PINYON JAY MOVEMENT, NEST SITE SELECTION,

NEST FATE, AND RENESTING IN

CENTRAL NEW MEXICO

By

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Abstract: Pinyon jays (*Gymnorhinus cyanocephalus*) are an avian species of conservation concern in the southwest U.S. Due to habitat elimination and degradation, pinyon jay numbers have decreased approximately 3.5% per year since 1960. Pinyon jay reproductive rates are low, making it difficult for populations to recover. While numerous studies on pinyon jays have been conducted in ponderosa pine (*Pinus ponderosa*) forest, research has only recently taken place in pinyon pine (*Pinus edulis*) and juniper (*Juniperus monophylla*) woodland. Therefore, my objectives were to investigate pinyon jay flock movement, nest site selection, nest fate, and renesting in pinyon-juniper habitat. I trapped and affixed VHF radio transmitters to pinyon jays on Kirtland Air Force Base (KAFB) in central New Mexico from December to April in 2017 and 2018. I used radio telemetry to compare seasonal flock movements and core activity areas as well as find pinyon jay nesting colonies. Habitat surveys that recorded vegetation type, species, size, and foliage cover were performed at every nest site (n=42) as well as a similar number of randomized locations (n=41) within pinyon-juniper habitat. Movement data was analyzed using kernel density estimates to identify core activity areas. Nest site selection habitat data were compared to habitat at random sites using generalized linear models (GLMs) evaluated with Akaike's Information Criterion corrected for small sample size (AICc). Variables that affected nest fate were used in GLMs with a logistic exposure function, then evaluated using AICc.

Results suggest that there were 2 flocks on KAFB and spatial analyses should be conducted for each flock to determine accurate home ranges. Pinyon jays selected nest sites with fewer dead juniper trees and nest trees that were larger than surrounding trees in the same survey plot. Nest fate models did not perform better than the null model. Pinyon jays in this study did not renest as much as in ponderosa pine forest, perhaps due to lack of food and water availability. Furthermore, pinyon jays did not nest in satellite colonies as in other studies. Management recommendations are to remove smaller, less healthy trees in pinyon jay habitat when tree thinning occurs and leaving larger, healthier trees.

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CHAPTER I

INTRODUCTION

The western United States is a biodiversity hotspot that has gone through dramatic landscape

changes since European colonization and will continue to transform with human development and

impacts from climate change (Lanner 1981, Romme et al. 2009, Grunau et al. 2017, Jones et al.

2019). This region has been altered by urbanization, natural resource extraction, farming,

livestock production, and invasive species (Lanner 1981, Marzluff and Balda 1992, Romme et al.

2009, Grunau et al. 2017, Jones et al. 2019). Specifically, pinyon and juniper woodlands have

been changing since the 18th century, with some areas being eliminated for human development,

and remaining areas encroaching on shrubland and infilling existing woodland stands (Lanner

1981, Marzluff and Balda 1992, Romme et al. 2009, Grunau et al. 2017, Jones et al. 2019).

Consequently, land managers must be cognizant of these trends to appropriately maintain

populations of sensitive species such as gray vireos (*Vireo vicinior*) and mule deer (*Odocoileus

hemionus*; Romme et al. 2009; Bombaci and Pejchar 2016).

Pinyon jays (*Gymnorhinus cyanocephalus*) are endemic to the western U.S. and have experienced

large population declines in the past 70 years due to habitat loss and degradation (Marzluff and

Balda 1992; Balda 2002; Johnson et al. 2017, 2018; Boone et al. 2018). Pinyon jay populations

have declined by approximately 3.5% per year between 1966 and 2015 (Rosenberg et al. 2016,

Sauer et al. 2017). They are listed as a Department of Defense Species at Risk, a New Mexico Partners in Flight (NMPIF) Level 1 Species of Concern, a Species of Greatest Conservation Need by the state of New Mexico, and are listed on the North American Partners in Flight Watch List (New Mexico Department of Game and Fish 2006, NMPIF 2007, Johnson et al. 2011, Rosenberg et al. 2016). Historically, large tracts of woodland within pinyon jay range have been clear-cut by chaining for mining, agriculture, wildfire fuel reduction, and urban development (Lanner 1981, Balda 2002, Jones et al. 2019). Stands of remaining habitat have since expanded and infilled to create dense woodlands which recent studies have suggested may be undesirable or unideal pinyon jay habitat (Johnson et al. 2017, Boone et al. 2018). Furthermore, pinyon trees (*Pinus edulis*) have been experiencing widespread mortality and degradation from threats such as insect infestation, drought, and climate change (McDowell et al. 2016, Johnson et al. 2017, Boone et al. 2018). Therefore, research must focus on identifying, preserving, and managing ideal habitat for pinyon jays and other wildlife in a rapidly changing landscape.

Pinyon jays are a non-migratory species and forage year-round over home ranges up to 64 km^2 (Balda 2002). Pinyon jays are known for their mutualism with pinyon pine trees, having specially adapted bills for smashing and prying apart pinyon cones in order to access seeds (Lanner 1981, Marzluff and Balda 1992, Balda 2002). They can collect approximately 40 seeds in their expandable esophagi and transport them up to 11 km away to a caching ground (Ligon 1978, Vander Wall and Balda 1981). Seeds are buried or placed in crevices to be retrieved by pinyon jays at a later date (Marzluff and Balda 1992, Balda 2002, Wiggins 2005). However, not all of these seeds are recovered, which allows the buried seeds to germinate (Lanner 1981). The interaction between pinyon jays and pinyon trees may determine the rate at which pinyon habitat can shift and regenerate (Wiggins 2005, Grunau et al. 2017). Therefore, preserving pinyon jays and their habitat can be a management technique beneficial to pinyon-juniper woodlands and their residents.

Pinyon jays live in flocks of between 50–300 individuals, the size of which can change seasonally (Balda and Bateman 1971, Ligon 1971, Marzluff and Balda 1992, Balda 2002). In winter, all individuals in a flock forage together across the entirety of their home range (Balda and Bateman 1971, Ligon 1971, Marzluff and Balda 1992, Balda 2002). When breeding season begins, flocks subdivide into smaller groups to establish breeding colonies (Balda and Bateman 1971, Ligon 1971, Marzluff and Balda 1992, Balda 2002).

Breeding pairs of pinyon jays whose nests fail due to predation, extreme weather, or lack of food, will often try to build a new nest (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). In Flagstaff, Arizona, groups of unsuccessful nesters build new nests away from the original colony in a smaller group known as a "satellite" colony (Balda and Bateman 1971, Gabaldon 1978, Marzluff and Balda 1992, Balda 2002). If nests in this satellite colony fail, the breeding pairs will move elsewhere and establish yet another satellite colony (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). In Arizona, pinyon jays will continue trying to produce a brood in subsequent satellite colonies until they either successfully fledge young, or stop trying for the season (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). However, renesting and satellite colonies occurred less frequently in central New Mexico than in Arizona, perhaps due to less precipitation and food availability (Ligon 1978).

In the late summer, pinyon jays start to aggregate into their full-sized flock and forage together again (Balda and Bateman 1971, Ligon 1971, Marzluff and Balda 1992, Balda 2002). In fall, pinyon jays will wander widely, even outside of their traditional home range, in search of pine crops from masting pinyon trees or other conifers (Marzluff and Balda 1992, Balda 2002, Wiggins 2005). Sometimes fall flocks will encounter other flocks of pinyon jays with which they will temporarily associate, travel, and forage (Marzluff and Balda 1992). In the winter, pinyon jays will move back to their traditional home range to begin their yearly cycle again (Marzluff and Balda 1992, Balda 2002).

While research on pinyon jays has been fundamental to characterization of the species natural history, it is important to note that most of it was conducted in just one study site in Flagstaff, Arizona and may not be representative of pinyon jays across their range (Marzluff and Balda 1992, Balda 2002, Great Basin Bird Observatory 2013, Boone et al. 2018). Pinyon jay range extends from central Oregon to Montana in the north and from the Mexican states of Baja California to Chihuahua in the south (Marzluff and Balda 1992). The vegetation in Flagstaff is dominated by ponderosa pine trees (*Pinus ponderosa*) and during nest site selection studies there, researchers found that pinyon jays nested almost exclusively in ponderosa pine (Gabaldon 1978). However, much of pinyon jay species range is located within pinyon-juniper woodland habitat, and researchers or land managers may not apply findings from Flagstaff studies (Marzluff and Balda 1992, Balda 2002, Wiggins 2005). Furthermore, pinyon jay nests in Flagstaff frequently failed due to cold weather and heavy snowfall during the beginning of breeding season. However, much of pinyon jay range is located in arid, semi-desert environments that do not experience the same magnitude of winter precipitation (Clark and Gabaldon 1979, Marzluff 1988, Balda 2002). In the last decade, more research has been conducted in different areas of pinyon jay range. Studies in Nevada and Idaho have investigated habitat use of pinyon jays in pinyon-juniper woodlands (Great Basin Bird Observatory 2013). In New Mexico, some studies have examined nest site selection of pinyon jays at both small and large scales in pinyon-juniper habitat (Johnson et al. 2016, 2017).

In addition to habitat use, pinyon jay behavior in other regions may vary from studies in Arizona. Satellite colonies occur in Flagstaff, Arizona, but studies in New Mexico suggest that pinyon jays there do not renest frequently and other studies have not documented satellite colonies (Balda and Bateman 1973, Ligon 1978, Marzluff and Balda 1992, Johnson et al. 2016). It is unclear if satellite colonies occur in New Mexico. Pinyon jay flock sizes and group dynamics are also difficult to determine because pinyon jays frequently alter their grouping. Different flocks can

merge until winter, and flocks that inhabit adjacent home ranges can be difficult to distinguish (pers. obs). The timing of life history events, such as establishing breeding colonies and searching for seeds, is variable, especially in a region where rainfall and food production are patchy (Ligon 1971, Marzluff and Balda 1992). More study is needed on pinyon jay flock composition and satellite colonies outside of Arizona.

My study was conducted on Kirtland Air Force Base (KAFB) in central New Mexico. Kirtland Air Force Base contains 77 km^2 of pinyon-juniper woodland habitat (Johnson et al. 2016). The area is largely undeveloped. Previous studies conducted at KAFB have documented locations of pinyon jays, mapped nesting colonies, conducted nest site selection analyses, and delineated habitat (Johnson et al. 2016, 2017). These studies suggested that pinyon jays on KAFB belong to one large flock that regularly subdivides to breed and are reliant on pinyon pines for food and nesting substrate. For this study, I wanted to further investigate the number of pinyon jay flocks on base, as well as nest site selection, nest fate, and renesting.

After this introduction, my second chapter will be a comparison of pinyon jay flocks between their pre-breeding and breeding season home ranges. I will use this information to determine if the two groups of pinyon jays on base are separate flocks or just one, large flock that subdivides during the breeding season to establish separate colonies. My third chapter will examine nest site selection to determine if pinyon jays prefer nesting in areas with specific habitat composition. My fourth chapter will analyze the effects of habitat composition on pinyon jay nest survival, as well as investigate the potential existence of satellite colonies in central New Mexico.

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CHAPTER II

PINYON JAY MOVEMENT AND FLOCK DYNAMICS ON KIRTLAND AIR FORCE BASE,

CENTRAL NEW MEXICO

ABSTRACT

Pinyon jay (*Gymnorhinus cyanocephalus*) populations continue to decline despite increased

management across their range. Their unique social structure requires that researchers identify

pinyon jay flocks and delineate home ranges for future management. Kirtland Air Force Base

(KAFB) in central New Mexico manages pinyon-juniper habitat containing one or more groups

of pinyon jays. My objectives were to determine if pinyon jays on KAFB belonged to one large

flock that divided into discrete breeding colonies or multiple flocks that inhabited separate

regions. I mounted VHF radio transmitters on pinyon jays to record their movements from

January through July in 2017 and 2018. There were two major flocks of pinyon jays on KAFB

comprising approximately 65 individuals each that subdivided into smaller, spatially-separate

breeding colonies. The number of breeding colonies each year was likely related to availability of

food and water. I created kernel density estimates to determine home ranges of the two flocks in

breeding and non-breeding seasons. Previous studies on KAFB performed spatial analyses of

both flocks together as one group,

however, my research indicates that home range estimates were overestimated by conducting spatial analyses in this manner. This study demonstrates that it is critical to determine the number of pinyon jay flocks to correctly delineate pinyon jay home ranges and the habitats they occupy. Seasonal home range findings can inform future habitat management on KAFB.

INTRODUCTION

Accurate delineation of animal home ranges is necessary to create appropriate research and management plans. Land management plans in the southwestern United States have included efforts to monitor and conserve pinyon jays (*Gymnorhynus cyanocephalus*) because they are a species of concern in some regions such as New Mexico (Grunau et al. 2017, Boone et al. 2018). However, a majority of the research on pinyon jays comes from one flock in Flagstaff, Arizona, and only recent efforts have described pinyon jay ecology in New Mexico (Johnson et al. 2016, 2017; Boone et al. 2018). Information about the Flagstaff flock is unique to the habitat it resides in, the number of flock members in it, and the number of adjacent flocks nearby. Because differences in resource availability would necessarily alter their ecology, using studies of this flock to predict home ranges and activity areas of pinyon jays in different regions may result in improper management efforts.

Pinyon jays are a nomadic, non-migratory species whose habitat is increasingly being degraded by urbanization, clear cutting of trees, insect infestation, grazing practices, and an increase in wildfires (Marzluff and Balda 1992, Balda 2002, Bombaci and Pejchar 2016, Johnson et al. 2018, Boone et al. 2018). Pinyon jays have a mutualist relationship with pinyon pine (*Pinus edulis*), acting as consumers and dispersers of pinyon seeds (Lanner 1981, Marzluff and Balda 1992, Balda 2002). This species is distinctive due to the large size of their home ranges, as well as the sociality and cohesiveness of flock members. Pinyon jays live in flocks of 50–300 individuals that travel as far as 25 km per day across home ranges that can be 1,600 ha–6,400 ha (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). A flock is described as a group of pinyon jays that inhabit the same annual home range (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). A flock may subdivide into smaller breeding colonies, but these are still considered part of the same flock because they reassemble into the full group after breeding (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002, Johnson et al. 2011). Flocks

may interact with other flocks for a short time, especially in the fall while searching for seed crops, but will eventually return to their respective home ranges (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). Areas of regular activity, known as core areas, change depending on breeding status or food availability (Balda and Bateman 1971, Shank 1986, Marzluff and Balda 1992, Kenward 2001, Johnson et al. 2011). Successful conservation of pinyon jays must take into account the number of flocks in an area, number of flock members, home range size, location of core areas, and changes in these factors.

Previous pinyon jay studies on Kirtland Air Force Base (KAFB) in central New Mexico initially found evidence of two groups inhabiting distinct areas (Johnson et al. 2011). Further study revealed that these groups sometimes aggregate during the non-breeding season, although the timing, location, and circumstances were not well known (Johnson et al. 2011, 2016). These studies of flock composition relied on telemetry observations of radio-tagged pinyon jays (n=14) over three years and counting the size of groups during pinyon jay sightings (Johnson et al. 2011, 2016). It was assumed that pinyon jays on KAFB represented one large flock that subdivided into two large subgroups during the breeding season, however, due to the difficulty of finding and following pinyon jays across mountainous terrain, data on the autumnal behavior of pinyon jay flocks on base are lacking (Johnson et al. 2011, 2016). It is unclear if the groups of pinyon jays were independent flocks that were sometimes found together or if the groups comprised one dynamic flock that subdivided during breeding season (Johnson et al. 2011).

Therefore, my objective was to determine if pinyon jays on KAFB belonged to one large flock that divided into discrete breeding colonies during breeding season, or if there were multiple flocks on base that inhabited separate regions. Furthermore, I documented and compared seasonal pinyon jay movements in the non-breeding and breeding season to inform potential management decisions in the future. This study is instructive for researchers and land managers working in

similar ecoregions to assess pinyon jay flock identity and how it affects home range spatial

analyses in order to better allocate management resources in vital pinyon jay areas.

METHODS

Study Area

This study occurred in 2017–2018 on KAFB in central New Mexico. Kirtland Air Force Base is

located south of Albuquerque, New Mexico and encompasses 210 km^2. Elevation ranges from

5200 m–8000 m from scrub steppe in the west to juniper (*Juniperus monosperma*) savanna,

pinyon-juniper woodlands, and ponderosa pine (*Pinus ponderosa*) forest at progressively higher

elevations to the east (KAFB 2012). The majority of pinyon jay habitat on KAFB is located

within a location known as the Withdrawn Area in the east which includes 77 km^2 of pinyon and

juniper habitat (Johnson et al. 2016).

Data Collection

Preliminary searches for pinyon jays were conducted on KAFB between 1 March–1 May in 2016

(McMurry et al. 2016). Point counts were conducted with playback of pinyon jay vocalizations at

50 randomized points spaced at least 500 m apart in pinyon-juniper habitat on base (Ralph et al.

1993, Lor and Malecki 2002, McMurry et al. 2016). During these surveys observers witnessed

groups of birds comprising 1–35 individuals. Additionally, a group of pinyon jays was observed

with over 100 members in August 2016 (McMurry et al. 2016).

In 2017, I conducted playback surveys for pinyon jays to locate as many groups as possible.

These road-based surveys were performed along every accessible road in the wooded areas on

base. I found two groups of pinyon jays approximately 5.1 km apart separated by a mountain

range. Because of their grouping during surveys, I decided to refer to the two groups as

independent flocks for clarity. One flock was in the south of KAFB and one was in the north

(hereafter Starfire flock and Madera flock, respectively). I found no other flocks despite continued surveys throughout 2017.

I conducted trapping from 20 January–2 March in 2017 and from 10 January–22 March in 2018 to band and radio-tag pinyon jays. Trapping efforts were divided between the Starfire flock and the Madera flock. Presence of bird feeders maintained by a gate guard at the Starfire Optical Range (SOR) in the southern portion of the base impacted our capture efforts for the Starfire flock. The Starfire flock regularly visited feeders in the non-breeding season. I used baited, walk-in style pigeon traps near the feeders at this location (Johnson et al. 2011, 2016; Great Basin Bird Observatory 2013). In the north of KAFB, no feeders were permanently established. In 2017, I used a variety of techniques to catch pinyon jays from the Madera flock, including baiting with pinyon seeds, using playback calls to lure pinyon jays to walk-in traps and mist-nets, and using predator decoys to instigate mobbing behavior near mist-nets (Marzluff and Balda 1992; Johnson et al. 2011, 2016). I attempted to lure and trap pinyon jays in areas where I had observed them regularly in large numbers, including near breeding colonies. These methods were not effective, likely due to our baiting techniques and the wariness of pinyon jays. Because I was unable to sufficiently disguise mist-nets in open woodlands, they detected and avoided the nets. Pinyon jays in Madera Canyon did not eat from tube feeders like the Starfire flock. Furthermore, our inability to replenish bait on the ground with sufficient frequency made it difficult to passively attract pinyon jays to traps. In 2018, I established an automatic feeder stocked with peanuts, black oil sunflower seeds, millet, and pinyon seeds in a location where I had regularly observed the Madera flock. The feeder dispersed seed onto a raised platform which pinyon jays in the area discovered and began visiting regularly. Afterwards, I was able to successfully capture pinyon jays with walk-in traps. This project was approved by the Oklahoma State University Animal Care and Use Committee (Protocol #AS1516).

I monitored the traps from a vehicle and removed trapped birds immediately. Birds were placed in a cloth bag until they were ready to be processed. I applied a serially-numbered USGS aluminum band and a unique combination of three plastic color bands to the legs of trapped pinyon jays. I then recorded wing chord, tail length, age, sex, feather wear, feather molt, body molt, fat score, presence of cloacal protuberance, presence of brood patch, tarsus length, mass, bill height, bill length, and bill depth (Johnson 1988, Pyle 1997, Balda 2002). Measurements collected were potential indicators of age, sex, breeding status, and relative health which were important in determining flock composition and deciding how to allocate transmitters among individuals. Pinyon jays were classified as either second-year or after-second-year in age by examining the contrast between the primary and secondary coverts (Pyle 1997). Pinyon jays are monomorphic and difficult to distinguish in the field, but females can be smaller, have smaller mandibles, and are typically more dully colored than males (Johnson 1988, Pyle 1997). While some displayed breeding characteristics such as a cloacal protuberance or brood patch, I only found these on two individuals later in the season after the majority of banding had been conducted (Pyle 1997). Therefore, I took a blood sample to genetically assess sex (Fair et al. 2010). I used a 26-gauge beveled needle to puncture the brachial vein of pinyon jays and collected blood in capillary tubes. Blood was transferred to a blood card and sent to a laboratory for analysis (Animal Genetics, Inc., Talahassee, FL). I applied radio transmitters to suspected female pinyon jays by tying a 2.0 g tail-whip VHF radio transmitter (Holohil, Inc., Carp, ON, Canada) to the top of the two central rectrices and reinforcing it with cyanoacrylic glue (Yaremych et al. 2004; Johnson et al. 2011, 2016).

In 2017, I banded 34 adult pinyon jays. Three were from the Madera flock while 31 were from the Starfire flock. DNA tests indicated that 16 individuals were male and 13 were female. Difficulties drawing blood and early release of stressed individuals prevented us from collecting blood from 5 pinyon jays which were therefore of unknown sex. I placed 14 transmitters on 13

pinyon jays (one transmitter was replaced) that I believed were likely to be females (Balda 2002, Johnson 1988). DNA tests revealed that 9 individuals with transmitters were females and 4 were males.

In 2018, I banded 68 adult pinyon jays with 39 from the Madera flock and 29 from the Starfire flock. DNA tests indicated that 38 were male, 25 were female, and 5 were of unknown sex. I placed transmitters on 51 pinyon jays. While I tried to primarily place transmitters on likely females or individuals identified as female from previous DNA tests, I was less discriminate about this criterion than in 2017 to deploy as many transmitters as possible. This allowed me to track pinyon jays as they subdivided into progressively smaller groups throughout breeding. I deployed 24 transmitters on females, 25 on males, and 2 on individuals of unknown sex. Five transmitters that fell off during the project were redeployed on other individuals.

