although shrublands comprise a portion of the Gray Vireo territories delineated at WSMR, there is no indication that this habitat is frequently used by the vireos. Additionally, the Pinyon Jay has not been documented within this habitat.



#### WSMR – Oscura Mountains

The Shrubland map unit includes both lowland and upland types at WSMR. Lowland shrubs occupy broad drainages dominated by fourwing saltbush, winterfat (*Krascheninnikovia lanata*), and scattered juniper with locally abundant grasses such as western wheatgrass (*Pascopyrum smithii*), tobosagrass, alkali sacaton (*Sporobolus airoides*), or grama grasses. Lowland shrubs



follow ephemeral drainages and are locally abundant in disturbed sites. Upland shrubs occupy south and west-facing slopes on Chupadera Mesa along the eastern boundary and dry slopes below NOP. Upland shrubs may include mountain mahogany, wavyleaf oak, sacahuista, or *Yucca* spp. Shrublands cover approximately 3020 ha (13%) of the mapped area, ranging in elevation from 1678- 2621 m.

### **WSMR – San Andres Mountains**

In the San Andres, Shrubland map units include both lowland and upland types. Lowland shrubs are as in the Oscuras. Within the San Andres mapped area, there is much less lowland Shrubland than upland. The upland Shrubland is more diverse, with wavyleaf oak and mountain mahogany, often co-dominants occurring with sacahuista and *Yucca* spp. on all aspects and at elevations ranging from 1320- 2436 m. Grasses vary in abundance, with grama grasses throughout and others such as New Mexico muhly and Scribner’s needlegrass locally abundant. Other shrubs and subshrubs such as *Acacia* spp., catclaw mimosa (*Mimosa aculeaticarpa* var. *biuncifera*), featherplume (*Dalea Formosa*), and common sotol (*Dasyilirion wheeleri*) occur on the more xeric slopes, especially in the southern portion of the San Andres. This unit covers approximately 41% of the mapped area within this range.

### **5a. Lowland Shrubland**



### **KAFB**

Lowland Shrubland predominates along drainages within the broad basins at KAFB. It is characterized by fourwing saltbush, rubber rabbitbrush, winterfat, tree cholla, and very scattered oneseed juniper. Grasses are relatively sparse, but grama grasses are most common. The map unit covers approximately 238 ha (2.5%) of the mapped area and ranges in elevation from 1753- 2124 m. The Gray Vireo has been detected within this map unit but typically within the very scattered junipers found there. Gray Vireo nests are often found within juniper habitat in close proximity to this unit. There are no detections within this unit for the Pinyon Jay.

## 5b. Upland Shrubland



### **KAFB**

Upland Shrubland occupies dry slopes with southern and western exposures on moderate-to-steep slopes. Shrubs include mountain mahogany, sacahuista, tree cholla, *Yucca* spp., wavyleaf oak, and *Opuntia* spp. Grasses can be sparse to relatively dense. This unit covers approximately 171 ha (1.8%) of the mapped area and ranges in elevation from 1854- 2279 m. There are no recorded instances of use by the Gray Vireo or Pinyon Jay within this map unit.

## 6. Grassland

Grasslands indicate relatively large areas dominated by grassland and lacking the woody vegetation characteristic of the woodland and savanna units. Neither Gray Vireo nor Pinyon Jay has been detected within this unit.



### **KAFB**

Grasslands are typically dominated by either blue or black grama; however, sideoats grama may dominate on some of the more rocky slopes. Tobosagrass or New Mexico feathergrass can be locally dominant. Mesic grasslands such as western wheatgrass occur with blue grama within openings of the Ponderosa Pine Woodland. This map unit covers 401 ha, comprising 4% of the mapped area with elevation ranging from 1759- 2343 m.

### **WSMR – Oscura Mountains**

Grasslands typically occur within broad, open valleys of Pinyon Pine Woodland dominated by blue grama-western wheatgrass or at the base of low, dry hills where blue grama is associated with sub-shrubs such as winterfat. Tobosagrass and alkali sacaton may be locally dominant. In the Oscura Mountains, the Grassland unit covers 250 ha, approximately 1.1 % of the mapped area and is found in mid-elevations ranging from 1823- 2385 m.

### **WSMR – San Andres Mountains**

This map unit delineates broad, upland interior valleys within the San Andres that cover 487 ha (1.1%) of the mapped area with elevations ranging from 1749- 2218 m. Grama grasses typically dominate, often with relatively high densities of soap tree yucca (*Yucca elata*). New Mexico feathergrass may be a co-dominant with grama grasses.

## **7. Arroyo Riparian**

Arroyo habitat is an ephemeral drainage in the arid Southwest that becomes inundated with water during seasonal rainfall events. These are found within the valley floor and at higher elevations, as in the San Andres Mountains at WSMR. The structural and plant diversity of these areas provide important wildlife habitat. Gray Vireo territories include this habitat, along with the adjacent upland juniper woodlands. Nests have been found within the ecotone between these two habitats.



### **WSMR – San Andres Mountains**

The Arroyo Riparian map unit has high plant species richness. This unit consists of very narrow bands within canyon bottoms flanked by juniper, pinyon-juniper woodlands, and/or shrubland habitats. 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). However, in more xeric canyons, viscid acacia (*Acacia neovernicosa*), catclaw mimosa (*Mimosa aculeaticarpa* var. *biuncifera*), and common sotol extend downslope into arroyo riparian areas (Hobert et al. 2009). Although this unit covers only 2.3% (1037 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- 2132 m in elevation.

## 8. Wetland



### **KAFB**

A small wetland at Coyote Springs (~1 ha) lies just north of the Coyote Springs Road. The wetland is mostly herbaceous with cottonwoods (*Populus deltoides*). Pinyon Jays and Gray Vireos have been detected at the wetland but they do not nest at this site.

## 9. Burn



### **KAFB**

Pinyon Jays have been observed caching seeds on a previously-burned hillside north of Madera Canyon Road. The hillside holds remnants of former Pinyon-Juniper Woodland and is in transition from the burn. Pinyon seedlings suggest that seeds cached by the jays are facilitating this transition back to pinyon-juniper. The date of the burn is unknown. The burn covers approximately 66 ha, 0.7% of the study area.

## 10. Built-up Land

Built-up land includes disturbances within the natural landscape. These disturbances may include buildings, mechanically scraped lands, or other manmade modifications that alter the natural landscape. At KAFB this map unit covers 102 ha (1.0%) of the mapped area. At WSMR, within the Oscura and San Andres Mountains, these disturbances occupy 78 ha (0.3%).

## 11. Roads

Most major, maintained roads within the study area are delineated in this map unit. Two-tracks are typically not included, unless well-travelled. On KAFB roads cover 125 ha (1.3%) of the mapped area. At WSMR, within the Oscura and San Andres Mountains, roads occupy 165 ha (0.6%).

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