Observers conducted radio telemetry surveys to search for radio-tagged individuals at least twice per week. Telemetry was conducted using omnidirectional telemetry, homing, and triangulation using an R-1000 handheld telemetry receiver (Communications Specialists, Inc., Orange, CA; Millspaugh et al. 2012). Observers used a short omnidirectional antenna to identify individuals in visible flocks at close range (< 200 m). Because of the short range of the omnidirectional antenna, the variability of elevation, and the strong tendency for pinyon jays to move in flocks, I was confident that individuals were correctly identified in this way. Homing telemetry was conducted with a 3-element yagi. When an observer identified a signal from an individual pinyon jay, they slowly scanned the yagi across the horizon to identify the strongest signal coming from the transmitter (Millspaugh et al. 2012). The observer then walked in the direction of the strongest signal until encountering the individual with the transmitter (Millspaugh et al. 2012). Finally, triangulation was used in cases where observers could not see pinyon jays and transmitter signals did not indicate that they were nearby. After initially detecting pinyon jays using a yagi antenna, observers estimated the bearing of the strongest signal to determine where to position two

observers for an official reading (Millspaugh et al. 2012). Ideal positioning of observers was such that their potential bearings would intersect at an angle that would provide the least error (25°–155°), considering factors such as topography and radio interference from roadside electrical transformers (Springer 1979, Millspaugh et al. 2012). Two observers stood at separate locations, took bearings on each transmitter, and recorded bearings of the strongest signals (Millspaugh et al. 2012, Millspaugh et al. 2012). Locations of individuals were inferred from the intersection of the two bearings using ArcMap 10.2 (ESRI, Inc., Redlands, CA). Because of the inherent error in estimating where triangulated birds were, I calculated a spatial confidence interval, in this case a circle. The resulting points were located within a 95% confidence circle with a radius of 0.33 km (SE = 0.026 km) and an area of 0.34 km^2 derived from the following equation from Withey et al. (2001):

$$radius = predicted\ mean\ linear\ error + (1.96)(SE\ of\ mean\ linear\ error)$$

Considering the extreme mobility of pinyon jays, a confidence circle of this size was appropriate for triangulation estimations and the points were unaltered before subjecting them to analysis.

Because pinyon jays usually travel in flocks, I consolidated individual location points of pinyon jays that were detected in the same place and time to avoid overweighting spatial analyses. This was critical because transmitters stopped functioning or fell off as the season progressed, and I did not want to miscount the individuals in a flock because there were fewer transmitters to detect later in the season. Furthermore, because trapping was inadequate for the Madera flock in 2017, I used visual observations of pinyon jay flocks to supplement locational data in that area that year. Locations of flocks were entered into analysis as one data point similarly to group detections of transmetered pinyon jays.

Locations were divided for comparison by flock, year, and season (breeding and non-breeding). Season was determined by estimating the date of first egg laid in each nest in a flock and

averaging this value for each flock. We began searching for nests when transmetered females stopped visiting the feeders in mid-March, indicating they were beginning to construct nests. First egg laying dates were estimated by aging chicks in the nest then backdating by the number of days in nest (≤ 17), the number of days for incubation (21), and the number of days between the first laid egg and when the female begins to brood (3) (Marzluff and Balda 1992, Balda 2002). This was likely not affected by the clutch size as pinyon jays rarely lay fewer than three eggs and begin incubating after laying the third egg (Marzluff and Balda 1992, Balda 2002). Average first lay dates in 2017 were 5 March (Madera flock; N=6) and 12 March (Starfire flock; N=6). Average first lay dates in 2018 were 1 April (Madera flock; N=5) and 16 March (Starfire flock; N=4).

Data Analysis

I created minimum convex polygons (MCPs) using the Minimum Bounding Geometry tool in ArcMap 10.2. I inputted all location points from flock sightings, omnidirectional telemetry, and triangulation. Minimum convex polygons define home range boundaries but do not provide information about relative densities or core areas (Kernohan et al. 2001, Withey et al. 2001). Therefore, I used the Geospatial Modeling Environment tool suite (Beyer 2012; R Version 3.4.1, www.r-project.org, accessed 10 Sep 2017) to create kernel density estimates (KDEs). These are useful for estimating the relative activity levels of pinyon jays across their home range (Kernohan et al. 2001, Johnson et al. 2016). Kernel density estimates create a raster from point data which contain an estimate of the spatial density of those points (Fotheringham et al. 2000). I used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 (Johnson et al. 2011, 2016). I selected a fixed bandwidth because it closely resembles the best performing adaptive kernel, the plugin kernel, but is less sensitive to outliers and clumped data points (Kernohan et al. 2001, Kie et al. 2010). The lower sensitivity to clumped

data points was necessary because many points were taken at feeders where pinyon jay regularly visited.

To identify the most important areas within pinyon jay home ranges, KDEs were divided into different activity intensity levels using a percentage volume contour (PVC) isopleth tool (Beyer 2012). Percentage volume contours calculate an area containing a specified percentage of volume in a KDE raster (Kernohan et al. 2001). The resulting polygon indicates the probability of a cell located within having a value that is equal to or greater than the specified range. For example, the area of 95 PVC comprises 95% of the total value from a KDE, and any cell in the polygon has a density probability that is within 95% of the total range of values (Kernohan et al. 2001). Kernel density estimates were separated into 50, 90, and 95 PVC groups that encompass a similar proportion of the total detection points (Edenius et al. 2004, Yaremych et al. 2004, Vigallon and Marzluff 2005, Lorenz and Sullivan 2009, Johnson et al. 2011).

RESULTS

Pinyon jays were located mostly on KAFB, but sometimes went off base to breed or forage (Figs. 2.1–2.3). Pinyon jays self-grouped into two distinct flocks during the study. Each flock split into at least two smaller groups during breeding season. Individuals in the Madera flock remained primarily in the northern region of KAFB and individuals in the Starfire flock were found in the southern region of KAFB. These two groups comprised approximately 60–75 members each in the non-breeding season. Shortly before breeding season started I found pinyon jays in smaller groups of 10–30 individuals. Each breeding colony was established > 3 km from other colonies. Although their occupied habitat changed during breeding, pinyon jays from the Madera colonies remained primarily in the north and the breeding groups of the Starfire flock remained in the south (Figs. 2.2, 2.4–2.7). There was little overlap in home ranges of the two flocks and they were never observed associating with each other (Fig. 2.2).

In 2017, my most successful trapping efforts were with the Starfire flock, allowing me to deploy many transmitters early in the season. The Starfire flock was found mainly around the SOR facility during the non-breeding season and along the foothills in the southern region of the Withdrawn Area (Figs. 2.2, 2.5). The non-breeding Starfire flock numbered approximately 60 individuals. When the Starfire flock subdivided for breeding, approximately half of the pinyon jays established a breeding colony (hereafter referred to as Starfire1) 2.0 km from the SOR feeders, while the other half were detected on Isleta Pueblo located immediately south of KAFB (Fig. 2.6d). Initially, the nests built at Starfire1 were grouped together in the same vicinity. When nests in the colony failed, pinyon jays from failed nests established new ones 0.28 km–2.06 km from the original colony. After the initial colony, I found subsequent nests in at least two other areas. The other half of the overall flock moved south to Isleta Pueblo. Because I was not allowed access onto that property, I used radio telemetry to determine the locations of radio-tagged individuals and presumed they had established a colony there (hereafter referred to as Starfire2). Individuals in this location in 2017 were not found back on base until late July.

In 2018, the non-breeding Starfire flock numbered approximately 65 individuals. At the beginning of breeding season, the flock subdivided into two groups as they had the previous year. Approximately half the flock established a breeding colony on Isleta Pueblo (Starfire2), which I was able to determine through radio telemetry surveys. I could not confirm their presence again on KAFB when the study ended in July 2018 because transmitters on individuals from that group had fallen off or were otherwise nonfunctional. The group that bred on base established an initial colony (hereafter referred to as Starfire3) 0.77 km from Starfire1. When initial nests failed, subsequent nests were built in nearby locations at 0.40–0.67 km from Starfire3.

The Madera flock was found primarily on Coyote Springs Road and in Madera Canyon (Figs. 2.2, 2.4). During the non-breeding season in 2017 this flock comprised approximately 65 individuals. Initially, pinyon jays were difficult to trap in this area. The 3 individuals I was able to affix

transmitters to, however, were critical for finding two breeding colonies. In 2017 the Madera flock subdivided into two groups which each established a breeding colony in March. Approximately one half of the flock started a colony (hereafter referred to as Madera in Sol Se Mete Canyon (Fig. 2.6b). I observed pinyon jays flying from Sol Se Mete Canyon to Winch Road and back again to deliver food to nests. The other half of the Madera flock established a breeding colony on the northwest slope of Madera Canyon (hereafter referred to as Madera2). No transmitters stayed on long enough in 2017 to observe renests. However, I did find one nest 2.06 km from Madera2 on 26 April. Because the nest was built after average first egg laying date of the Madera colonies and was established in the apparent absence of other nests, it was likely a renest from the Madera2 colony.

In 2018 I deployed 29 transmitters on individuals in the Madera flock. During the non-breeding season this flock comprised approximately 75 individuals. When the breeding season started, I expected this flock to subdivide into two groups to establish breeding colonies, but they did not. I observed just one breeding colony of approximately 40 individuals (hereafter referred to as Madera3). This colony was established on the northwest slope of Madera Canyon, 0.60 km away from 2017 Madera2 colony (Fig. 2.6b, 2.7b). The remaining individuals from the non-breeding flock were not associated with a breeding colony and did not nest. On numerous occasions I observed a group of 10–20 foraging individuals, including many after-second-year females. I did not observe these individuals near the Madera3 breeding colony or maintaining nests of their own. As they were not restricted to maintaining a close proximity to a nest, I found this group of foraging pinyon jays over much of the home range and some locations I had not previously recorded. For instance, I observed this foraging group of adult jays as far as the U.S. Forest Service ranger station in Tijeras, New Mexico, 7.60 km from the Madera3 colony, as well as along the boundary of the Starfire flock home range.

Home Range Analysis

Year-round home range MCP was larger when constructed from all pinyon jay locations than the summed value of MCPs of each flock separately (Table 2.1; Figs. 2.1, 2.2). However, year-round home range PVCs at all levels were smaller when constructed from all pinyon jay locations than the summed value of each flock separately (Table 2.1).

Home range MCPs and PVCs were larger for the Madera flock than for the Starfire flock, except at the 50 PVC in 2017, which was slightly smaller than for the Starfire flock (Table 2.1; Figs. 2.2, 2.4–2.7). All breeding home range MCPs and PVCs were larger than non-breeding home ranges, except the Madera flock MCPs in 2017 (Table 2.1, Figs. 2.6, 2.7).

DISCUSSION

Flock Analysis

Johnson et al. (2011, 2016) asserted that it is likely the two groups of pinyon jays on KAFB are one flock that splits up for breeding season. However, my data do not support this finding. Of the 102 pinyon jays I banded and the 67 transmitters I deployed during the two years of this project, I did not find any individuals that changed flocks. Johnson et al. (2011) recorded one flock of pinyon jays with 135 individuals and a biologist on KAFB recorded a flock of more than 100 individuals in late August 2018, but observations of flocks this large are few and their duration is uncertain.

I observed two non-breeding groups acting independently three months before breeding season. If this was one group, it would be notable that the flock divided so long before breeding. This behavior is not supported in the literature (Marzluff and Balda 1992, Balda 2002, Johnson et al. 2016). It is possible that the two groups of pinyon jays were sometimes found foraging together in autumn, a consistent behavior of pinyon jays, which range widely in the fall to forage for seeds crops and sometimes associate with other conspecific groups (Bent 1964, Marzluff and Balda 1992). Pinyon jays have been seen in autumn groups of up to 1000 members comprising different

independent flocks temporarily associating with each other (Bent 1964, Marzluff and Balda 1992).

Land managers on KAFB should consider the Madera and Starfire flocks as independent. Combining locations and movements of the two flocks, especially during the breeding season, alters spatial analyses. For example, the MCP of both flocks together, as opposed to separately, overestimated pinyon jay use on base by 304.6 ha. Furthermore, knowing how many individuals are in each flock can inform estimates of how many breeding colonies may be found on or near KAFB. When breeding begins, land managers on KAFB can likely expect to find at least one breeding colony from each flock. Finally, separating the two flocks increases the number of high activity areas generated from KDEs. Analyses of all pinyon jays together identified high activity areas mostly from the Starfire flock, which had more location points due to it being easier to trap and access. Failure to separate pinyon jay flocks in spatial analyses will limit identification of critical pinyon jay areas for both flocks.

Accurately assessing the number of pinyon jay flocks on base is also necessary for population estimates. Johnson et al. (2011) considered all groups on KAFB as one overall flock, and used their highest observed count of pinyon jays in a group (135 individuals) as their basis for determining the number of individuals on base. However, care must be taken to ensure this is an accurate count of pinyon jays that stay on KAFB year-round, as members of flocks from off base may be temporarily associating with the flocks on KAFB. My data, taken during consistent observations from winter to summer over two years, show that there are two flocks of pinyon jays on base, each with approximately 60–75 individuals, based on repeated counts of each flock. Therefore it appears pinyon jay populations remained stable since monitoring began in 2009 (Johnson et al. 2011). Finally, accurately identifying the number of flocks on KAFB is critical for comparison of pinyon jay studies elsewhere where flock sizes might be different, such as the

study flock in Flagstaff, Arizona, where the approximate size was between 140–200 individuals (Marzluff and Balda 1992, Balda 2002).

Future research on pinyon jays should strive to uniquely identify flocks. Initial assumptions of flock identities may be made just before the breeding season in January–March, just before pinyon jays begin courtship when flock composition is relatively stable (Marzluff and Balda 1992, Balda 2002). To add more certainty to assumptions about flock identity, researchers should continue to monitor individuals using color banding or telemetry techniques for long term monitoring.

Home Range Analysis

Research on corvids frequently includes an estimate of home range size. Edenius et al. (2004) estimated that Swedish Siberian jay (*Perisoreus infaustus*) home ranges were 50 ha. Yaremych et al. (2004) found that adult American crows (*Corvus brachyrhynchos*) in Illinois occupied a 610 ha home range, but noted that home ranges of American crows varied by region. Vigallon and Marzluff (2005) found home ranges of Steller's jays (*Cyanocitta stelleri*) averaged 57.7 ha. Clark's nutcrackers (*Nucifraga columbiana*), a species that is frequently compared to pinyon jays for their similarity in wide-spread seed collection and caching, had summer home ranges that averaged 318 ha in Washington (Lorenz and Sullivan 2009). Pinyon jays often have larger ranges than other corvids. Home ranges have been recorded between 1600 ha–6400 ha in Arizona and 2890 ha–5978 ha in New Mexico (Ligon 1971, Balda 2002, Johnson et al. 2016).

A meta-analysis of corvids by Shank (1986) found a positive correlation between total food energy requirements of conspecific corvid social groups and the nutritional productivity of a home range. In other words, corvids that live in groups that require a greater total number of calories per day tend to inhabit home ranges that, due to size or unit productivity, produce more food to feed all the members. This may explain why pinyon jays have such large home ranges in

conifer dominated landscapes, such as pinyon-juniper woodlands and ponderosa pine forests, where seed production is irregular (Lanner 1981, Marzluff and Balda 1992, Balda 2002).

Previous studies in Arizona found pinyon jays in landscapes dominated by ponderosa pine (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). Even though ponderosa forest is apparently suitable habitat for pinyon jays in Arizona, I did not find pinyon jays in the higher-elevation ponderosa forest on KAFB. Instead, I found pinyon jays exclusively in juniper savanna and pinyon-juniper woodland. This demonstrates that habitat requirement recommendations based on research from Arizona may not apply in New Mexico.

Although I considered pinyon jays on KAFB as two independent flocks, I also produced home range maps including all the pinyon jays on base as one group for comparison with previous studies (Johnson et al. 2011, 2016). The size of the home range MCPs from these previous studies (5027.4 ha and 5978.0 ha, respectively) were based on calculating points from pinyon jays and nest sites from both groups. Analyzing location data from my study using pinyon jay location points from both groups on KAFB yielded a larger polygon (6482.7 ha). The primary differences between these MCPs are due to my observations of pinyon jays relatively far from base in Isleta Pueblo and Tijeras, whereas Johnson et al. (2011, 2016) did not detect pinyon jays far from the boundaries of KAFB.

Johnson et al. (2011) produced a 95 PVC for all of pinyon jays, collectively, on KAFB (5741.7 ha) which was nearly double the size of the 95 PVC I generated (3289.3 ha). This could be due to a variety of factors that involve the particular location and number or density of observations (Kernohan et al. 2001, Jones et al. 2015). The Johnson et al. (2011) analyses used 135 location points where mine used 343 points, which is partially a result of having more pinyon jays with transmitters in my study than in previous studies. The higher number of points used in my study made my analyses less sensitive to outlying observations. Therefore my 95 PVC does not extend

to accommodate infrequent, isolated pinyon jay observations. However, the MCP home range maps produced by Johnson et al. (2011, 2016) are similar in size and location to my analyses, with some exceptions. There are a few areas where Johnson et al. (2011) found pinyon jays in higher densities than I did, such as at their southern feeder and the Lurance Canyon Burn Site. There are also areas I found pinyon jays where Johnson et al. (2011, 2016) did not, such as Isleta Pueblo and in Tijeras. Additionally, the seasonal spatial analyses are similar to Johnson et al. (2011) in that non-breeding pinyon jays are most frequently detected at feeding stations such as the feeders at the SOR gate and temporary automatic feeders. Some geographical differences between my PVCs and the ones produced by Johnson et al. (2011), especially the 50 PVC, are likely due to different placement of feeders during the non-breeding season. Johnson et al. (2011) placed a feeder in the foothills on the southern boundary of KAFB while I placed a feeder on Winch Road in Madera Canyon.

When I performed spatial analyses of each KAFB flock separately, home range estimates were similar to pinyon jay home ranges in other parts of New Mexico. Johnson et al. (2011) recorded the home range of one pinyon jay flock on White Sands Missile Range in south-central New Mexico and found the home range MCP for one flock there was 3415.7 ha and a 95 PVC was 3486.8 ha. Johnson et al. (2015) found the MCP home range for a pinyon jay flock in Farmington, New Mexico was 3102.9 ha and a 95 PVC was 4033.7 ha. These home range estimates closely resemble home range size estimates for the Madera flock, which I was able to collect thorough locations over 7 months. However, they are larger than my estimates for the Starfire flock due to limitations on accessing the entirety of their home range on KAFB. This comparison indicates that the home ranges of fully sampled flocks in three regions of New Mexico are similar (Kernohan et al. 2001, Jones et al. 2015).

MCP analyses are not as accurate at defining a home range as contouring methods are (Kernohan et al. 2001). I compared PVC areas between pinyon jay flocks (Starfire, Madera), year (2017,

2018), and breeding status (nonbreeding, breeding). The key differences between PVC areas involved the number of breeding colonies found, the location of feeders or water, the extent at which I was able to detect pinyon jays, and possibly the effects of severe drought in 2018. These factors frequently affected the 90 and 95 PVC differently than the 50 PVC. For example, the difference between the PVC areas of both flocks was large at 95 and 90 PVCs but small at 50 PVC. The area the Madera flock inhabited at 95 and 90 PVCs was greater than for the Starfire flock because I was able to observe and follow most of their movements. In contrast, I was not able to follow the Starfire pinyon jays on Isleta Pueblo, where they likely established a breeding colony in the same area both years, which resulted in a reduced area sampled and analyzed for their flock. Areas were more similar at the 50 PVC for both flocks because each flock concentrated their activity around 1 or 2 important areas depending on the season. In the non-breeding season, pinyon jays regularly visited a feeder in their area, whereas during breeding, each flock spent most of their time around their breeding colony. When each flock had an equal number of feeders or breeding colonies on base, 50 PVC areas were similar.

I found that PVC estimates were larger at the 95 and 90 PVCs in 2018 than in 2017, but were smaller at the 50 PVCs. Larger areas in 2018 possibly result from my better knowledge of pinyon jay activity on site, an increased number of deployed transmitters, and changes in pinyon jay behavior on KAFB that year due to extreme drought. Drought may have suppressed arthropod production that spring and, therefore, reduced potential food sources for nesting pinyon jays (Ligon 1978). This may have caused many members of the Madera flock to forego breeding. Pinyon jays that did not establish and tend nests were therefore able to wander far from their core home range during breeding season. Smaller area estimates at the 50 PVC in 2018 were also likely affected by drought that year. In 2017, the Madera flock established 2 breeding colonies, however, in 2018 the Madera flock only established 1 breeding colony, likely due to drought. The

Starfire flock appeared to be less affected by drought because of its year-round access to food and water provided by humans.

Areas of all PVCs were higher in the breeding season than in the non-breeding season. This is due to three factors. Firstly, pinyon jays visited feeding stations in the non-breeding season and limited their movements around those feeders. When the breeding season started, pinyon jays no longer visited the feeders and ranged more widely across their home range to forage or retrieve caches. Secondly, when the flocks subdivided into breeding colonies, it increased the amount of pinyon jay high activity centers. Thirdly, the non-breeding season was from January to mid-March while the breeding season lasted from mid-March until the end of July. Thus, I collected breeding season observations for two months more than for non-breeding.

There were limitations of my research that are common to radio telemetry studies. Radio telemetry equipment is most effective when observers have clear lines of sight to deployed transmitters (Millspaugh et al. 2012). The terrain in the Withdrawn Area on KAFB is mountainous and obscures signals from transmitters that are too far up the mountain from access roads (Johnson et al. 2011, 2016). Future studies might use GPS loggers to collect locations even when pinyon jays are not near places accessible to observers (Millspaugh et al. 2012). The technology is still developing to make GPS units that are small enough to use on pinyon jays. I affixed transmitters to the top two retrices of pinyon jays, which is a minimally invasive technique but subject to many transmitters falling off while still attached to the feathers. For studies that require consistency of transmitters on individuals, a leg-loop harness with a "weak link" can ensure long-term attachment which will fall off after the unit runs out of battery (Kessler 2011).

Other environmental factors also likely influenced pinyon jay locations. For example, a fire occurred in March 2018 which burned 80 ha, including part of the Starfire1 colony. The fire

altered the vegetation structure of the area which might have been why pinyon jays in 2018 established the Starfire3 colony 0.84 km away from the initial Starfire1 colony from 2017. Another factor likely affecting pinyon jay locations was severe drought in 2018. Yearly precipitation from April 2016–March 2017 and April 2017–March 2018 were below the normal yearly precipitation (19.86 cm, 17.32 cm, 24.0 cm, respectively; NOAA 2018). The drought caused multiple national forests closures in New Mexico due to fire warning, including the Cibola National Forest, of which the Withdrawn Area on KAFB is part of. It is possible this affected pinyon seed production in 2018, and thus, pinyon jays on KAFB, however there are no estimates for pinyon seed production for those years (Lanner 1981, Marzluff and Balda 1992, Parmenter et al. 2018). This might be why the Madera flock established only one breeding colony in 2018 despite having access to food provided at Winch Road from December–March. One female that nested in the Madera3 colony that year did not renest when her first attempt failed on 23 April, well before breeding usually ends in late July. Instead, she joined the foraging flock for the remainder of the breeding season. This is another indication that drought may have had adverse effects on pinyon jay breeding in 2018 and altered PVCs that year.

CONCLUSION

I determined there were two pinyon jay flocks on KAFB by monitoring non-breeding season movements. Each flock had 60–75 individuals that subdivided into smaller groups to establish breeding colonies in March and April. Flocks were most active around feeders during the non-breeding season. The number and location of feeders and breeding colonies affected the size and shape of pinyon jay core activity areas. These insights provided useful information about how to determine the number and location of pinyon jay flocks and how that affects home range analyses. Future studies on KAFB should record year-round movements of pinyon jays to identify flocks in the winter and breeding colonies in the spring, as well as investigate wandering flocks and interactions with neighboring flocks in the fall. Regular monitoring of pinyon pine crops in

addition to precipitation and ambient weather data can serve as an indicator of pinyon jay food

availability and, thus, pinyon jay breeding propensity. This information can be useful in

explaining or predicting pinyon jay flock and breeding dynamics in central New Mexico.

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TABLES AND FIGURES

Table 2.1 – The areas of pinyon jay home ranges on Kirtland Air Force Base, New Mexico in 2017 and 2018. Home range analyses consisted of minimum convex polygons (MCP) and kernel density estimates (KDEs). Kernel density estimates used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 to show probability densities of pinyon jays (Beyer 2012). Kernel density estimates were divided into 95, 90, and 50 percent volume contours. The number of points used in analyses are listed because it impacted the resulting area (Jones et al. 2015, Kernohan et al. 2001).

Year	Flock	Breeding	MCP	95 PVC (ha)	90 PVC (ha)	50 PVC (ha)	Points Used
2017	Madera	Non	1144.3	850.2	664.0	153.7	29
2017	Madera	Breed	1100.3	1202.9	955.3	255.7	35
2017	Starfire	Non	498.6	691.6	538.1	157.5	41
2017	Starfire	Breed	855.4	1008.9	747.8	205.4	45
2018	Madera	Non	1452.6	1311.4	970.9	138.8	39
2018	Madera	Breed	3570.2	1635.3	1272.8	200.6	35
2018	Starfire	Non	718.6	830.4	558.8	88.8	49
2018	Starfire	Breed	828.4	871.4	654.9	197.3	71
2017	All	All	4029.2	2574.6	1935.5	541.2	150
2018	All	All	6144.4	2911.5	2044.4	370.7	194
All	Madera	All	4775.7	2581.0	1829.4	436.0	138
All	Starfire	All	1402.4	1164.0	808.5	211.1	206
All	All	Non	4037.4	2516.4	1729.4	260.7	158
All	All	Breed	5197.8	2699.5	1999.1	468.1	186
All	All	All	6482.7	3289.3	2367.4	494.8	344

Figure 2.1 – Pinyon jay home range Minimum Convex Polygon (MCP) for combined Madera and Starfire flocks on Kirtland Air Force Base (KAFB), New Mexico. The MCP comprises all pinyon jay location data from January to July in 2017 and 2018. The area of the MCP is 6482.7 ha.

Area shown is Withdrawn Area
on Kirtland Air Force Base

Kirtland Air Force Base

Combined Home Range

0 1 2 3 4 5 Kilometers

N
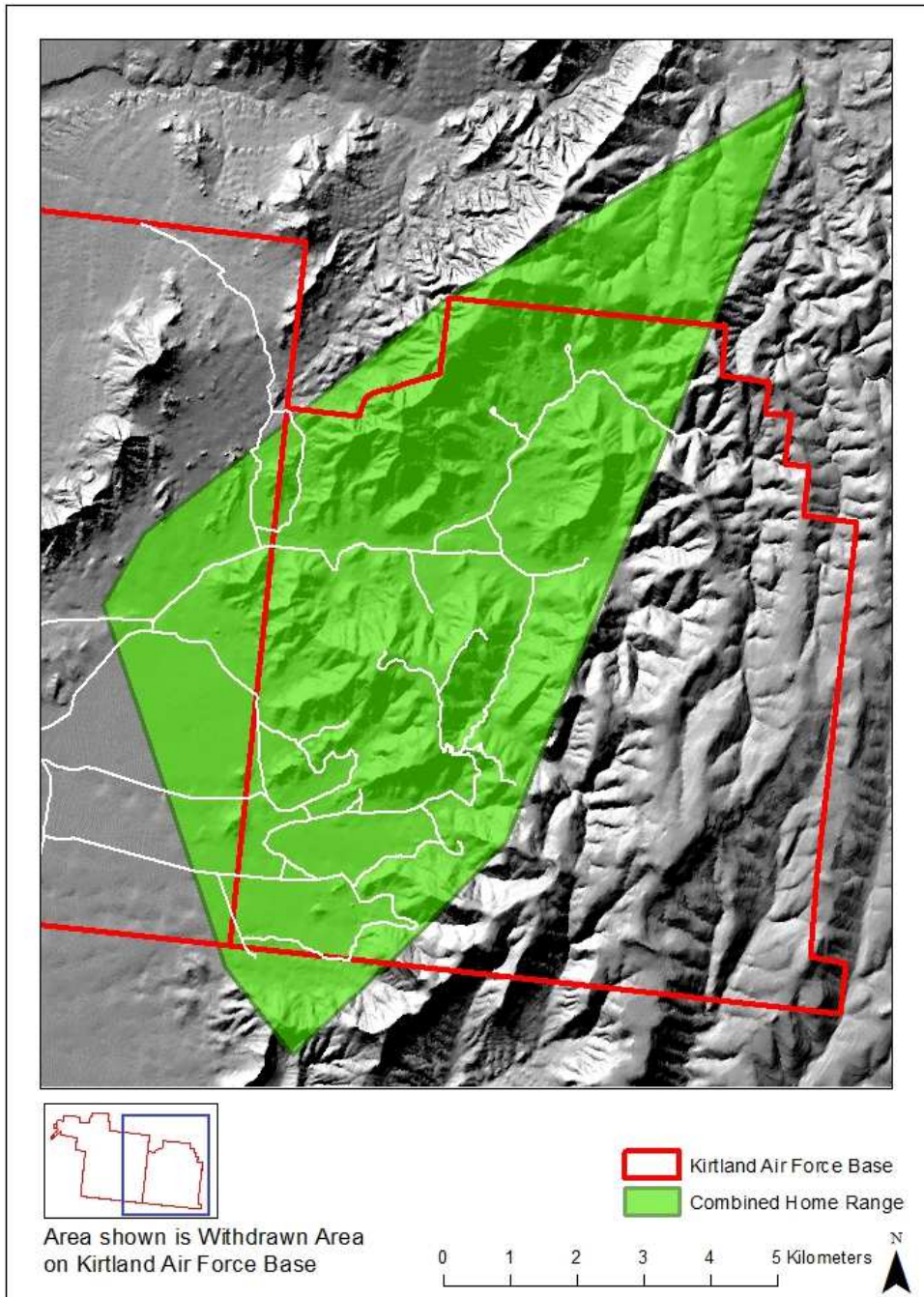
Figure 2.2 – Pinyon jay home range Minimum Convex Polygons (MCPs) for the Madera and Starfire flocks on Kirtland Air Force Base, New Mexico. The MCP comprises all pinyon jay location data from January to July in 2017 and 2018. Home range MCPs for the Madera and Starfire flocks were 4775.7 ha and 1402.4 ha, respectively. Their home ranges overlapped by 150.4 ha.
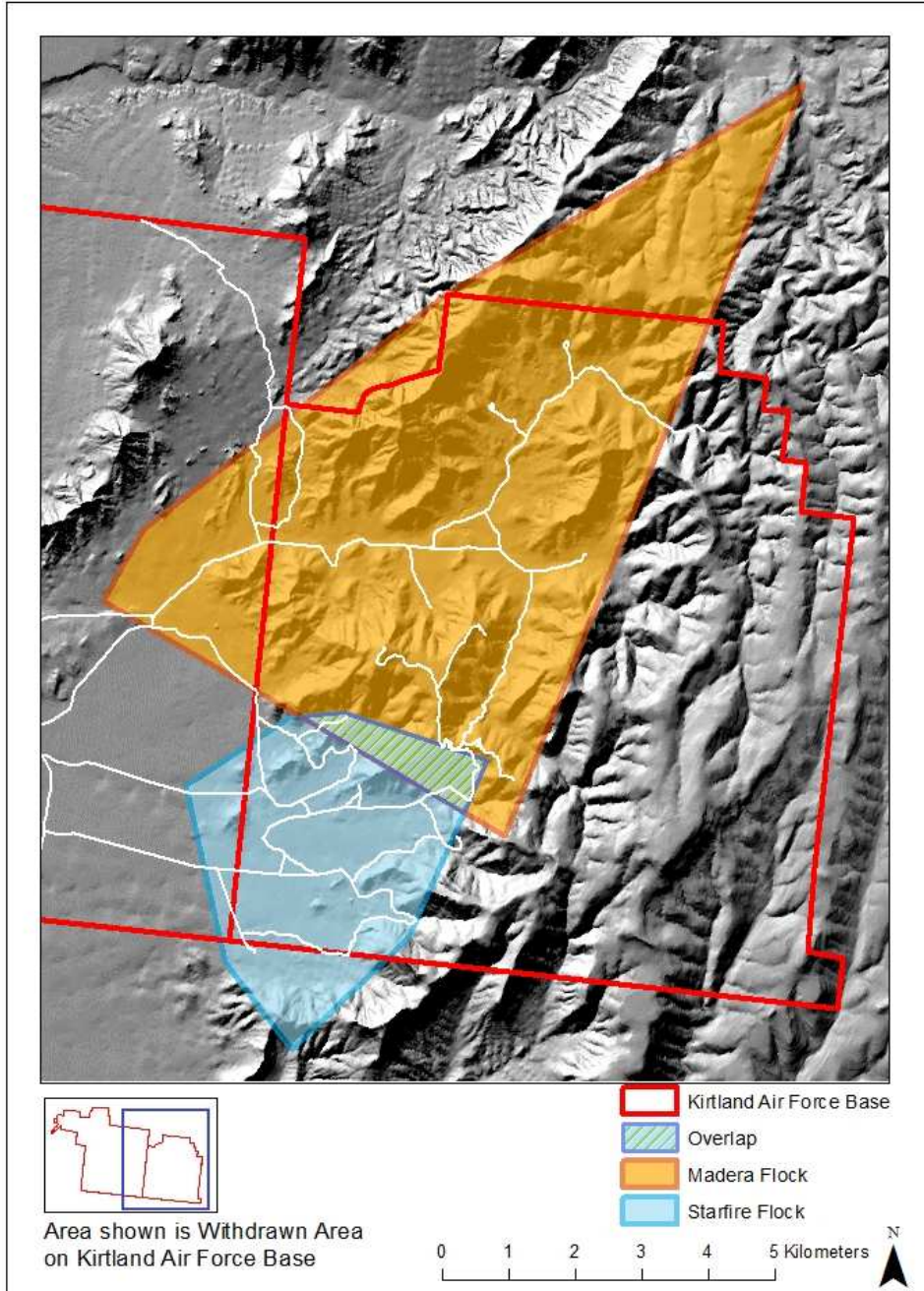
Figure 2.3 – Pinyon jay home range kernel density estimate for the combined Madera and Starfire flocks on Kirtland Air Force Base, New Mexico. This analysis includes all pinyon jay locations from January to July in 2017 and 2018. I used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 (Beyer 2012). Kernel densities are divided between 50, 90, and 95 percent volume contours (PVCs).
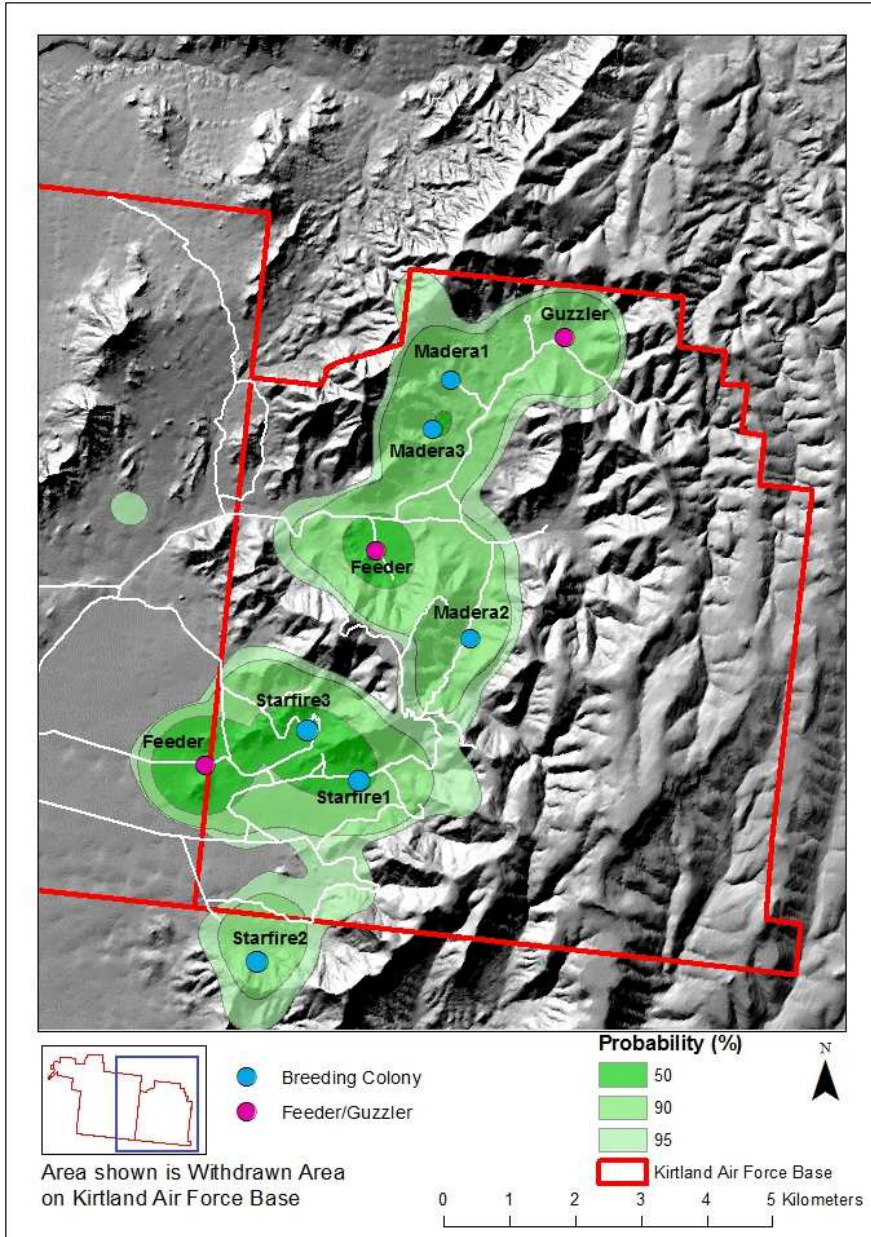
Figure 2.4 – Pinyon jay home range kernel density estimate for the Madera flock on Kirtland Air Force Base, New Mexico. This analysis includes all pinyon jay locations in the Madera flock from January to July in 2017 and 2018. I used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 (Beyer 2012). Kernel densities are divided between 50, 90, and 95 percent volume contours (PVCs).
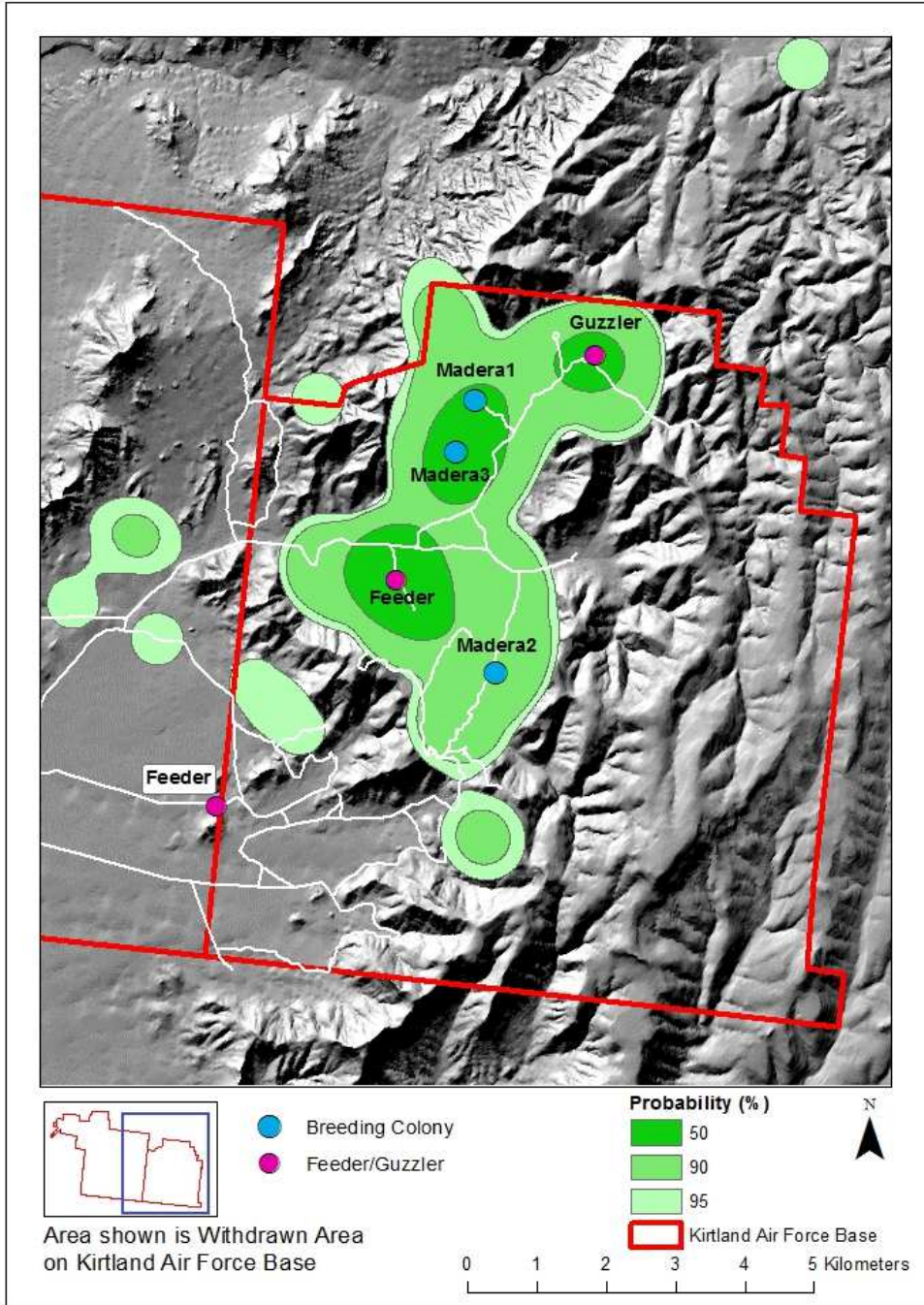
Figure 2.5 – Pinyon jay home range kernel density estimate for the Starfire flock on Kirtland Air Force Base, New Mexico. This analysis includes all pinyon jay locations in the Starfire flock from January to July in 2017 and 2018. I used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 (Beyer 2012). Kernel densities are divided between 50, 90, and 95 percent volume contours (PVCs).
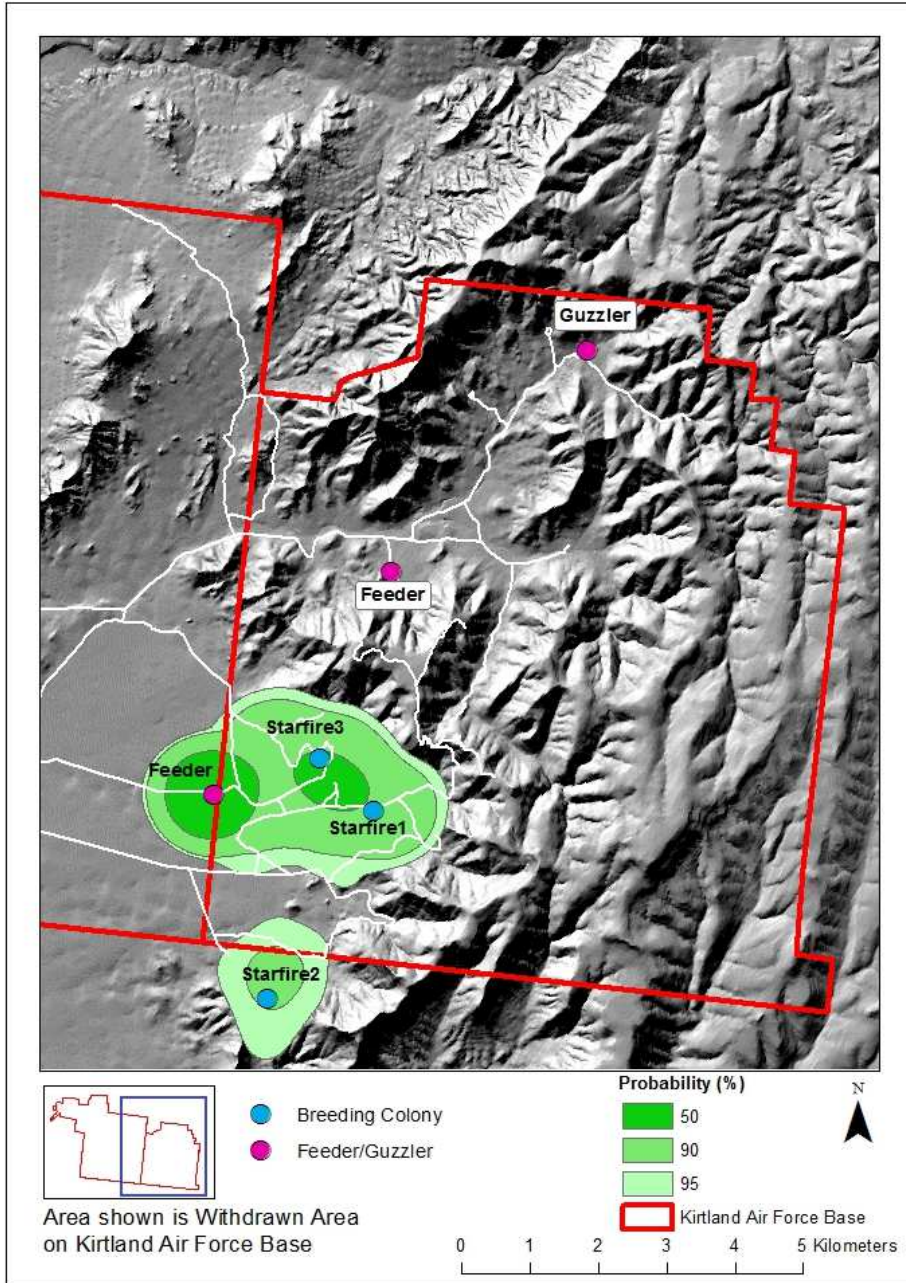
Figure 2.6 – Pinyon jay home range kernel density estimate on Kirtland Air Force Base, New Mexico in 2017. Analyses are for the a) Madera flock in the non-breeding season, b) Madera flock in the breeding season, c) Starfire flock in the non-breeding season, and d) Starfire flock in the breeding season. I used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 (Beyer 2012). Kernel densities are divided between 50, 90, and 95 percent volume contours (PVCs).
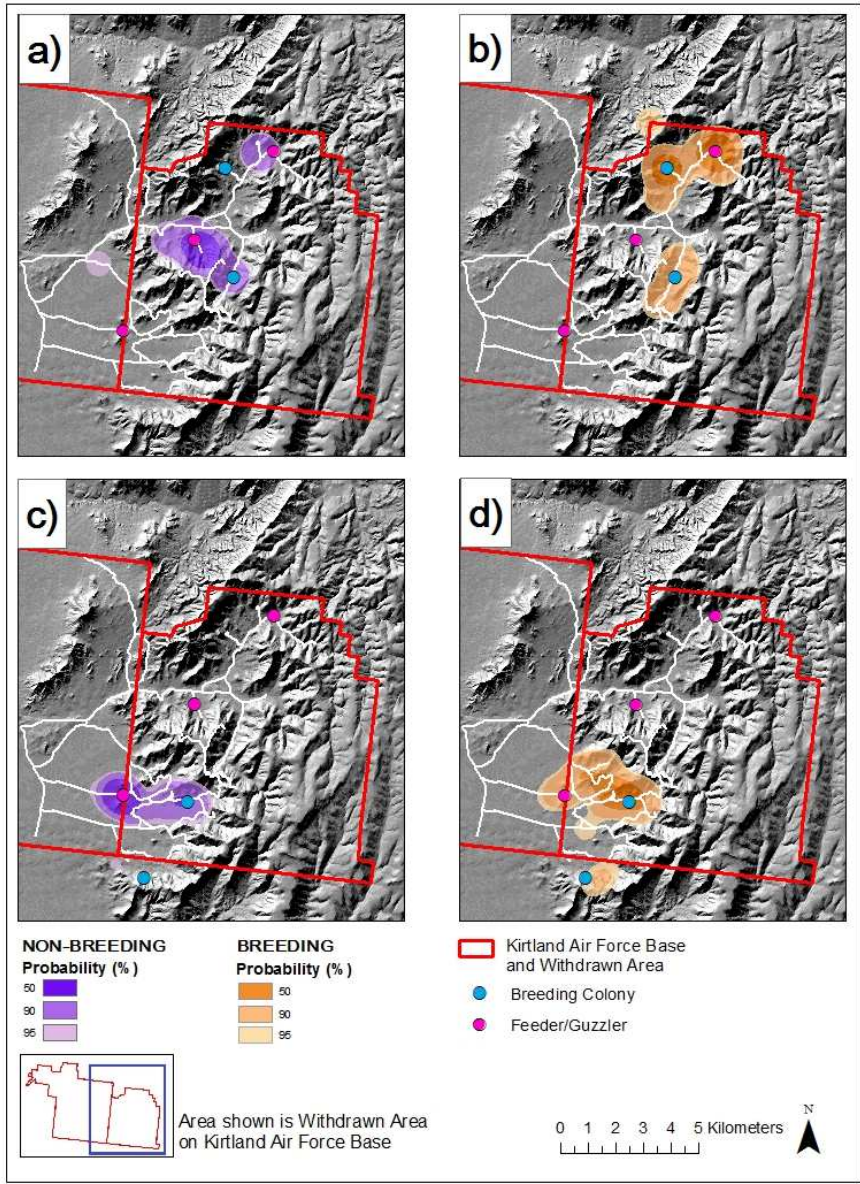
Figure 2.7 – Pinyon jay home range kernel density estimate on Kirtland Air Force Base, New Mexico in 2018. Analyses are for the a) Madera flock in the non-breeding season, b) Madera flock in the breeding season, c) Starfire flock in the non-breeding season, and d) Starfire flock in the breeding season. I used a fixed kernel with bandwidth = 1000, kernel = quartic (biweight), cell size = 30, and scaling factor = 1000000 (Beyer 2012). Kernel densities are divided between 50, 90, and 95 percent volume contours (PVCs).
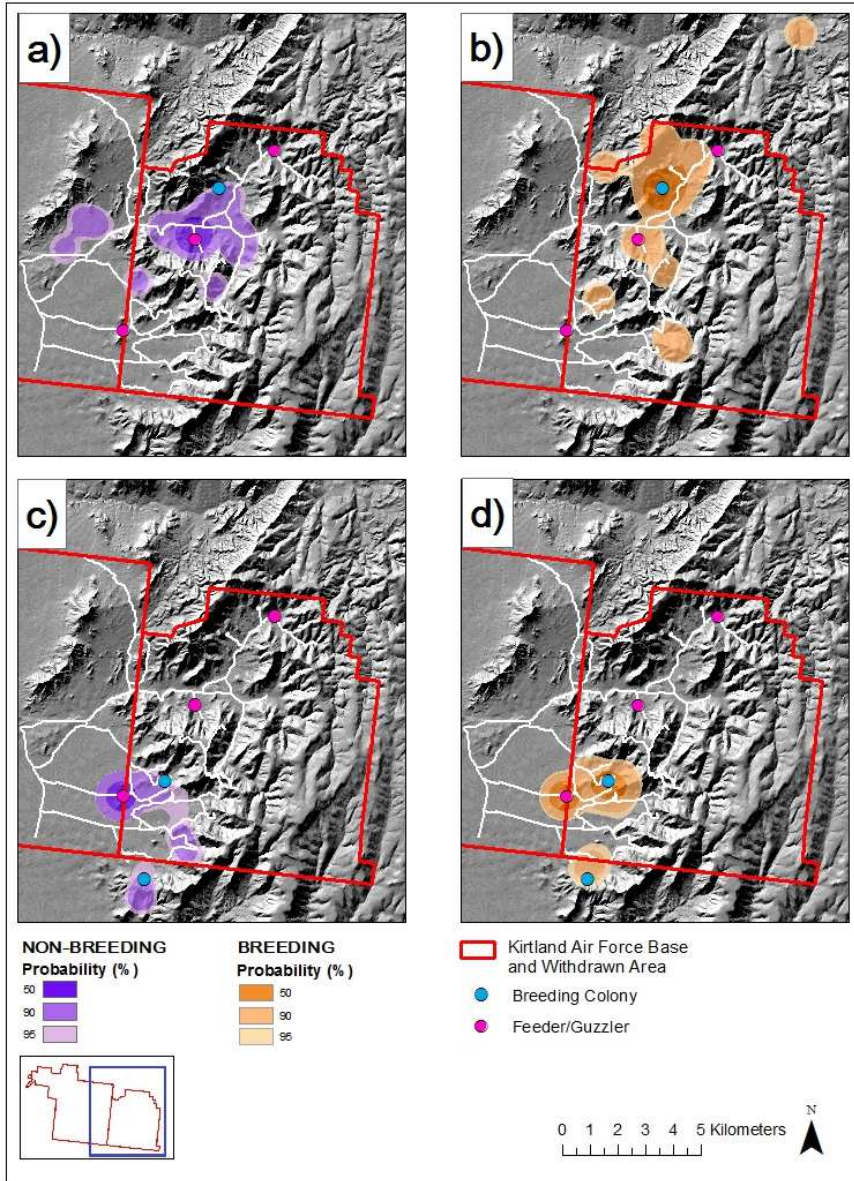
CHAPTER III

PINYON JAY NEST SITE SELECTION IN CENTRAL NEW MEXICO

ABSTRACT

Pinyon jays (*Gymnorhinus cyanocephalus*) are experiencing population declines primarily in response to habitat degradation. Furthermore, few studies have investigated pinyon jay nest site selection in pinyon-juniper woodlands. Therefore, I conducted a nest site selection study on pinyon jay breeding habitat on Kirtland Air Force Base in central New Mexico. I compared tree size, foliage, and species composition in 42 17.5-m radius plots around pinyon jay nests to 41 same-sized vegetation plots in random locations in pinyon-juniper habitat using binomial generalized linear models. I evaluated models of habitat characteristics with Akaike's Information Criterion corrected for small sample sizes. The strongest model indicated that pinyon jays preferred nesting in areas with fewer dead juniper trees. Furthermore, using Student's paired t-tests, I found that pinyon jays built nests in trees with greater height ($p < 0.001$) and nests were built below the tree line ($p = 0.001$). Finally, pinyon jays nested in plots with relatively open-canopied pinyon-juniper woodland ($\bar{x} = 23.67\%$ tree area) which has implications for pinyon-juniper stand management currently practiced in the western United States.

INTRODUCTION

Habitat characterization is central to identifying and setting conservation priorities (Guisan et al. 2013). When habitat loss is imminent, such as the expected conifer mortality projected in the western U.S. by the end of this century, habitat characterization is critical for designing appropriately targeted mitigation strategies (Hoegh-Guldberg et al. 2008, Johnson et al. 2016, McDowell et al. 2016, Johnson et al. 2017b). It is especially important to protect breeding habitat for species of conservation concern (Brown et al. 1995, Margules and Pressey 2000, Sutherland et al. 2004, Johnson et al. 2016). This can be difficult for species with large ranges that live in a variety of habitats, such as the pinyon jay (*Gymnorhinus cyanocephalus*; Marzluff and Balda 1992; Balda 2002).

Unfortunately, little is known about pinyon jay breeding habitat over significant portions of their range (Balda 2002, Boone et al. 2018). Until recently, most research on pinyon jays occurred at one study site in Flagstaff, Arizona (Gabaldon 1979, Marzluff and Balda 1992, Balda 2002). The Flagstaff site was situated in a ponderosa pine (*Pinus ponderosa*) forest interspersed with grassland (Gabaldon 1979, Marzluff and Balda 1992). Individual pinyon pine (*Pinus edulis*) and juniper (*Juniperus spp.)* trees were also present (Gabaldon 1979, Marzluff and Balda 1992). While these studies provided the basis of much of what is known about pinyon jays, this site is just a small portion of their range which comprises many regions with different habitat structures (Ligon 1978, Lanner 1981, Marzluff and Balda 1992, Balda 2002, Romme et al. 2009). In the past decade researchers have begun to publish studies that focus on pinyon jays in pinyon-juniper habitats (Great Basin Bird Observatory 2013; Johnson et al. 2016, 2017b, 2018; Boone et al. 2018).

Pinyon jays are a nonmigratory species endemic to the western United States (Marzluff and Balda 1992, Balda 2002). They are closely associated with pinyon trees because they eat pinyon seeds

and use the tree as nest substrate (Lanner 1981, Marzluff and Balda 1992, Balda 2002). These social corvids live in flocks of between 50–300 individuals and occupy home ranges from 16 km^2–64 km^2 (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). During the breeding season, flocks subdivide into smaller groups of 14–32 nesting pairs to establish breeding colonies (Gabaldon 1979, Marzluff and Balda 1992, Balda 2002, Johnson et al. 2016). Breeding colonies are large because nests within it are spaced approximately 110 m apart from each other (Marzluff and Balda 1992, Balda 2002, Johnson et al. 2016). Due to the large size of their home range, pinyon jays are sensitive to large-scale habitat alterations, such as human development, woodland clear-cutting for wildfire fuel reduction, and climate change (Marzluff and Balda 1992, Balda 2002, Romme et al. 2009, Johnson et al. 2017b, Boone et al. 2018).

Currently, pinyon jays are viewed as an ecologically sensitive species by numerous organizations and agencies (NatureServe 2004, New Mexico Department of Game and Fish 2006, New Mexico Partners in Flight 2007, Birdlife International 2016, Rosenberg et al. 2016). Pinyon jay populations have declined by approximately 3.5% per year between 1966 and 2015 (Sauer et al. 2017). Changes in habitat may have contributed to this decrease (Boone et al. 2018). Over the past 150 years, pinyon-juniper woodlands have experienced reductions due to human development, while remaining stands of pinyon-juniper have experienced expansion and infilling (Lanner 1981, Balda 2002, Jones et al. 2019). European settlers in the western U.S. deforested millions of hectares of pinyon forests to support mining and grazing operations (Lanner 1981, Balda 2002). More recently, remaining pinyon-juniper landscapes have been expanding and infilling, likely due to reduced fire regimes and changes in land-use practices (Romme et al. 2009, Boone et al. 2018, Jones et al. 2019). Elimination and replacement of open woodland, which appears to be preferred pinyon jay habitat in some parts of their range (Johnson et al. 2017, Boone et al. 2018), with dense, closed-canopy woodland may also be responsible for modern population decline (Boone et al. 2018). Further, rising temperatures and prolonged droughts

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associated with climate change may be contributing to pinyon tree mortality and habitat

degradation (Gitlin et al. 2006, Romme et al. 2009, Adams et al. 2017, Johnson et al. 2017b,

Boone et al. 2018). Pinyon jays are the primary disperser for pinyon seeds, thus, detrimental

effects on either pinyon jays or pinyon trees are likely to have synergistic effects on pinyon

woodland extent and quality (Lanner 1981, Lanner 1996, Boone et al. 2017). The most direct way

to arrest pinyon jay decline is to identify prime habitat across their range and protect it from

habitat threats (Marzluff and Balda 1992, Balda 2002, Bombaci and Pejchar 2016, Boone et al.

2018).

I studied pinyon jays on Kirtland Air Force Base (KAFB) in New Mexico to investigate nest-site

habitat characteristics in pinyon-juniper landscape. Two flocks (approx. 135 individuals total)

occurred in juniper (*Juniperus monophylla*) savanna and pinyon-juniper woodland on KAFB

(Chapter 2). Specifically, I recorded tree type, size, and foliage cover to compare with habitat at

random locations within pinyon-juniper woodland. Furthermore, I compared size and foliage

cover of nest trees to the non-nest trees in study plots. Based on these results I identified habitat

variables potentially indicating suitable habitat criteria for pinyon jay breeding areas.

METHODS

Study Area

Kirtland Air Force Base is located south of Albuquerque, New Mexico and encompasses 210 km^2

including 77 km^2 of pinyon-juniper habitat (KAFB 2012). The base is situated on an elevational

gradient from the Rio Grande Valley in the west to the Manzanita Mountains in the east (KAFB

2012). In the western lowlands, the habitat is characterized as scrub steppe, transitioning east

along the elevational gradient through juniper savanna, pinyon-juniper woodland, and ponderosa

pine forest in the mountains (KAFB 2012). Under the Sikes Act Improvement Act of 1997,

species of concern, like the pinyon jay in New Mexico, must be monitored and managed for

conservation on federal lands, including Department of Defense lands (NatureServe 2004, BirdLife International 2016).

Data Collection

This study took place in 2017 and 2018. Pinyon jays were captured from January–March with walk-in traps baited with pinyon seeds (Great Basin Bird Observatory 2013, Johnson et al. 2016). To re-identify individuals, I fitted pinyon jays with a serially-numbered, USGS aluminum leg band and a unique combination of three, plastic color bands. I attached VHF radio transmitters to the two central rectrices of individuals we thought likely to be female (Johnson 1988, Pyle 1997, Balda 2002). In 2017 I tried to exclusively attach transmitters to females, however, in 2018 I was less discriminating in order to deploy more transmitters. With a greater number of transmitters I could more consistently locate nests and follow different parts of a pinyon jay flock as it subdivided into smaller groups during breeding (Marzluff and Balda 1992, Balda 2002).

After attaching transmitters to pinyon jays, I tracked birds as they established breeding colonies. I monitored pinyon jay movements and behaviors until I determined that nesting had begun in early March of both years (Marzluff and Balda 1992, Balda 2002). At this time I monitored nesting behaviors such as collecting nest material or continually returning to the same location (Gabaldon 1979, Marzluff and Balda 1992, Ralph et al. 1993, Balda 2002). Additionally, I located nesting females by observing that their transmitter signals remained stationary.

After determining pinyon jays were nesting in an area, I searched for nests by homing telemetry and visual observation. For homing telemetry, I stood near the colony and used a yagi antenna to assess direction of the strongest signal (Millspaugh et al. 2012). I walked in the direction of the strongest signal until finding the approximate nest site, then visually searched until spotting the nest. I also found nests by watching unmarked pinyon jays return to nests to deliver nesting material or food (Ralph et al. 1993). After discovering a nest and recording its location, I

retreated to avoid unnecessary disturbance. I monitored nests every few days until they either successfully fledged offspring or failed. Furthermore, I attempted to locate renesting attempts from unsuccessful breeding pairs by following radio-tagged pinyon jays.

I found 3 breeding colonies in 2017 and 2 in 2018. Additionally, I found 4 nests that were not apparently associated with breeding colonies that were likely renesting attempts. I found 25 nests in 2017 and 17 in 2018. Four of these were renesting attempts, where I knew the location of the previous nest, and 8 were likely renesting attempts due to nest establishment date and location. I determined age of nests by identifying what stage the nest was at (incubation, brooding, or fledging), then backdating to the date of the first laid egg (Balda 2002).

In June and July each year, when nesting was complete, I conducted habitat surveys at all nest sites and at a similar number of randomly determined locations within pinyon-juniper habitat on KAFB. Pinyon pine and juniper trees have been observed to grow new needles and elongate their stems in June and July, however stem growth is less than 1 cm per year and, thus, did not appreciably change between pinyon jay nest construction in mid-March and vegetation surveys in June (Herman 1956, Jaindl et al. 1995). Needle growth may have led to small increase in foliage between nesting and vegetation surveys (Herman 1956, Jaindl et al. 1995). Random locations were generated using the Create Random Points tool in ArcGIS (ESRI, Inc., Redlands, CA) within pinyon-juniper habitat as delineated by previous studies (Johnson et al. 2016). Each survey plot was a circle with a radius of 17.5 m (Krofcheck et al. 2016). The center of the circle for nest points was the nest and the center of the circle for random points was the randomly generated point wherever it lay. After the center of the circle was identified, I used a tape to place flags 17.5 m away from the center of the circle in each of the cardinal directions to use as landmarks during the survey.

Pinyon-juniper woodlands contain singular trees as well as "multi-trees" comprising an intertwined, contiguous aggregate of two or more individual trees (Gabaldon 1979). Therefore, I took measurements of these multi-trees rather than just an individual tree. I took measurements for multi-trees when they occurred while also recording the number of individual trees within them and their species. I did not take measurements for individual trees within multi-trees. Therefore, I could not analyze total area or volume of pinyon and juniper trees. Furthermore, averages of pinyon and juniper size and foliage values reflect only free-standing trees.

I recorded elevation (± 1 m) and UTM coordinates (± 3 m) at survey plots with a GPS unit and slope with a clinometer. If the plot was at a nest site, measurements were taken of the nest and nest tree (or multi-tree). Previous studies of pinyon jay nests measured relative nest placement compared to height and width of the nest tree as a proxy for next exposure to predators and solar radiation (Gabaldon 1979, Marzluff 1988). Therefore, I measured nest height above the ground (m) and used it to calculate relative nest height, which is a ratio of nest height to nest tree height. I also generated a value for the ratio between nest height and average non-nest tree height in the plot. To calculate nest placement relative to tree width, or relative edge distance, I divided distance of the nest to the center of the tree by distance of the edge of the tree to the center. Most nests in this study were in juniper, which grow in irregular shapes and do not have a centrally located trunk (Johnson et al. 2014). Therefore, I recorded diameter of the nest tree at the height and directional aspect of the nest, then divided this by two to determine tree radius. Then I measured distance of the nest from the edge of the tree and subtracted it from the radius to get distance between the nest and center of tree (Gabaldon 1979, Marzluff 1988).

To measure the other trees at a site, a technician and I started at the same side of the plot circle and worked in opposite directions until we met on the other side. We made measurements for every plant greater than 1 m in height. This criteria was useful for concentrating on vegetation structures that pinyon jays could potentially use as a nest or security cover (Marzluff and Balda

1992). We measured the greatest width, the corresponding perpendicular length, and the height

(m) of trees and shrubs beginning with the side of greatest width (KAFB 1998, Krofcheck et al.

2016). We recorded the plant species if it was alive or dead. We estimated foliage cover for live

trees but not for shrubs or dead trees. Foliage estimates were taken using the Braun-Blanquet

Cover-Abundance Scale (Wilkum and Shanholtzer 1978) on four opposing sides of each tree,

beginning with the side with the longest width. We stood 3–5 m in front of the tree and estimated

how much foliage was present on a scale of 0–100%. To simplify estimates, we divided the 0–

100% scale into four levels: 1 (1–25% foliage present), 2 (26–50% foliage present), 3 (51–75%

foliage present), and 4 (76–100% foliage present). We practiced these measurements on two trees

outside the plot before each survey to ensure our estimates were similar. We classified all pinyon

and juniper as trees, and all other short, woody stems, including scrub oak (*Quercus turbinella*),

as shrubs, which typically do not grow greater than 3 m in height (KAFB 1998, Körner 2012).

I used the tree measurements to generate area and volume of trees in a plot. I calculated top-down

tree area as an ellipse with radii of half the greatest length and half the corresponding

perpendicular width (Krofcheck et al. 2016). I calculated tree volume as an ellipsoid with radii of

half the greatest length, half the perpendicular width, and half the height (Krofcheck et al. 2016).

I calculated volume as an ellipsoid because it followed naturally from the elliptical area

calculation and was the most approximate shape to pinyon and juniper trees (Krofcheck et al.

2016). Previous pinyon jay habitat studies have compared characteristics of the nest tree to trees

surrounding it (Gabaldon 1979; Johnson et al. 2014, 2017). Thus, I used tree measurements to

create comparative ratios of the height, area, volume, and foliage, respectively, between nest trees

and non-nest trees in the plot.

Data Analysis

To assess factors that may influence pinyon jay nest site selection, I compared vegetation measurements of nest plots to randomly dispersed plots. I analyzed vegetation measurements among habitat survey plots using binomial generalized linear models (GLMs) constructed with the R package lme4 (Bates et al. 2015; R Version 3.4.1, www.r-project.org, accessed 10 Sep 2017) and evaluated them using Akaike's Information Criterion corrected for small sample size (AICc; Burnham and Anderson 2002). I used fixed effect GLMs instead of mixed models because I did not have enough data points for the random effect to fit the model (Harrell 2015). To make all habitat characteristic variables comparable to each other, I standardized each variable by subtracting the mean of the variable from each value in that variable and dividing by the standard deviation (Anderson and Burnham 2002, Symonds and Moussalli 2011). The response variable was binomial (nest site or random site). Habitat characteristics were incorporated as fixed effect explanatory variables. I only created univariate models because the power of my analysis was low (Harrell 2015). Models were not considered predictive if their AICc value relative to the best model was too great ($\Delta_i \leq 2$).

I also identified the p-value from each GLM, separately. While this might increase the chance of type I and II errors, this work is exploratory and is a valuable first step into identifying potentially important habitat characteristics for future hypothesis testing. Average area, volume, and foliage values for pinyon, multi-trees, and shrubs could not be evaluated by AICc because not all plots contained those trees or shrubs and, thus, missing values could not be compared to average values. Therefore, I removed plots missing those values before evaluating GLMs.

Nest tree characteristics from nest plots could not be paired with random plots. Therefore, I compared nest tree characteristics to non-nest trees in the plot. I conducted one-way paired t-tests to determine if nest tree height, area, volume, and foliage cover, respectively, were different than the values from one randomly selected tree in the surrounding plot.

RESULTS

I conducted habitat surveys at 42 nest sites and 41 random locations. Data were grouped into general habitat characteristics (Table 3.1) and nest tree characteristics (Table 3.2). I excluded some variables before AICc evaluation (Table 3.3), along with terrain variables because I wanted to focus on vegetation characteristics of the study site, and some variables because they could not be measured in all plots. For example, I did not measure separate individual trees of each multi-tree, therefore, I could not analyze total pinyon or juniper tree volume. Further, I did not use average area, volume, and foliage measurements for pinyon trees, multi-trees, or shrubs because they were not present in all plots, thus, average measurements could not be compared with the absence of measurements in an AICc evaluation (Burnham and Anderson 2002).

When two variables were correlated, I eliminated the more complex one, usually when one variable was a component of, or was used to calculate, the other ($|r| > 0.6$; Table 3.3; Burdett et al. 2010; Goldenberg et al. 2016). For instance, I eliminated average juniper tree volume because average juniper tree area was used to calculate the volume. I eliminated average tree area because average juniper area is a more specific subset of average tree area. After eliminating correlated variables, the remaining models were: number of dead pinyon, number of dead juniper, number of dead multi-trees, average live tree height, average shrub area, average juniper area, and percentage of dead pinyon. Although number of dead pinyon and percentage of dead pinyon were somewhat correlated ($r = 0.59$), they did not meet the threshold for elimination (Table 3.3).

The top performing model in the AICc evaluation included the variable for the number of dead juniper trees ($\beta = -1.1770$; Table 3.4; Fig. 3.1). The next best model was not was not predictive of nest site selection ($\Delta_i = 8.2$; $\beta = 0.22739$, Table 3.4). The null model was also not competitive with the top model ($\Delta_i = 10.7$; Table 3.4) indicating the potential power of the dead juniper model to predict nest site selection. Nest sites were negatively associated with the number of dead

juniper in a plot, meaning pinyon jays selected areas with relatively fewer dead juniper trees (Fig. 3.1).

GLM p-values reinforced AICc results. Number of dead juniper and percentage of dead juniper were both greater for random plots than for nest plots (Table 3.1). Average juniper area was greater in nest plots than random plots (Table 3.1). Additionally, pinyon jays nested at lower elevations than randomly selected plots (Table 3.1).

Pinyon jays nested in juniper (n = 33) and pinyon trees (n = 8). I also found 1 nest in a large shrub oak. I found the majority of nests in single trees (n = 27), but pinyon jays also built nests in multi-trees (n = 15). In paired, one-way t-tests, height was greater for surrounding trees in the same plot (Table 3.5). Area, volume, and foliage of nest trees were not different from other trees in the plot (Table 3.5). Finally, nest height was lower than the mean height of the non-nest trees in the plot ($p = 0.001$, $r = 0.07$).

DISCUSSION

Model Selection

Number of dead juniper performed best in the AICc evaluation, meaning pinyon jays nested in areas with approximately a third as many dead juniper trees. Many dead juniper were formerly mature trees that did not show visible effects of fire. Because juniper can live for hundreds of years (Waichler et al. 2001), it is possible that the age of these dead junipers are indicative of the age of the rest of the trees in the stand, suggesting that pinyon jays selected younger stands. Another possible explanation is that dead juniper are potential roosting or perching substrate for aerial predators such Cooper's hawks (*Accipiter cooperii*; Reinert 1984), which we observed in pinyon jay home ranges.

While recent research has specifically explored the relationship between pinyon tree characteristics and pinyon jays, the role of juniper in pinyon jay nesting ecology has not been examined (Johnson et al. 2014, 2017; Boone et al. 2018). Models in this study incorporating juniper variables were biologically relevant because juniper trees were present at all nest sites and frequently were the only tree species present. Therefore, even though many pinyon tree variables, such as total pinyon area in plot and average pinyon size, could not be included in the AICc evaluation because of survey design or non-applicable values, evaluating the role of juniper in pinyon jay nest site selection provided valuable information about an understudied component of pinyon jay ecology.

Models in this analysis were fixed effect GLMs that treated nest site location as independent. This assumption was violated as pinyon jays nest in colonies. The process of colony formation is unclear, but after an area is established, pinyon jay breeding pairs build nests in the area with the rest of the flock (Marzluff and Balda 1992). I tried to account for potential autocorrelation by including colony as a random effect in a generalized linear mixed model, but there were too few data points to fit the random effect for the model (Harrell 2015).

Habitat Characteristics

Gabaldon (1979) conducted nest site selection analyses in Flagstaff, AZ on pinyon jays whose home range primarily comprised ponderosa pine forest interspersed with individual pinyon and juniper trees. Out of 121 pinyon jay nests, she found 120 in ponderosa trees and 1 in a pinyon pine. I did not test for preference of nest tree species, however, pinyon jays constructed the majority of nests in juniper trees, even though pinyon trees were also available in most nest plots. This may be in part because juniper trees typically outnumbered pinyon trees on nest plots and some sites (n = 8) were located within juniper savanna which did not have any live pinyon. Because pinyon jays chose to nest in areas with few or no pinyon trees, it suggests pinyon are not

always preferred in habitat immediately surrounding the nest. There is a large ponderosa pine forest on KAFB, but during frequent surveys over the course of two seasons we did not detect pinyon jays there. This suggests that although ponderosa pine forest is available to nest in, it is not preferred breeding habitat for pinyon jays on KAFB.

Nearly all habitat and nest measurements in Gabaldon (1979) were taken from ponderosa trees, however, this study is still comparable with mine. Mean nest tree height was 11.77 m and mean nest height was 5.55 m above the ground (Gabaldon 1979), which were much higher than on KAFB due to the greater height of ponderosa trees. My study supports findings from Gabaldon (1979) and others that pinyon jays nest in trees that are taller than the trees surrounding them and that nests are placed below the height of surrounding trees (Johnson et al. 2014, 2017b). The reasons for this are not clear, but Gabaldon suggested that tall nest trees may have more potential nesting branches, might provide a better vantage point to see predators, or may serve as a landmark for pinyon jays returning to their nest. Nests may be lower than the average tree height in nest plots because they are more hidden from predators or destructive weather. Tree area and volume were not larger than non-nest trees in the same plot. It is unclear why area was nest tree area was not larger than non-nest tree area because there are more locations to build a nest in a larger tree (Gabaldon 1979) and more area would allow a nest to be built behind more foliage which may provide more nest concealment. While nest tree height was larger than non-nest tree height, similarities in volume may be due to non-significant results from tree area. Foliage was neither a factor in nest site selection nor did pinyon jays select trees with higher foliage scores than non-nest trees. This might be because foliage estimates are a poor proxy for nest concealment.

Johnson et al. (2014, 2017b) studied tree density in four pinyon jay colonies on KAFB as well as one on White Sands Missile Range in Socorro County, NM, which was also located in pinyon-juniper woodland. They found that the density of trees in nest areas was 965.1 trees/ha

(SE = 97.88/ha). In my study, I extrapolated the density of trees in nest plots to 332.60 trees/ha (SE = 60.28/ha). Even though pinyon jay flocks on KAFB were of similar size and had similar home ranges between studies, colonies were established in different locations. Pinyon jays in Johnson et al. (2014, 2017b) established colonies on high-elevation ridges with a greater proportion of pinyon to juniper trees, whereas in my study, colonies were established in lower elevation habitats with more juniper than pinyon. Lower elevation areas on KAFB were usually characterized by juniper savanna or less dense pinyon-juniper woodland (KAFB 2012). Habitat becomes more thickly wooded with pinyon and juniper as elevation increases on KAFB (Padien and Lajtha 1992, KAFB 2012). Johnson et al. (2014, 2017b) did not provide measurements of canopy coverage that were comparable with mine due to sampling technique, so it is possible that the difference in the number of tree stems per hectare does not reflect a similar change in the openness of the canopy. Pinyon jays might have moved from higher to lower elevation colonies because of significant pinyon mortalities on KAFB in the past decade (Johnson et al. 2017b, Boone et al. 2018). Results from my study and others show that most pinyon-juniper habitat on base, possibly excepting completely closed-canopy pinyon-juniper forest, was potentially suitable for pinyon jay nest site selection.

A study in Farmington, NM found that tree area in a study plot was approximately 21.82% (Johnson et al. 2017a). Similarly, in my study, mean tree area was 23.67%. Johnson et al. (2017a) also found that 71% of pinyon jay nests were in pinyon-juniper woodlands with a tree cover area of 16.75% or more. In my study, 60% of nests were found in similarly open canopy. Pinyon jays in my study nested in relatively open canopy, which was not consistent with a previous study on KAFB (Johnson et al. 2014), but was similar to pinyon jay nesting habitat in Farmington, New Mexico (Johnson et al. 2017a). Nests in my study were mostly found in open juniper savanna or pinyon-juniper woodland. These areas can be considered edge or transitional areas between scrub steppe and densely wooded pinyon and ponderosa forest (KAFB 2012, Johnson et al. 2016).

Furthermore, pinyon jays nested in artificially created edge habitat where roads were constructed through woodland habitat. Two of four colonies from Johnson et al. (2014) and 22 nests from that study were situated less than 100 m from a road. In my study, three of five colonies were either intersected by dirt roads or were directly adjacent to one. The other two colonies were 200 m and 400 m, respectively, from a dirt road. Characterization of pinyon jays as an edge or near-edge species is important to accurately portray these birds because of the way woodlands are being managed in the western U.S.

Federal and state agencies have been trying to mitigate pinyon-juniper encroachment and infilling out of concern for wildfire fuel management, pine beetle infestation, and habitat improvement for other species such as mule-deer (Romme et al. 2009, Kramer et al. 2015, Bombaci and Pejchar 2016, Jones et al. 2019). The primary treatment of pinyon-juniper habitat to mitigate these concerns is to clear cut large tree stands, healthy or otherwise (Bombaci and Pejchar 2016, Johnson et al. 2017b, Jones et al. 2019). It is hoped that this technique simultaneously reduces the spread of conifer pests and fuel for wildfires, while creating habitat for species of concern (Kramer et al. 2015, Bombaci and Pejchar 2016, Johnson et al. 2017b, Jones et al. 2019). My study and others suggest that this technique may be detrimental to pinyon jays because it can fragment or eliminate their habitat (Boone et al. 2018, Great Basin Bird Observatory 2013, Johnson et al. 2017b, Jones et al. 2019).

Currently, pinyon-juniper landscapes in the western U.S. are changing due to complex factors including climactic conditions and human land use, however fire suppression might not be severe or widespread enough to significantly impact open pinyon juniper woodlands like the habitat pinyon jays were found in on KAFB (Gitlin et al. 2006, Romme et al. 2009, Bombaci and Pejchar 2016, Jones et al. 2019). While pinyon-juniper woodlands are currently infilling formerly open stands and encroaching on shrub lands, their range in the next century is projected to contract due to climate change, especially in southern regions such as New Mexico (Romme et al. 2009,

McDowell et al. 2016, Bombaci and Pejchar 2016, Boone et al. 2018, Jones et al. 2019). If climate change causes conifer mortality, there are few mitigation procedures to protect pinyon jays from widespread habitat degradation (Breshears et al. 2010). Prescribed fire programs are not appropriate as a management technique for pinyon jays in open woodland because they likely not burn effectively enough in open pinyon-juniper habitat to affect the landscape appreciably (Romme et al. 2009). Boone et al. (2018) suggested that selectively thinning smaller pinyon trees and leaving taller ones may improve growing conditions for remaining trees, while also preserving trees pinyon jays have shown preference for nesting in. This management strategy is consistent with my results suggesting pinyon jays on KAFB preferred to nest in larger than average trees in a nest plot. While one short-term study on pinyon jay nesting habitat altered by tree thinning showed few impacts, longer term studies on tree reduction are needed (Balda 2002, Bombaci and Pejchar 2016, Johnson et al. 2018, Jones et al. 2019). It is questionable if woodland thinning is having the desired impact for wildfire prevention or conservation of wildlife (Bombaci and Pejchar 2016, Jones et al. 2019). If these treatments show little or no mitigation efficacy, it may be appropriate rethink how and when they are implemented.

CONCLUSION

Pinyon jays within pinyon-juniper habitat on KAFB nested in areas with fewer number of dead juniper trees. Findings from this study suggest ideal pinyon jay nest site habitat included fewer than 16 dead juniper trees per hectare. Pinyon jays nested in trees that were taller and larger than the trees surrounding it and placed nests below the average survey plot tree height. They also nested in relatively open woodlands with fewer trees than in other studies, suggesting suitable pinyon jay breeding habitat may be variable within pinyon-juniper woodland. Therefore, maintaining pinyon and juniper trees in a range of densities and canopy areas may be ideal for conserving pinyon jay habitat in New Mexico. When tree removal does occur, efforts should be made to selectively thin smaller trees and dead juniper while leaving larger live trees.

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TABLES AND FIGURES

Table 3.1 – Habitat characteristics of vegetation survey plots around pinyon jay nests on Kirtland Air Force Base, New Mexico 2017-2018. While there is an elevated chance of type I and II errors, this work is exploratory and is a valuable first step into identifying potentially important habitat characteristics for future hypothesis testing.

Variable	Nest Site		Random Site			
	$\overline{X}$	SE	$\overline{X}$	SE	F	P
No. of shrubs [a]	12.16	2.28	10.23	1.82	0.263	0.609
No. of trees [a]	32.00	5.80	44.05	7.44	1.641	0.204
No. of pinyon [a]	23.60	6.45	34.03	8.31	0.492	0.485
No. of juniper [a]	21.05	2.94	28.02	3.19	2.587	0.112
No. of multi-trees [a]	6.29	1.50	7.16	1.52	0.521	0.472
No. of live trees	26.71	4.22	34.12	5.72	1.093	0.299
No. of live pinyon	17.21	4.51	24.30	7.41	0.323	0.572
No. of live juniper	20.50	2.86	25.39	2.75	1.516	0.222
No. of live multi-trees	5.79	1.28	6.57	1.37	0.544	0.463
No. of dead trees	8.54	3.13	13.57	3.38	1.957	0.166
No. of dead pinyon	12.05	4.43	13.04	3.82	0.425	0.516
No. of dead juniper	1.53	0.17	5.40	0.91	11.36	0.001*
No. of dead multi-trees	4.25	0.85	4.40	1.78	0.131	0.718
Mean live tree height (m)	2.94	0.09	2.90	0.09	0.096	0.757
Mean live shrub area (m^2)	3.96	0.51	3.26	0.32	1.347	0.250
Mean live tree area (m^2)	13.36	1.46	11.64	1.06	0.909	0.343
Mean live pinyon area (m^2)	1.30	0.22	1.79	0.26	2.031	0.160
Mean juniper area (m^2)	10.32	1.39	7.13	0.71	4.115	0.046*
Mean multi-tree area (m^2)	20.85	2.97	19.76	2.12	0.091	0.762
Total live shrub area (m^2)	44.19	7.03	37.79	8.21	0.203	0.654
Total live tree area (m^2)	227.72	20.43	258.72	23.19	1.008	0.318
Total live multi-tree area (m^2)	81.78	12.69	84.30	12.20	0.366	0.547
Total live vegetation area (m^2)	260.34	22.90	287.29	25.06	0.632	0.429
Live shrub area (%)	4.59	0.73	3.93	0.85	0.203	0.654
Live tree area (%)	23.67	2.12	26.89	2.41	1.008	0.318
Live vegetation area (%)	27.06	2.38	29.86	2.60	0.632	0.429
Mean live shrub volume (m^3)	5.35	0.78	4.31	0.50	1.243	0.269
Mean live tree volume (m^3)	33.23	4.60	27.84	3.01	0.952	0.332
Mean live pinyon volume (m^3)	2.94	0.62	4.37	0.70	2.234	0.132
Mean live juniper volume (m^3)	25.67	4.43	16.20	1.91	3.784	0.0552
Mean live multi-tree volume (m^3)	54.19	10.40	50.62	5.92	0.093	0.762

*Indicates statistical significance

[a] Live or dead

Table 3.1 - (continued)

Variable	Nest Site		Random Site			
	$\overline{X}$	SE	$\overline{X}$	SE	F	P
Total live shrub volume (m^3)	65.73	11.40	52.58	12.75	0.392	0.533
Total live tree volume (m^3)	535.22	48.50	599.26	58.41	0.714	0.400
Total live multi-tree volume (m^3)	206.43	33.51	208.15	29.53	0.253	0.616
Total live vegetation volume (m^3)	583.73	52.42	639.02	61.22	0.472	0.494
Mean foliage cover	2.50	0.06	2.35	0.08	2.244	0.138
Mean pinyon foliage cover	2.33	0.11	2.09	0.13	1.902	0.173
Mean juniper foliage cover	2.52	0.08	2.35	0.10	1.745	0.190
Mean multi-tree foliage cover	2.58	0.09	2.50	0.10	0.390	0.534
Elevation (m)	1938.1	9.2	2006.9	16.4	13.64	< 0.001*
Slope (degrees)	20.24	1.82	16.68	1.80	1.922	0.169
Dead trees (%)	14.39	2.08	19.91	2.70	3.736	0.057
Dead pinyon (%)	28.99	5.41	36.83	6.20	2.238	0.139
Dead juniper (%)	7.28	1.10	13.53	1.82	6.912	0.010*

* Indicates statistical significance

Table 3.2 – Pinyon jay nest tree characteristics on Kirtland Air Force Base, New Mexico in 2017-2018.

Variable	$\overline{X}$	SE
No. of individual trees in a multi-tree nest tree	2.80	0.33
Height of nest tree (m)	3.77	0.13
Area of nest tree (m^2)	19.21	1.49
Volume of nest tree (m^3)	49.61	4.76
Foliage cover of nest tree (0-4 scale)	2.57	0.08
Nest height (m)	2.27	0.11
Relative nest height 1[a]	60.43%	2.30%
Relative nest height 2[b]	78.96%	4.33%
Distance of nest to tree center (m)	0.97	0.10
Distance of nest to tree edge (m)	0.88	0.09
Relative edge distance [c]	49.71%	3.80%

[a] Relative nest height 1 – Ratio of nest height to nest tree height.

[b] Relative nest height 2 – Ratio of nest height to average non-nest tree height in the study plot.

[c] Relative edge distance – Ratio of the distance from the nest to the center of the tree compared to the distance from the edge of the tree to the center.

Table 3.3 – Habitat characteristic variables eliminated before nest site selection AICc evaluation. Some variables were eliminated before evaluation because they showed little or no slope when plotted, indicating weak association with nest site selection. Other variables were eliminated because they were highly correlated with other variables, or could not be applied across all plots for AICc evaluation. Kirtland Air Force Base, New Mexico 2017-2018.

Variable	Reason Eliminated	Correlated Variable	r
Number			
No. of shrubs	Correlation	Total live shrub area	0.90
No. of trees	Correlation	Total live tree area	0.89
No. of pinyon	Correlation	Total live tree area	0.79
No. of juniper	Correlation	Total live tree area	0.80
No. of multi-trees	Correlation	Total live tree area	0.69
No. of live trees	Correlation	Total live tree area	0.89
No. of live pinyon	Correlation	Total live tree area	0.89
No. of live juniper	Correlation	Total live tree area	0.81
No. of live multi-trees	Correlation	Total live tree area	0.71
No. of dead trees	Correlation	No. of dead juniper	0.61
Mean live shrub area (m^2)	Not on all plots		
Mean live tree area (m^2)	Correlation	Mean juniper area	0.81
Mean live pinyon area (m^2)	Not on all plots		
Mean multi-tree area (m^2)	Not on all plots		
Total live multi-tree area (m^2)	Correlation	Total live tree area	0.69
Total live vegetation area (m^2)	Correlation	Total live tree area	0.97
Live shrub area (%)	Correlation	Total live shrub area	1.00
Live tree area (%)	Correlation	Total live tree area	1.00
Live vegetation area (%)	Correlation	Total live tree area	1.00
Mean shrub volume (m^3)	Not on all plots		
Mean live tree volume (m^3)	Correlation	Mean juniper area	0.82
Mean live pinyon volume (m^3)	Not on all plots		
Mean live juniper volume (m^3)	Correlation	Mean juniper area	0.98
Mean live multi-tree volume (m^3)	Not on all plots		
Total live shrub volume (m^3)	Correlation	Total live shrub area	0.98
Total live tree volume (m^3)	Correlation	Total live tree area	0.96
Total live multi-tree volume (m^3)	Correlation	Total live tree area	0.67
Total live vegetation volume (m^3)	Correlation	Total live tree area	0.95
Mean foliage cover	Correlation	Total live tree area	0.70
Mean pinyon foliage cover	Not on all plots		
Mean juniper foliage cover	Correlation	Total live tree area	0.63

Table 3.3 – (continued)

Variable	Reason Eliminated	Correlated Variable	*r*
Mean multi-tree foliage cover	Not on all plots		
Elevation (m)	Not vegetation		
Slope (degrees)	Not vegetation		
Dead trees (%)	Correlation	No. of dead juniper	0.65
Dead juniper (%)	Correlation	No. of dead juniper	0.80

Table 3.4 – Support for models explaining nest site selection by pinyon jays on Kirtland Air Force Base, New Mexico in 2017-2018. The model containing the number of dead juniper best predicts nesting sites. I rejected all models listed below except the highest ranked model due to high Δ_i values ($\Delta_i \geq 2$; Arnold 2010).

Variable	Intercept	Coefficient	df[a]	AICc[b]	Δ_i[c]	ω_i[d]
No. dead juniper	-0.1240	-1.1770	2	106.4	0	0.9642
Mean live juniper area	0.05049	0.22739	2	114.6	8.2	0.0163
Percentage dead pinyon	0.01941	-0.34432	2	116.9	10.5	0.0050
Null	0.0241		1	117.1	10.7	0.0046
Total tree area	0.02339	-0.22649	2	118.2	11.8	0.0027
No. dead pinyon	0.02347	0.22014	2	118.8	12.4	0.0020
Total live shrub area	0.02431	0.10119	2	119	12.6	0.0018
No. dead multi-tree	0.02396	-0.08167	2	119.1	12.7	0.0017
Mean live tree height	0.02416	0.06952	2	119.1	12.7	0.0017

[a] df - Degrees of freedom

[b] AICc – Akaike's Information Criterion corrected for small sample sizes.

[c] Δ_i– Akaike's Information Criterion relative to the highest ranked model

[d] ω_i– Akaike weight

Table 3.5 – Results of one-way paired t-tests comparing pinyon jay nest tree (n = 42) measurements against a randomly selected non-nest tree in the same nest vegetation survey plots on Kirtland Air Force Base, New Mexico in 2017-2018.

Parameter	Nest Tree		Plot Trees				
	$\overline{X}$	SE	$\overline{X}$	SE		r	P
Height (m)	3.77	0.13	2.91	0.03		0.31	< 0.001
Area (m^2)	19.21	1.49	15.79	0.46		0.33	0.118
Volume (m^3)	49.61	4.76	38.68	1.36		0.33	0.103
Foliage	2.57	0.08	2.57	0.02		0.34	0.500

Figure 3.1 – Regression demonstrating the relationship between the number of dead juniper trees in a vegetation survey plot and the percent probability the plot was a pinyon jay nesting site. Data points represent either nest plots (y = 1) or random plots (y = 0) and are jittered to show overlapping points. The gray region represents the confidence interval. Kirtland Air Force Base, New Mexico 2017-2018.
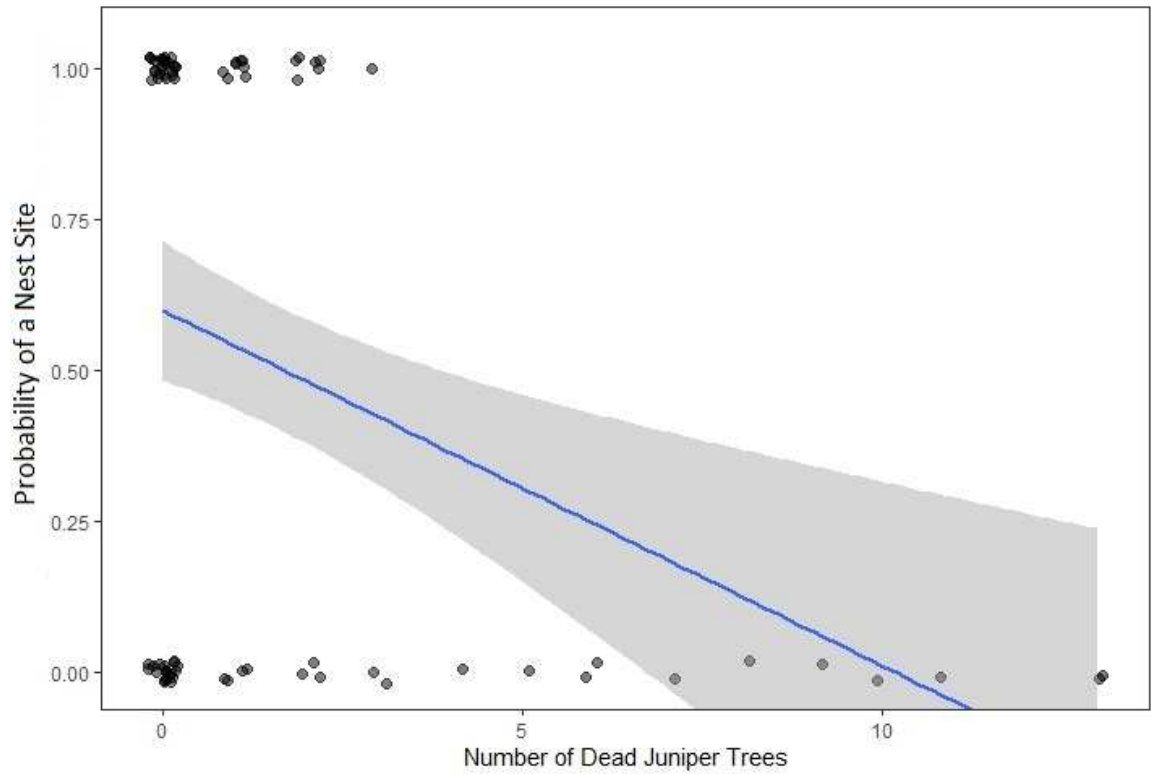
CHAPTER IV

PINYON JAY NEST FATE AND RENESTING IN CENTRAL NEW MEXICO

ABSTRACT

Pinyon jay (*Gymnorhinus cyanocephalus*) populations are declining by almost 3.5% per year

which may be related to low reproductive success. However, pinyon jay nest success and

renesting propensity has not been studied in pinyon-juniper habitat. Therefore, my objectives

were to compare habitat characteristics of successful and unsuccessful nest sites in central New

Mexico as well as to investigate renesting and potential instances of pinyon jay satellite colonies.

I attached radio telemetry transmitters to pinyon jays to locate nesting sites, then conducted

habitat surveys at each nest location. I measured number, species, area, volume, and foliage of

trees at 37 nest sites in addition to nest and nest tree characteristics. To assess which variables

affected daily nest fate, nest plot characteristics were incorporated into binomial generalized

linear models with a logistic exposure function, then evaluated with Akaike's Information

Criterion corrected for small sample size (AICc). No habitat differences were found between

successful and unsuccessful nests. Satellite colonies were not detected, but some breeding pairs

did renest > 1.5 km from their original colony. Renesting mostly occurred in the original colony.

Renesting was common in one flock that had year-round access to food and water, and less

common in another flock that did not. To assess which variables affected renesting propensity,

nest plot vegetation variables were compared between 10 original and 10 subsequent nest sites,

then incorporated into binomial generalized linear models and evaluated with AICc. Total tree area and average juniper tree area models best predicted renesting sites. Nest success was 21.43% including an estimated 40 fledglings, but likely was an ineffective measure of population trends for pinyon jays on the study site because we found few nests relative to the breeding population. Count surveys indicated the pinyon jay numbers on KAFB has remained similar for at least eight years and potentially grew in the second year of this study. Results suggest pinyon jay habitat with greatest nest success in a pinyon-juniper landscape would have large nest trees (54.34 m^3), open canopy (20% tree area), and healthy pinyon trees. When prescribed thinning occurs in pinyon jay habitat, dead and less vigorous pinyon trees should be removed while larger healthy trees should be preserved.

INTRODUCTION

Factors influencing nesting success in birds are important to identify in species of concern (Willis 1974). Studies of songbirds frequently investigate how habitat characteristics such as number of trees, nest tree species, canopy cover, and tree size affect nest success (Liebezeit and George 2002, St-Louis et al. 2010, Francis et al. 2011). The effects of habitat characteristics on nesting success are species specific (Liebezeit and George 2002, St-Louis et al. 2010, Francis et al. 2011). There are many birds that require research into how habitat characteristics affect nest success, especially species of concern with declining populations such as the pinyon jay (*Gymnorhinus cyanocephalus*; Marzluff and Balda 1992; Balda 2002; Rosenberg et al. 2016).

Pinyon jays are a colonially-nesting species distributed throughout the western United States (Marzluff and Balda 1992, Balda 2002). Pinyon jay populations have declined approximately 3.5% per year, in part due to low breeding success (Marzluff and Balda 1992, Balda 2002, Rosenberg et al. 2016). Only 55% of pinyon jay eggs hatch and 56% of hatched eggs fledge young (Marzluff and Balda 1992, Barber et al. 2001, Balda 2002). Pinyon jays, however, have relatively long lifespans, which can compensate for low nesting success by allowing them to nest a greater number of times over their lives (Marzluff and Balda 1992). Breeding pairs of pinyon jays often try to nest more than once in a season if their first attempt is unsuccessful (Balda 2002, Walker and Marzluff 2017, Benvenuti et al. 2018). Therefore, overall reproductive success often depends on the success of renesting attempts (Marzluff and Balda 1992, Morris et al. 2015).

When pinyon jays renest, they often do so 1.2 km–5.0 km away from the original breeding colony in a group of other renesting breeding pairs (Balda and Bateman 1971, Marzluff and Balda 1992). Groups of renesting pinyon jays that have dispersed away from the original colony have been called "satellite colonies" which can comprise 3–12 nests (Balda and Bateman 1971, Marzluff and Balda 1992, Balda 2002). This behavior has been observed in Flagstaff, AZ and is understood

as an established part of the pinyon jay life cycle, but it has not been investigated or mentioned in other regions of pinyon jay habitat (Ligon 1978; Johnson et al. 2016, 2017, 2018). For example, multi-year studies in central New Mexico delineated the boundaries of pinyon jay colonies established at the beginning of breeding season, but researchers did not detect satellite colonies (Johnson et al. 2016, 2017, 2018). Satellite colonies may not have been observed or mentioned in other pinyon jay literature because pinyon jays in some regions might not often renest or make satellite colonies (Ligon 1978). Pinyon jays have been known to alter the height at which they construct subsequent renests after predation or destructive weather causes a first nest to fail, but it is unclear if the circumstances of previous nest failures cause pinyon jays to select different habitat to renest (Marzluff 1988).

Therefore, my objectives were to evaluate if nest habitat characteristics affect pinyon jay nest fate, as well as compare nest habitat characteristics between first and subsequent nesting attempts. Additionally, I measured the distance between renest attempts and determined if satellite colonies existed on the study site.

METHODS

Study Area

I conducted this study on Kirtland Air Force Base (KAFB) in 2017 and 2018. Kirtland Air Force Base is located in central New Mexico and comprises habitat types that follow an elevational gradient from west to east (KAFB 2012). The scrub-steppe lowlands in the west transition to juniper (*Juniperus monophylla*) savanna, pinyon (*Pinus edulis*) and juniper woodland, and ponderosa pine (*Pinus ponderosa*) forest in the east (KAFB 2012). KAFB is 210 km^2, including 77 km^2 of pinyon-juniper woodland (Johnson et al. 2016). Two flocks of pinyon jays resided in pinyon-juniper woodlands on KAFB (Chapter 2). The Madera flock inhabited the north region and the Starfire flock inhabited the south near the Starfire Optical Range (SOR; Fig. 4.1). I did

not observe the two flocks associating with each other between December and July. Under the Sikes Act Improvement Act of 1997, species of concern, such as the pinyon jay in New Mexico, must be monitored and managed for conservation on Department of Defense lands (NatureServe 2004, BirdLife International 2016)

Data Collection

I trapped pinyon jays between December and March in both years. Regularly stocked bird feeders maintained by the SOR gate attendant regularly attracted the Starfire flock. In the north, I also established an automatic feeder in an area of high pinyon jay activity in 2018 (Johnson et al. 2016). The feeder dispensed shelled peanuts, black-oil sunflower seeds, and millet.

I trapped pinyon jays in walk-in style pigeon traps and a large box trap baited with pinyon seeds (Johnson et al. 2016). Trapped pinyon jays were immediately placed in cloth bags (Ralph et al. 1993). All pinyon jays had serially-numbered USGS aluminum bands attached and a unique combination of three, plastic color bands to identify individuals. I determined age of pinyon jays by the presence or absence of molt limits in their flight feathers (Pyle 1997). Male and female pinyon jays are monomorphic and difficult to differentiate (Balda 2002). Although literature indicates that males have more blue on their head, are slightly larger, and have slightly larger bill measurements than females, these characteristics are not precise and I recorded many individuals as "unknown sex" (Johnson 1988, Pyle 1997, Balda 2002). I collected blood samples from the brachial vein of all trapped pinyon jays and sent them to a genetics lab for definitive sex determination (Animal Genetics, Inc., Talahassee, FL).

I attached VHF radio transmitters weighing 2.0 g to a subset of pinyon jays by tying transmitters around the base of their central two rectrices and reinforcing it with cyanoacrylic glue (Holohil, Inc., Carp, ON, Canada; Johnson et al. 2016). To find nests, I attempted to deploy transmitters on

as many females as possible. In 2017 and 2018, I deployed transmitters on 9 and 24 females, respectively. I also deployed transmitters on 32 pinyon jays that were male or unknown sex.

When pinyon jays subdivided from the two main flocks into breeding colonies (Chapter 2), I located nests by homing in on transmitter signals from nesting females (Millspaugh et al. 2012). I used telemetry to find the strongest signal from transmitters of likely-nesting females, i.e. females with transmitters signaling no movement throughout the day during breeding season. Males with transmitters were useful for finding colonies, but moved too quickly for me to locate their nests. I found other nests by watching the breeding colony from a vantage point (Johnson et al. 2010). When colony members carrying food or nesting material returned to nests, I determined where they entered or exited trees, then tried to find nests in those areas (Johnson et al. 2017). To identify nest owners without transmitters, I hid nearby and noted the color bands on each parent if present (Marzluff and Balda 1992). I could not identify subsequent nests if parents were unbanded.

When nests failed I tried to relocate individuals to see if they constructed new nests. This was accomplished by following radio-tagged females whose nests had recently failed. I found 4 renests using this technique. However, most of the first nests I found either did not belong to a female with a transmitter, or else their transmitter had fallen off. This made locating renests difficult. Most nests are established in an original colony within 10 days, thus, I assumed nests established after this to be renests (Marzluff and Balda 1992, Balda 2002). I determined nest start date by identifying the nesting stage (incubation, brooding, or fledging), then counting backward the number of days it took to reach that stage (Marzluff and Balda 1992, Balda 2002). To determine the start date of each colony, I calculated the first lay date for every known nest in each original colony to determine the average first lay date. I found 8 nests established sufficiently later than the average first lay date of the original colony to call them renests. I used the Measure tool in ArcGIS 10.2 (ESRI, Inc., Redlands, CA) to find: the distance between renests and their

previous nests; the distance between renests and the closest nest of the original colony; and, for

all colony nests, the closest neighboring nest (Gabaldon 1979, Marzluff and Balda 1992).

Habitat Measurements

After nesting ended in a colony, I conducted habitat surveys at every nest location with the help

of a technician. Habitat survey plots were a circle with a 17.5 m radius in which we collected

measurements of the terrain and the nest, as well as vegetation data from the nest tree and non-

nest trees in the plot (Johnson et al. 2014, Krofcheck et al. 2016). We found the nest tree at the

center of the plot, recorded the GPS coordinates, and measured the slope of the ground with a

clinometer (Gabaldon 1979, Krofcheck et al. 2016). Then we used a tape measure to place flags

17.5 m away at the edges of the plot in the four cardinal directions to make a visible boundary for

reference while collecting data.

We measured nest height off the ground, directional aspect of the nest in the tree relative to the

center, nest distance to tree edge, and nest distance to tree center (Gabaldon 1979). Pinyon jays

constructed the majority of their nests in juniper trees which grow asymmetrically and do not

have an easily identifiable center (Waichler et al. 2001). Thus, to calculate distance from the nest

to the center of the tree, I measured tree width at the height and aspect of the nest and divided that

value by two to find the radius of the tree. I then subtracted distance of the nest to tree edge from

the radius to find distance of the nest from the center. I used these values to calculate relative

height and edge distance of the nest in the tree, which are ratios that describe the location of the

nest within a nest tree (Marzluff 1988). Relative edge distance was defined as the distance from

the nest to the center of the tree divided by the distance from the center to the edge (Marzluff

1988). Nests closer to the tree edge had higher relative edge distance values than nests closer to

the center. Similarly, relative nest height (hereafter relative height 1) was defined as height of the

nest above the ground divided by total tree height (Marzluff 1988). Relative height values were

greater for nests higher up in the nest tree. The closer a nest was to the top of the tree, the higher

the relative height value was. Additionally, I computed a second relative height (hereafter relative

height 2) value that compared nest height to the average non-nest tree height in the plot

(Gabaldon 1979). This is a measure of the height of the nest above or below the local canopy, and

therefore a proxy of nest concealment from predators or protection from destructive winds

(Gabaldon 1979).

The technician and I surveyed the remainder of the vegetation beginning from the same side of

the plot and working in opposite directions until we met on the other side. We recorded species of

woody plants > 1 m tall and noted if they was alive or dead (KAFB 1998). I imposed this height

limit to include only plants potentially used for nesting by pinyon jays (Marzluff and Balda

1992). All pinyon and juniper were classified as trees, and all other short, woody-stemmed plants

including scrub oak (*Quercus turbinella*) were classified as shrubs, which typically do not grow

greater than 3 m in height (KAFB 1998, Körner 2012). We measured the length, width, and

height for each plant, beginning with the side of greatest length (Krofcheck et al. 2016). Tree area

was calculated as an ellipse with radii of half the greatest length and half the corresponding

perpendicular width (Krofcheck et al. 2016). Tree volume was calculated as an ellipsoid with

radii of half the greatest length, half the perpendicular width, and half the height (Krofcheck et al.

2016). I chose to calculate volume as an ellipsoid because it followed naturally from the elliptical

area calculation and was the most approximate shape to pinyon and juniper trees (Krofcheck et al.

2016). I estimated visible foliage using the Braun-Blanquet Cover-Abundance Scale (Wilkum and

Shanholtzer 1978). I stood 3–5 m from each tree and evaluated it from four sides, beginning with

the side of longest width and continuing every 90°. Scores were from 1–4 for each side of the

tree: 1 (1–25% foliated); 2 (26–50%); 3 (51–75%); 4 (76–100%).

Some trees were intertwined with one or more other trees that affected their growth and, thus,

their size and foliage measurements (Gabaldon 1979). I measured the collection of intertwined

trees together (hereafter multi-tree), and did not measure each constituent tree separately. I did record how many trees comprised the multi-tree and their species.

I compared characteristics of the nest tree to other trees in the plot. These values potentially indicate important nest tree characteristics (Gabaldon 1979). For each nest plot, I compared the ratio of the height, area, volume, and foliage cover, respectively, between the nest tree and the average of the non-nest trees in the plot (Gabaldon 1979).

Data Analysis

To assess effects of pinyon jay nest site habitat characteristics on nest successful, I created a set of binomial generalized linear models (GLMs) and evaluated them with Akaike's Information Criterion corrected for small sample sizes (AICc; Burnham and Anderson 2002). I used GLMs instead of mixed models with a random effect for colony because I did not have enough data points for the random effect to fit the model (Harrell 2015). To make all variables comparable to each other for AICc analysis, I standardized variables by subtracting the mean of each variable from every data value within it and dividing those values by the standard deviation (Anderson and Burnham 2002, Symonds and Moussalli 2011). I did not include nests for which I could not determine if the nest fledged or failed. Using the lme4 R package (Bates et al. 2015; R Version 3.4.1, www.r-project.org, accessed 10 Sep 2017), I created GLMs with a logistic exposure link to evaluate nest mortality as a function of nest exposure in days (Shaffer 2004, Bolker 2014). Because nests that are found with older clutches are more likely to be successful than with younger clutches, and nests that fail are less likely to be discovered than active nests tended by adults, the logistic exposure function is appropriate to use because it considers the number of days nests were monitored (Shaffer 2004). The binary response variable was nest fate at each nest check, which was given a value of 1 if active or 0 if failed. Nests which fledged at least one chick

were given a value of 1 for that nest check. The fixed explanatory variables were habitat characteristics of the nest site.

Evaluations of AICc are more informative about a given set of variables when the number of models is small (Anderson and Burnham 2002, Dochtermann and Jenkins 2011). Therefore, I analyzed a subset of the habitat characteristics I measured (Table 4.1). For example, I excluded terrain measurements from analysis because I wanted to assess vegetation characteristics of nest sites, however, terrain measurements were useful for comparing colony locations with previous studies on KAFB. I also removed some before analysis (Table 4.2). I eliminated variables from AICc analysis if they could not be meaningfully measured in all plots. For example, I did not measure the individual trees comprising a multi-tree, so I could not analyze the total area and volume for pinyon or juniper. I also excluded the average area, volume, and foliage measurements for pinyon trees or multi-trees because they were not present to be measured in all plots and, therefore, could not be used in an AICc evaluation (Anderson and Burnham 2002). I also removed variables that were highly correlated ($|r| \geq 0.6$; Burdett et al. 2010; Goldenberg et al. 2017). After evaluation, I rejected models with relatively large AICc values ($\Delta_i \leq 2$; Richards 2008, Arnold 2010).

I also compared habitat characteristics between all original nests and renests using an AICc analysis that evaluated binomial GLMs constructed from a subset of measured habitat variables (Table 4.3). The response variable was the type of nest (original or renest). The fixed explanatory variables were the habitat characteristics of the nest site. I removed variables before analysis as noted above (Table 4.4).

RESULTS

Nest Fate

I found 42 nests during the study, 38 of which nest fate was known (Table 4.5). Predation was likely the cause of failure for most nests, but some were abandoned (Table 4.5). Nest predation occurred during the incubation (n = 18) and brooding stages (n = 8) of nesting. I could not count how many individual eggs were predated because I typically did not check nest contents until the female began brooding. There were 43 nestlings that did not survive, most of which were likely predated, however, 6 were from nests that eventually fledged at least one chick. Pinyon jay nests produced 21 fledglings and I found a minimum of 9 other hatch-year birds which fledged from unobserved nests.

I collected habitat data at 42 pinyon jay nest sites, but eliminated 5 nests from the AICc analysis. I removed 4 nests of unknown fate and 1 nest that had fledged before discovery because they could not be analyzed with the logistic exposure function (Bolker 2014). Specifically, nests found after fledging (0 exposure days) could not be calculated because it would require the function to divide by 0 and result in an error (Bolker 2014). After removing variables from the analysis, the following variables were included in the AICc evaluation: number of dead pinyon, number of dead juniper, average juniper area, total shrub area, total tree area, percentage of dead juniper, average juniper foliage cover, relative edge distance, nest tree area, nest tree foliage cover, nest tree to average non-nest tree area ratio, and nest tree to average non-nest tree foliage ratio, and relative nest height 1. I evaluated only univariate models because of the low power of this analysis (Harrell 2015). The AICc evaluation yielded 9 best models ($\Delta_i \leq 2$) (Table 4.6). The best model included the variable for nest tree area and had a confidence set of 0.158, meaning that there is a 15.8% chance that the best model truly is the best of the ones evaluated (Table 4.6). The null model was too similar to the top model to reject as a predictive model ($\Delta_i < 2$; Table 4.6).

Additionally, I conducted ANOVAs on GLM models from every variable, even those excluded from AICc analysis (Table 4.1). Since pinyon, multi-trees, and shrubs were not present on every plot, variables of average size and foliage measurements could not be compared to missing

values. Therefore, I excluded plots that did not have those vegetation categories before processing each GLM and conducting an ANOVA (Table 4.1).

Renesting and Satellite Colonies

When breeding began, pinyon jays from each flock subdivided to establish breeding colonies in smaller groups. In 2017, the Madera flock established two nesting colonies: one in Sol Se Mete Canyon (hereafter Madera1; nests = 5) and the other on the northwest edge of Madera Canyon (hereafter Madera2; nests = 6; Fig. 4.2). In 2017, the Starfire flock split into two colonies. They built one colony (hereafter Starfire1; nests = 9) on base near the Combat Arms Training and Maintenance firing range (Fig. 4.3) and likely established another (hereafter Starfire2) across the southern border of KAFB on Isleta Pueblo (Fig. 4.1), but I did not have access to this location. I determined this group to be nesting because females with radio transmitters were repeatedly detected at the same bearing for several days. In 2018, the Madera flock nested in one colony (hereafter Madera3; nests = 8). The Starfire flock established two colonies in 2018. They nested at Starfire 2 again and created a new colony (hereafter Starfire 3; nests = 9; Fig. 4.4) near the High Energy Research and Technology Facility.

I found 30 nests that were first nesting attempts. Additionally, I found 4 renests for which I knew the previous nest location, and 8 for which I did not, but I determined by backdating nests that the latter were of renest age. Pinyon jays did not renest within the same tree. I did not find pinyon jays nesting in satellite colonies, rather, they built some renests "contiguously" with the original colony (< 0.7 km; n = 8; hereafter "contiguous renests"), while some were built far from the original colony (> 1.5 km; n = 4; Figs. 4.2–4.4). Importantly, when pinyon jays lost nests and renested nearby, the active boundary of the colony shifted, so although all contiguous renests were less than 0.7 km away from the original colony boundary, they were much closer to the contemporaneous, reshaped colony boundary. Contiguous renests ranged 0.28 km–0.61 km ($\bar{x}$ =

0.44, SE = 0.05 km) from the closest nest in the original colony (Table 4.7). Non-contiguous nests ranged 1.6 km–2.1 km ($\bar{x}$ = 1.8 km, SE = 1.11 km) from the closest nest in the original colony (Table 4.7). The average distance of contiguous nests from their nearest neighbor did not differ compared to the average distance of nearest neighbors in the original colony (t = 0.51, P = 0.62).

In 2017 I found nests in the Madera1 and Madera2 colonies using traditional nest searching techniques, but without an adequate number of pinyon jays with transmitters, I could not track them to potential renests. I found one nest 1.6 km from Madera2 (Fig. 4.2). Additionally, I located three nests far from Starfire1 whose breeding pairs originated from there and four contiguous nests less than 0.4 km from the original colony (Fig. 4.3). In 2018, I located four renests at Starfire3 which were all contiguous with the original colony and therefore I do not consider them satellite nests (Fig. 4.4).

The majority of renests were in Starfire1 and Starfire3 (n = 10, 91%). Therefore, to compare habitat characteristics between original nests and renests, I analyzed these two colonies because were in a similar location and comprised the same flock. After removing variables (see above), the models I evaluated in the AICc analysis included: number of dead pinyon, number of dead juniper, average juniper area, total shrub area, total tree area, average juniper foliage cover, percentage of dead pinyon, nest tree height, nest tree area, nest tree foliage cover, nest tree to average non-nest tree height ratio, relative nest height 1, and relative edge distance. The top models included the variable for average juniper tree area and total tree area, which were negatively associated with renests (Table 4.8). The null model was not competitive (Δ_i = 2.3; Table 4.8).

DISCUSSION

Nest Success

Although researchers have recently been studying nest site selection of pinyon jays in New Mexico, there has been little research on nesting success in pinyon-juniper habitat (Balda 2002; Johnson et al. 2016, 2017, 2018). The lack of studies on pinyon jay nest success is concerning because populations are declining as the habitat they live in is changing rapidly (Romme et al. 2009, Breshears et al. 2010, Rosenberg et al. 2016). This study provided exploratory nest fate data for pinyon jays in pinyon-juniper habitat.

The majority of nests in this study failed due to predation. In most instances, the lack of egg or nestling remnants in a relatively undisturbed nest cup indicated predation by common ravens (*Corvus corax*), Woodhouse's scrub-jays (*Acephalocoma woodhouseii*), or bull snakes (*Pituophis catenifer sayi*), all of which were observed on KAFB (Marzluff 1988, Petyk 2004, Stake et al. 2004). Three nests in this study were abandoned with nestlings. I made an effort to disturb nests as little as possible, typically only verifying at a distance if females were still maintaining the nest and only checking nest contents when the adults were not present. It is possible one nest failed due to loud noises from high-velocity impact testing at the nearby Aerial Cable Facility.

The AICc evaluation of factors influencing nest fate yielded 9 best models with weak confidence sets, meaning there was not enough evidence to select a best model. In a preliminary analysis, I tried to use mixed effects models to compare habitat differences among colonies, but they had random effect variances equal to zero, meaning that there were not enough data to compare among five colonies (Harrell 2015). Therefore, I analyzed nests in a fixed effect model, but it is uncertain how the results are affected by autocorrelation. Further, the null model produced similar results to the top model ($\Delta_i < 2$), indicating the predictive power of the best models were weak. Therefore, variables in the best models should not be assumed as good predictors of pinyon jay nest success within pinyon-juniper woodland; rather, they may be candidates for further investigation.

The best model included nest tree area which was positively associated with nest success. Nest tree to average non-nest tree area ratio was also an important variable and positively associated with nest success. Larger nest trees have more branches and offer a greater number of potential nesting sites than smaller trees (Gabaldon 1979). Furthermore, the larger area of a nest tree might serve as a proxy for greater nest concealment because, even if green foliage was lower in larger trees, there would still be a greater amount of vegetation, green or not, obscuring the location of the nest from predators (Gabaldon 1979, Best and Stauffer 1980).

The second best model in the nest fate analysis included total tree area around nest sites, which was negatively associated with nest success. This was consistent with findings from other studies that showed pinyon jays in pinyon-juniper habitat prefer nesting in relatively open woodland (Johnson et al. 2014, 2017). The reasons why total tree area might affect nest fate are unclear because the lower density nest sites are closer to, or may be characterized as, edge habitat, which is frequently associated with greater predation and nest predation rates (Andrén and Anglestam 1988, Manolis et al. 2002, Stirnemann et al. 2015). However, nests in relatively open areas might be conducive for detecting predators (Gabaldon 1979, Götmark et al. 1995). Another explanation for the importance of total tree area on pinyon jay nest success is that a more open canopy might have greater exposure to solar radiation to keep chicks warm at the beginning of breeding season (Marzluff 1988, Marzluff and Balda 1992). This would need to be examined in temporally-focused research and was outside the scope of this study. Finally, it has been suggested that the loss of open sagebrush mosaic within pinyon-juniper landscape might be related to pinyon jay population decline by reducing the amount of seed caching sites. This loss has not been documented at KAFB, but it may be possible that open-canopied nesting areas indicate a closer proximity to ideal caching sites (KAFB 2012, Boone et al. 2018).

Relative edge distance was positively associated with nest success. Marzluff (1988) found that more exposed nests (i.e. higher up or closer to the edge of a nest tree) in AZ failed more

frequently than less exposed nests. In my study, cold weather was a potential risk for nests, and

pinyon jays may have benefitted from increased nest exposure measured as a larger relative edge

distance value because the increase in solar radiation might have kept eggs warm. However,

unlike Flagstaff, AZ, KAFB does not receive much snow, and the temperature during this study

rarely fell below freezing during breeding (NOAA 2019). Pinyon jays abandoned 3 nests (7.8%),

which was less than in AZ (14.8%), so weather may not have impacted nest success as much as in

AZ (Marzluff and Balda 1992).

The number of dead pinyon trees was negatively associated with nest success. This may be

because pinyon jays rely on pinyon seeds for much of their nutrition (Marzluff and Balda 1992,

Balda 2002). Pinyon jays in areas with fewer live or healthy trees may have less access to seeds.

Johnson et al. (2014, 2017) found pinyon jays frequently nested in areas with live pinyon trees

with higher vigor than random sites. However, they also found that pinyon vigor on KAFB was

declining, which could potentially cause pinyon jays to nest elsewhere when pinyon vigor

decreases past a certain threshold (Johnson et al. 2014, 2017). Indeed, five years after Johnson et

al. (2014, 2016, 2017), I found that pinyon jay colonies shifted to lower elevation juniper savanna

with fewer pinyon and fewer trees overall (KAFB 2012). Live pinyon trees have been a focus of

pinyon jay habitat research, however, I did not include variables for live pinyon trees in my AICc

analysis due to the lack of pinyon in many nest plots, the difficulty of measuring individual trees

within multi-trees, and the high correlation of pinyon size with total tree area (Johnson et al.

2014, 2017, 2018). Rather, pinyon jays in this study closely associated with juniper trees, by

nesting mostly in juniper, as well as inhabiting areas with more juniper (Chapter 3).

I recorded 21 fledglings from study nests and found evidence of at least 9 other hatch-year pinyon

jays. Assuming the Starfire2 colony on Isleta Pueblo produced offspring at a similar rate to the

three KAFB colonies (approx. 10 fledglings and hatch-years per colony), the two flocks could

have potentially produced 40 fledglings over two years. Marzluff and Balda (1992) found that

adult pinyon jays had a 74% annual survivorship. Survivorship rate for hatch-year and second-year birds is lower than for adults, but I did not have age composition data, so I used the adult survivorship rate to project the population trend over two years. Assuming there were 125 pinyon jays on KAFB at the beginning of breeding season in 2017 (Chapter 2), approximately 33 after-hatch-year pinyon jays would be expected to die within a year. It is likely that the 20 projected fledglings per year on KAFB, which experience the greatest mortality rates, would not be enough to replace all the adult mortalities. This population projection is likely not accurate because I likely did not find all fledglings produced during the study. Further, immigration and emigration from the flock likely occurred but were not measured. Considering the number of fledglings projected, a net total of 13 pinyon jays would have to immigrate to the KAFB flocks to stabilize the population, which is more than typically immigrated per year in Flagstaff (Marzluff and Balda 1992).

Marzluff and Balda (1992) believed a more accurate population model used direct counts of flock size. They found that pinyon jays in Flagstaff were declining at a rate of 7-12% per year. Previous pinyon jays studies on KAFB estimated 135 individuals which is similar to the number I found (Johnson et al. 2011). Thus, counts of pinyon jays on KAFB appear to have remained relatively stable since at least 2009. Between 2017 and 2018, the maximum flock count in my study grew from 60 to 65 individuals in the Starfire flock and from 65 to 75 individuals in the Madera flock (Chapter 2).

Renesting and Satellite Colonies

The majority of pinyon jay renesting research has been in Flagstaff, AZ (Gabaldon 1979, Marzluff 1988, Marzluff and Balda 1992). Gabaldon (1979) investigated renesting pinyon jays and found that older individuals had higher nesting success than younger ones. Marzluff (1988) studied renesting pinyon jays at the same site and focused on placement of renests within

subsequent nesting trees, but not landscape-scale spatial patterns of renests. His research showed that pinyon jays demonstrated specific changes in nest placement in response to nest failure due to either predation or weather events. Pinyon jays whose nests were preyed upon by aerial predators were more likely to renest in a less exposed location lower down in a subsequent nest tree. When pinyon jay nests failed because of snow or extreme cold, they were more likely to renest in a location that was more exposed to solar radiation, i.e. higher up or closer to the edge of the nest tree. These studies were conducted in ponderosa pine forests, however, and pinyon jay renesting site selection is potentially different in pinyon-juniper woodland.

Pinyon jay studies have recently been conducted in New Mexico pinyon-juniper landscapes, but investigations into renesting and satellite colonies are lacking (Ligon 1978, Johnson et al. 2016, 2017, 2018). Ligon (1978) did not observe pinyon jays renesting during a long-term study. He thought that this might have been due to lack of food and water in the dry climate. More studies have occurred in New Mexico since, but have not reported on renesting or satellite colonies (Johnson et al. 2016, 2017, 2018).

I deployed 31 transmitters on females, but was only able to find 4 renests for which I knew the original nest location. This was due to transmitters falling off, some pinyon jays nesting off base, and few renesting attempts (n = 12). In 2018, I only found one breeding colony for the Madera flock. Although I tracked many adult females from this flock (n = 16) throughout the breeding season, we located just 2 nests from these females and many of the remainder appeared to forego breeding. Rather, a group of approximately 20 adult individuals wandered and foraged across their home range throughout spring and summer, indicating they forwent nesting during this time. Of 9 nesting females with transmitters that year, all but 1 either successfully fledged a brood or else their transmitter fell off before renesting. The remaining radio-tagged female did not renest after her first nest failed. Following males with transmitters also did not yield any indication of

renesting. It is likely that no renesting occurred within the Madera3 colony due to lack of precipitation and poor food availability (Ligon 1978).

The Starfire flock established two colonies each year. Breeding pairs in the Starfire flock renested many times both years. Unlike the Madera flock, the Starfire flock had year-round access to food and water at feeders at the SOR front gate. This is perhaps why the Starfire flock was able to establish two colonies each year and have a high prevalence of renesting (Ligon 1978, Marzluff and Balda 1992).

I found no evidence of satellite colonies, but breeding pairs did construct renests $\geq$ 1.6 km from the original colony either alone or by one other nest. One breeding pair whose first nest failed renested twice in one season, first renesting far from the original colony, then renesting contiguously with it. Renesting in pinyon jays has not been well studied (Balda and Bateman 1971, Ligon 1978, Gabaldon 1979, Marzluff and Balda 1992, Balda 2002). Satellite colonies are described in the literature as discrete groups of nests, at least 1.2 km away from an original colony (Balda and Bateman 1971, Marzluff and Balda 1992). In this study, I found most renests less than 0.6 km from the original colony and, due to their proximity, they were difficult to distinguish from the original colony. Nests in the original colonies continued to fledge or fail concurrently with the construction of new nests in the area.

In Arizona, when nests fail at approximately the same time, the breeding pairs of the failed nests will begin a new colony group (Marzluff and Balda 1992, Balda 2002). This satellite colony can still receive new members for up to 30 days after the establishment of the colony (Marzluff and Balda 1992). The Starfire1 colony experienced two "pulses" of high nest failure. Although there were two large groups of failed nesters, just one breeding pair from each pulse established a nest by themselves far away from the original colony, demonstrating that the concurrent timing of nest failure did not result in a group establishing a satellite colony.

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Average juniper area was the best predictor of renesting and was negatively associated with renests. The reasons for this are unclear. The second best model was total tree area, which was negatively associated with renesting attempts. This suggests that pinyon jays select renest sites that are relatively more open than at their first nest. Analyses of renesting are complex because nesting preferences are dynamic and may be context dependent. Marzluff (1988) noted that the ecological factors that influence pinyon jay nest placement do not favor one fixed nest position within a nest tree, and that might be true for nesting habitat as well. For example, renesting pinyon jays may alter nest site selection based on the conditions of failure at their previous nests, but not all nests fail in the same way. Thus, any habitat differences between original nests and renests would not be consistent across breeding pairs (Gabaldon 1979, Marzluff 1988). Further investigation of habitat characteristics associated with renesting should focus on temporal changes and document types of predation.

CONCLUSION

No pinyon jay nest site habitat characteristics were sufficiently associated with nest success, however, nest tree area had the lowest AICc value and may be an ideal candidate for further investigation. Renesting pinyon jays preferred to build new nests in areas with relatively less total tree area and less average juniper area than original nest sites. Results suggest the ideal pinyon jay nesting habitat in a pinyon-juniper landscape would have nest trees with large areas (23.7 m^2), relatively sparse tree density (22.29 trees/ha), open canopy (20% tree area), and healthy pinyon trees. Therefore, areas such as this should be protected and managed for by removing smaller, unhealthy trees in pinyon-juniper woodland during non-breeding while letting larger trees remain. Pinyon jays did not nest in satellite colonies on KAFB, but did build some nests far from the original colony ($\geq$ 1.6 km). Findings suggest pinyon jays do not renest as much in New Mexico as they do in Arizona.

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TABLES AND FIGURES

Table 4.1 - Habitat characteristics of vegetation survey plots around successful and unsuccessful pinyon jay nests on Kirtland Air Force Base, New Mexico 2017-2018. Of 9 successful nests, 1 could not be used because it was found after nestlings had fledged and had no observed exposure time to use in the logistic exposure function of the model. P-values are based on evaluating GLM models. Tree counts are of both live and dead trees unless otherwise specified.

Variable	Successful (8)		Unsuccessful (29)		F	P
	$\bar{X}$	SE	$\bar{X}$	SE		
No. of shrubs [a]	6.14	1.83	10.46	2.91	3.925	0.049*
No. of trees [a]	22.29	5.76	34.27	7.91	4.838	0.029*
No. of pinyon[a]	10.71	3.68	20.58	7.03	3.021	0.035*
No. of juniper[a]	13.86	3.79	23.27	4.14	4.064	0.046*
No. of multi-trees [a]	2.29	0.99	5.50	1.67	3.338	0.070
No. of live trees	18.57	4.80	28.77	5.54	3.935	0.049*
No. of live pinyon	7.57	2.58	14.50	4.70	4.550	0.084
No. of live juniper	13.29	3.62	22.92	4.04	4.115	0.044*
No. of live multi-trees	2.29	0.99	5.08	1.47	2.899	0.070
No. of dead trees	3.71	1.74	5.50	3.09	4.296	0.040
No. of dead pinyon	3.14	1.83	6.08	3.31	5.157	0.025*
No. of dead juniper	0.57	0.30	0.35	0.15	0.312	0.577
No. of dead multi-trees	0.00	0.00	0.42	0.25	5.005	0.027*
Mean live tree height (m)	2.69	0.22	2.91	0.13	0.073	0.787
Mean live shrub area (m^2)	5.14	1.50	3.46	0.78	0.546	0.462
Mean live tree area (m^2)	14.16	4.45	12.85	1.94	0.911	0.341
Mean live pinyon area (m^2)	1.17	0.45	1.35	0.16	3.52	0.063
Mean juniper area (m^2)	11.00	2.72	10.54	2.06	1.129	0.290
Mean multi-tree area (m^2)	37.81	13.75	17.07	6.78	3.515	0.064
Total live shrub area (m^2)	32.42	11.77	33.54	8.73	2.648	0.106
Total live tree area (m^2)	187.85	32.14	232.21	25.91	3.533	0.062
Total live multi-tree area (m^2)	50.49	13.86	67.93	15.20	1.356	0.246
Total live vegetation area (m^2)	220.27	43.03	265.75	29.47	4.737	0.031*
Live shrub area (%)	3	1	3	1	2.648	0.106
Live tree area (%)	20	3	24	3	3.533	0.062
Live vegetation area (%)	23	4	28	3	4.737	0.031*
Mean live shrub volume (m^3)	7.73	2.25	4.63	2.17	0.436	0.511
Mean live tree volume (m^3)	35.33	13.37	32.18	6.37	0.937	0.335
Mean live pinyon volume (m^3)	2.40	1.20	2.99	0.46	3.859	0.052
Mean live juniper volume (m^3)	28.17	8.82	26.29	6.66	1.324	0.252
Mean live multi-tree volume (m^3)	110.52	51.75	42.83	23.87	2.800	0.097

* Indicates statistical significance

[a] Live or dead

Table 4.1 - (continued)

| Variable | Successful nests (8) | | Unsuccessful nests (29) | | | |
	$\bar{X}$	SE	$\bar{X}$	SE	*F*	*P*
Total live shrub volume (m^3)	58.47	21.14	49.60	13.51	2.242	0.316
Total live tree volume (m^3)	472.73	103.88	532.70	58.73	2.180	0.142
Total live multi-tree volume (m^3)	137.74	45.41	169.60	39.28	0.906	0.343
Total live vegetation volume (m^3)	522.84	1.73	582.30	64.82	2.797	0.096
Mean foliage cover	2.54	0.15	2.49	0.08	0.299	0.585
Mean pinyon foliage cover	2.18	0.21	2.42	0.43	0.099	0.753
Mean juniper foliage cover	2.69	0.22	2.51	0.09	1.644	0.202
Mean multi-tree foliage cover	2.39	0.22	2.57	0.45	0.145	0.704
Elevation (m)	1965.6	18.9	1939.7	10.5	0.098	0.754
Slope (degrees)	24.57	4.12	20.92	2.36	0.669	0.451
Dead trees (%)	14	5	6	2	0.085	0.771
Dead pinyon (%)	16	9	14	5	0.016	0.899
Dead juniper (%)	5	3	1	0	0.717	0.398
Nest height (m)	2.35	0.24	2.18	0.15	0.03	0.868
Height of nest tree (m)	3.47	0.23	3.74	0.15	0.015	0.901
Area of nest tree (m^2)	23.72	3.95	18.18	1.92	2.432	0.121
Volume of nest tree (m^3)	54.34	9.93	47.99	6.61	1.197	0.276
Foliage cover of nest tree	2.54	0.18	2.64	0.09	1.021	0.314
Nest tree/non-nest tree height ratio	1.31	0.06	1.32	0.07	0.056	0.813
Nest tree/non-nest tree area ratio	1.99	0.28	1.67	0.19	1.181	0.279
Nest tree/non-nest tree volume ratio	1.97	0.30	1.88	0.26	0.594	0.442
Nest tree/non-nest tree foliage ratio	1.00	0.06	1.07	0.03	4.196	0.042*
Relative nest height 1[b]	0.68	0.06	0.59	0.03	0.119	0.730
Relative nest height 2[c]	0.88	0.06	0.78	0.06	0.301	0.584
Distance of nest to center (m)	1.37	0.24	0.85	0.14	1.955	0.164
Distance of nest to edge (m)	0.58	0.19	0.93	0.12	0.796	0.374
Relative edge distance[d]	0.66	0.09	0.45	0.05	2.223	0.138

* Indicates statistical significance

[b] Relative nest height 1– Ratio of the height of the nest compared to the height of the nest tree.

[c] Relative nest height 2 – Ratio of the height of the nest compared to the average height of non-nest trees in the plot.

[d] Relative edge distance – Ratio of the distance from the nest to the center of the nest tree divided by the tree radius.

Table 4.2 - Habitat characteristic variables eliminated before pinyon jay nest fate AICc evaluation. Some variables were eliminated before evaluation because they showed little or no slope when plotted, indicating weak association with nest site selection. Other variables were eliminated because they were highly correlated with other variables or could not be evaluated in an AICc without values from all plots. Kirtland Air Force Base, New Mexico 2017-2018.

Variable	Reason Eliminated	Correlated Variable	r
No. of shrubs [a]	Correlation	Total shrub area	0.62
No. of trees [a]	Correlation	Total tree area	0.79
No. of pinyon [a]	Correlation	Total tree area	0.75
No. of juniper [a]	Correlation	Total tree area	0.88
No. of multi-trees [a]	Correlation	Total tree area	0.76
No. of live trees	Correlation	Total tree area	0.89
No. of live pinyon	Correlation	Total tree area	0.78
No. of live juniper	Correlation	Total tree area	0.88
No. of live multi-trees	Correlation	Total tree area	0.75
No. of dead trees	Correlation	Number dead pinyon	0.99
No. of dead multi-trees	Correlation	Total tree area	0.63
Mean live tree height (m)	Correlation	Average juniper area	0.73
Mean live shrub area (m^2)	Not on all plots		
Mean live tree area (m^2)	Correlation	Average juniper area	0.90
Mean live pinyon area (m^2)	Not on all plots		
Mean multi-tree area (m^2)	Not on all plots		
Total live multi-tree area (m^2)	Correlation	Total tree area	0.73
Total live vegetation area (m^2)	Correlation	Total tree area	0.96
Live shrub area (%)	Correlation	Total live shrub area	1.00
Live tree area (%)	Correlation	Total live tree area	1.00
Live vegetation area (%)	Correlation	Total live vegetation area	1.00
Mean shrub volume (m^3)	Not on all plots		
Mean live tree volume (m^3)	Correlation	Average juniper area	0.90
Mean live pinyon volume (m^3)	Not on all plots		
Mean live juniper volume (m^3)	Correlation	Average juniper area	0.99
Mean live multi-tree volume (m^3)	Not on all plots		
Total live shrub volume (m^3)	Correlation	Total live shrub volume	0.83
Total live tree volume (m^3)	Correlation	Total tree area	0.96
Total live multi-tree volume (m^3)	Correlation	Total tree area	0.73
Total live vegetation volume (m^3)	Correlation	Total tree area	0.94
Mean foliage cover	Correlation	Total tree area	-0.63

[a] Live or dead

Table 4.2 – (continued)

Variable	Reason Eliminated	Correlated Variable	r
Mean foliage cover	Correlation	Total tree area	-0.63
Mean pinyon foliage cover	Not on all plots		
Mean multi-tree foliage cover	Not on all plots		
Elevation (m)	Not Vegetation		
Slope (degrees)	Not Vegetation		
Dead trees (%)	Correlation	Number dead pinyon	0.72
Dead juniper (%)	Correlation	No. dead juniper	0.62
Nest height (m)	Correlation	Relative height 1	0.67
Height of nest tree (m)	Correlation	Relative area	0.66
Volume of nest tree (m^3)	Correlation	Area of nest tree	0.92
Nest tree/non-nest tree height ratio	Correlation	Relative area	0.66
Nest tree/non-nest tree volume ratio	Correlation	Relative area	0.97
Relative nest height 2[b]	Correlation	Relative area	0.67
Distance of nest to center (m)	Correlation	Relative edge distance	-0.79
Distance of nest to edge (m)	Correlation	Relative edge distance	0.89

[b] Relative nest height 2 – Ratio of the height of the nest compared to the average height of non-nest trees in the plot.

Table 4.3 - Habitat characteristics of vegetation survey plots around pinyon jay original nests and renests at Starfire1 and Starfire3 breeding colonies on Kirtland Air Force Base, New Mexico 2017-2018. P-values are based on ANOVA tests of GLM models. Tree counts are of live and dead trees unless otherwise specified.

Variable	Original Nests (10)		Renests (10)		*F*	*P*
	$\bar{X}$	SE	$\bar{X}$	SE		
No. of shrubs [a]	9.40	3.56	9.00	3.72	0.408	0.531
No. of trees [a]	15.70	4.61	10.30	0.73	1.336	0.263
No. of pinyon[a]	5.17	1.90	2.88	0.40	0.295	0.593
No. of juniper[a]	14.90	4.30	9.40	0.72	1.593	0.223
No. of multi-trees [a]	3.40	1.17	2.00	0.49	0.109	0.745
No. of live trees	14.70	4.20	9.80	0.83	1.311	0.267
No. of live pinyon	4.60	1.50	2.75	0.41	0.008	0.932
No. of live juniper	14.70	4.25	9.00	0.77	1.745	0.203
No. of live multi-trees	3.40	1.17	2.00	0.49	0.109	0.745
No. of dead trees	2.50	0.50	1.00	0.00	1.098	0.309
No. of dead pinyon	2.00	0.58	1.00	0.00	3.041	0.0982
No. of dead juniper	2.00	0.00	1.00	0.00	0.600	0.449
No. of dead multi-trees	0.00	0.00	0.00	0.00	NA	NA
Mean live tree height (m)	3.36	0.27	2.85	0.17	2.564	0.127
Mean live shrub area (m^2)	2.93	0.43	3.22	0.83	0.067	0.800
Mean live tree area (m^2)	21.87	4.61	14.21	1.98	2.332	0.144
Mean live pinyon area (m^2)	1.21	0.62	0.48	0.11	2.06	0.189
Mean juniper area (m^2)	19.11	4.37	10.50	1.03	3.678	0.071
Mean multi-tree area (m^2)	31.35	12.66	22.44	4.81	0.553	0.474
Total live shrub area (m^2)	33.21	15.43	30.96	13.66	0.308	0.586
Total live tree area (m^2)	202.54	28.15	134.99	18.94	3.964	0.144
Total live multi-tree area (m^2)	66.44	13.79	46.22	14.68	0.002	0.961
Total live vegetation area (m^2)	219.14	31.97	159.76	17.93	2.624	0.123
Live shrub area (%)	3	2	3	1	0.308	0.586
Live tree area (%)	21	3	14	2	3.964	0.144
Live vegetation area (%)	23	3	16	2	2.624	0.123
Mean live shrub volume (m^3)	3.66	1.56	3.22	0.79	0.081	0.782
Mean live tree volume (m^3)	58.12	15.92	32.43	5.41	2.335	0.144
Mean live pinyon volume (m^3)	3.35	2.10	0.43	0.12	3.065	0.118
Mean live juniper volume (m^3)	51.43	15.28	24.00	2.80	3.117	0.094
Mean live multi-tree volume (m^3)	75.04	34.00	48.36	12.22	0.706	0.420

* Indicates statistical significance

[a] Live or dead

Table 4.3 (continued)

Variable	Original Nests (10)		Renests (10)			
	$\overline{X}$	SE	$\overline{X}$	SE	Z	P
Total live shrub volume (m^3)	54.55	38.10	39.10	17.84	0.025	0.875
Total live tree volume (m^3)	466.76	52.09	311.53	53.41	4.329	0.052
Total live multi-tree volume (m^3)	153.73	34.50	108.97	42.55	0.000	0.990
Total live vegetation volume (m^3)	494.03	64.71	342.81	50.08	3.416	0.0811
Mean foliage cover	2.70	0.06	2.68	0.08	0.026	0.875
Mean pinyon foliage cover	2.62	0.26	2.90	0.36	0.325	0.584
Mean juniper foliage cover	2.71	0.06	2.62	0.12	0.454	0.509
Mean multi-tree foliage cover	2.88	0.28	2.71	0.13	0.368	0.558
Elevation (m)	1884.7	10.6	1911.0	14.1	2.227	0.153
Slope (degrees)	11.40	3.09	19.10	3.69	2.559	0.127
Dead trees (%)	13	4	12	1	0.056	0.816
Dead pinyon (%)	43	19	33	0	1.756	0.202
Dead juniper (%)	8	0	12	2	3.395	0.082
Nest height (m)	2.30	0.22	1.88	0.13	2.595	0.125
Height of nest tree (m)	3.80	0.22	3.44	0.23	1.328	0.264
Area of nest tree (m^2)	22.19	1.95	21.18	2.98	0.081	0.779
Volume of nest tree (m^3)	56.80	6.85	49.26	6.98	0.594	0.451
Foliage cover of nest tree	2.85	0.11	2.50	0.20	2.371	0.141
Nest tree/non-nest tree height ratio	1.17	0.09	1.22	0.07	0.150	0.703
Nest tree/non-nest tree area ratio	1.32	0.19	1.62	0.25	0.883	0.360
Nest tree/non-nest tree volume ratio	1.49	0.29	1.77	0.34	0.394	0.538
Nest tree/non-nest tree foliage ratio	1.05	0.03	0.92	0.05	3.531	0.077
Relative nest height 1[b]	0.60	0.05	0.56	0.04	0.352	0.561
Relative nest height 2[c]	0.71	0.08	0.67	0.04	0.235	0.634
Distance of nest to center (m)	1.08	0.21	1.13	0.23	0.026	0.874
Distance of nest to edge (m)	0.96	0.24	0.91	0.20	0.026	0.125
Relative edge distance[d]	0.51	0.08	0.55	0.07	0.128	0.725

* Indicates statistical significance

[b] Relative nest height 1– Ratio of the height of the nest compared to the height of the nest tree.

[c] Relative nest height 2 – Ratio of the height of the nest compared to the average height of non-nest trees in the plot.

[d] Relative edge distance – Ratio of the distance from the nest to the center of the nest tree divided by the tree radius.

Table 4.4 - Habitat characteristic variables eliminated and retained before AICc evaluation of pinyon jay renesting habitat. Some variables were eliminated before evaluation because they showed little or no slope when plotted, indicating weak association with nest site selection. Other variables were eliminated because they were highly correlated with other variables or could not be meaningfully applied among nest plots. Kirtland Air Force Base, New Mexico 2017-2018.

Variable	Reason Eliminated	Correlated Variable	r
No. of shrubs [a]	Correlation	Total shrub area	0.94
No. of trees [a]	Correlation	Total tree area	0.76
No. of pinyon [a]	Correlation	Total tree area	0.65
No. of juniper [a]	Correlation	Total tree area	0.80
No. of multi-trees [a]	Correlation	Total tree area	0.71
No. of live trees	Correlation	Total tree area	0.75
No. of live pinyon	Correlation	Number dead pinyon	0.68
No. of live juniper	Correlation	Total tree area	0.80
No. of live multi-trees	Correlation	Total tree area	0.71
No. of dead trees	Correlation	Total tree area	0.67
No. of dead pinyon	Correlation	Total tree area	0.69
No. of dead multi-trees	Not Present		
Mean live tree height (m)	Correlation	Average juniper area	0.82
Mean live shrub area (m^2)	Not on all plots		
Mean live tree area (m^2)	Correlation	Average juniper area	0.89
Mean live pinyon area (m^2)	Not on all plots		
Mean multi-tree area (m^2)	Not on all plots		
Total live multi-tree area (m^2)	Correlation	Total tree area	0.69
Total live vegetation area (m^2)	Correlation	Total tree area	0.93
Live shrub area (%)	Correlation	Total shrub area	1.00
Live tree area (%)	Correlation	Total live tree area	1.00
Live vegetation area (%)	Correlation	Total live vegetation area	1.00
Mean shrub volume (m^3)	Not on all plots		
Mean live tree volume (m^3)	Correlation	Average juniper area	0.89
Mean live pinyon volume (m^3)	Not on all plots		
Mean live juniper volume (m^3)	Correlation	Average juniper area	0.99
Mean live multi-tree volume (m^3)	Not on all plots		
Total live shrub volume (m^3)	Correlation	Total shrub area	0.93
Total live tree volume (m^3)	Correlation	Total tree area	0.92
Total live multi-tree volume (m^3)	Correlation	Total tree area	0.67
Total live vegetation volume (m^3)	Correlation	Total tree area	0.88

[a] Live or dead

Table 4.4 – (continued)

Variable	Reason Eliminated	Correlated Variable	r
Mean foliage cover	Correlation	Average juniper foliage	0.79
Mean pinyon foliage cover	Not on all plots		
Mean multi-tree foliage cover	Not on all plots		
Elevation (m)	Not Vegetation		
Slope (degrees)	Not Vegetation		
Dead trees (%)	Correlation	Average juniper area	0.62
Dead juniper (%)	Correlation	Number dead juniper	0.82
Nest height (m)	Correlation	Relative Height of Nest	0.67
Volume of nest tree (m^3)	Correlation	Area of nest tree	0.84
Nest tree/non-nest tree area ratio	Correlation	Relative Nest Tree Height	0.74
Nest tree/non-nest tree volume ratio	Correlation	Relative Nest Tree Height	0.89
Nest tree/non-nest tree foliage ratio	Correlation	Foliage cover of nest tree	0.90
Relative nest height 2[b]	Correlation	Relative Height of Nest	0.73
Distance of nest to center (m)	Correlation	Relative edge distance	0.85
Distance of nest to edge (m)	Correlation	Relative edge distance	-0.89

[b] Relative nest height 2 – Ratio of the height of the nest compared to the average height of non-nest trees in the plot.

Table 4.5 – Fate of pinyon jay nests on Kirtland Air Force Base, New Mexico in 2017–2018.

Nest Fate	2017		2018		Total	
	No. Nests	%	No. Nests	%	No. Nests	%
Fledged	4	16.0	5	29.4	9	21.4
Predated	16	64.0	10	58.8	26	61.9
Abandoned	2	8.0	1	5.9	3	7.2
Unknown	3	12.0	1	5.9	4	9.5
Total nests	25	100.0	17	100.0	42	100.0

Table 4.6 – Support for models explaining pinyon jay nest fate on Kirtland Air Force Base, New Mexico in 2017-2018. Support for all models was weak because the null model could not be rejected ($\Delta_i \leq 2$).

Variables	Intercept	Coefficient	df[a]	AICc[b]	Δ_i[c]	ω_i[d]
Nest tree area	3.1184	0.4261	2	145.4	0	0.158
Total tree area	3.0932	-0.3606	2	146.1	0.7	0.111
Relative edge distance	3.1338	0.3188	2	146.1	0.7	0.109
Total shrub area	3.0995	-0.3741	2	146.2	0.8	0.106
Average juniper foliage cover	3.1267	0.3494	2	146.5	1.1	0.090
Null	3.139		1	147.1	1.7	0.068
Nest tree/non-nest tree area ratio	3.1413	0.3218	2	147.1	1.7	0.068
Nest tree/non-nest tree foliage ratio	3.1173	-0.3038	2	147.1	1.7	0.066
No. dead pinyon	3.0968	-0.3904	2	147.1	1.8	0.066
Average juniper area	3.1582	0.3249	2	147.8	2.4	0.047
Relative nest height 1	3.1602	0.1471	2	148.5	3.1	0.033
Nest tree foliage	3.13863	-0.07977	2	148.9	3.6	0.027
No. dead juniper	3.13458	-0.06926	2	149.0	3.6	0.026
Percentage dead juniper	3.14081	0.01167	2	149.1	3.7	0.025

[a] df – Degrees of freedom

[b] AICc – Akaike's Information Criterion corrected for small sample sizes

[c] Δ_i – Akaike's Information Criterion relative to the highest ranked model

[d] ω_i – Akaike weight

[e] Relative edge distance – Ratio of the distance from nest to tree center compared to distance from nest to tree edge in the nest tree

[d] Relative nest height 1– Ratio of the height of the nest compared to the height of the nest tree

Table 4.7 – Distance of pinyon jay nests from their original colonies and neighboring nests on Kirtland Air Force Base, New Mexico in 2017-2018. Contiguous nests were renests built near the original colony (< 0.7 km) and non-contiguous nests were renests built far away from the original colony (≥ 1.5 km).

Distance (m)	n	$\overline{X}$	SE
Original colony nearest neighbor	12	137.86	34.55
Contiguous renest nearest neighbor	8	174.59	45.35
Non-contiguous nest to original colony	4	1767.90	111.42
Contiguous nest to original colony boundary	8	440.44	46.82
Renests from previous nest (when known)	4	1547.85	325.06

Table 4.8 – Support for models explaining the relationship between habitat variables and choice of pinyon jay renesting location on Kirtland Air Force Base, New Mexico in 2017-2018. The relative edge distance of nests trees best predicted nest fate. All models below the null model were rejected due to high Δ_i values ($\Delta_i \geq 2$; Arnold 2010; Symonds and Moussalli 2011).

Variables	Intercept	Coefficient	df[a]	AICc[b]	Δ_i[c]	ω_i[d]
Average juniper area	-0.2361	-1.7112	2	27.6	0	0.292
Total tree area	-0.04077	-1.01288	2	28.6	1.0	0.181
Null	0		1	29.9	2.3	0.09
Nest tree foliage	0.01067	-0.76931	2	30.0	2.4	0.088
Percentage dead pinyon	-0.1046	-0.9986	2	30.2	2.6	0.079
Nest tree height	0.003675	-0.576535	2	31.0	3.4	0.053
No. dead juniper	0.007189	0.389416	2	31.8	4.2	0.036
Average juniper foliage	0.001573	-0.329997	2	31.9	4.3	0.033
Relative nest height 1[e]	-0.0007597	-0.2887386	2	32.0	4.4	0.032
Total shrub area	0.001958	0.270665	2	32.1	4.5	0.031
Nest tree/non-nest tree height ratio	0.0004023	0.1883246	2	32.3	4.7	0.028
Relative edge distance [f]	-0.0001766	0.1734011	2	32.3	4.7	0.028
Nest tree area	-0.0001117	-0.1381537	2	32.3	4.7	0.027

[a] df – Degrees of freedom

[b] AICc – Akaike's Information Criterion corrected for small sample sizes

[c] Δ_i – Akaike's Information Criterion relative to the highest ranked model

[d] ω_i – Akaike weight

[e] Relative nest height 1– Ratio of the height of the nest compared to the height of the nest tree

[f] Relative edge distance – Ratio of the distance from nest to tree center compared to distance from nest to tree edge in the nest tree

Figure 4.1 - Map of 90 percent volume contours of a kernel density estimate for pinyon jay flocks on Kirtland Air Force Base, New Mexico in 2017-2018 (Chapter 2).
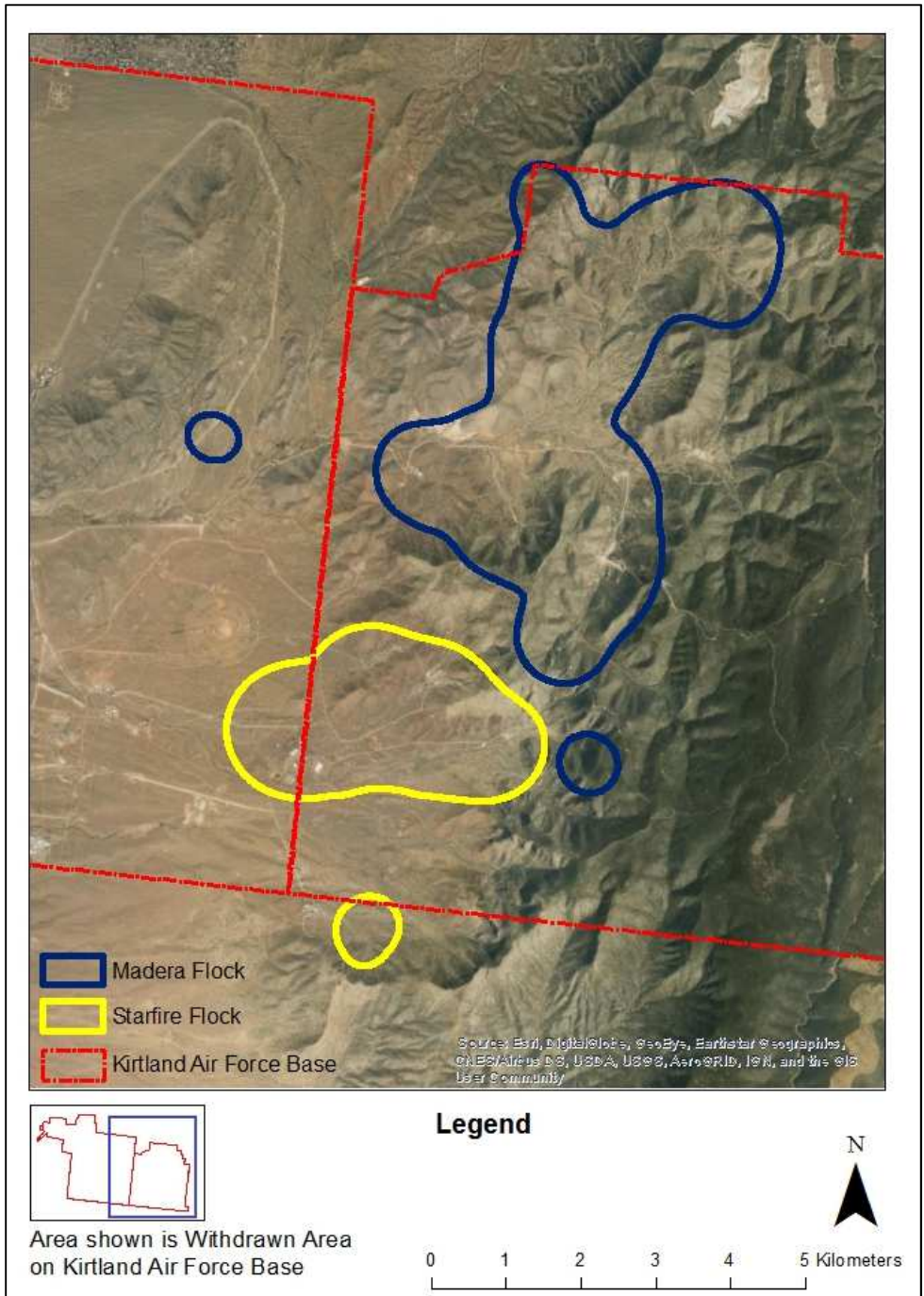
Figure 4.2 – Map of pinyon jay nests at the Madera2 breeding colony and a renest on Kirtland Air Force Base, New Mexico in 2017.
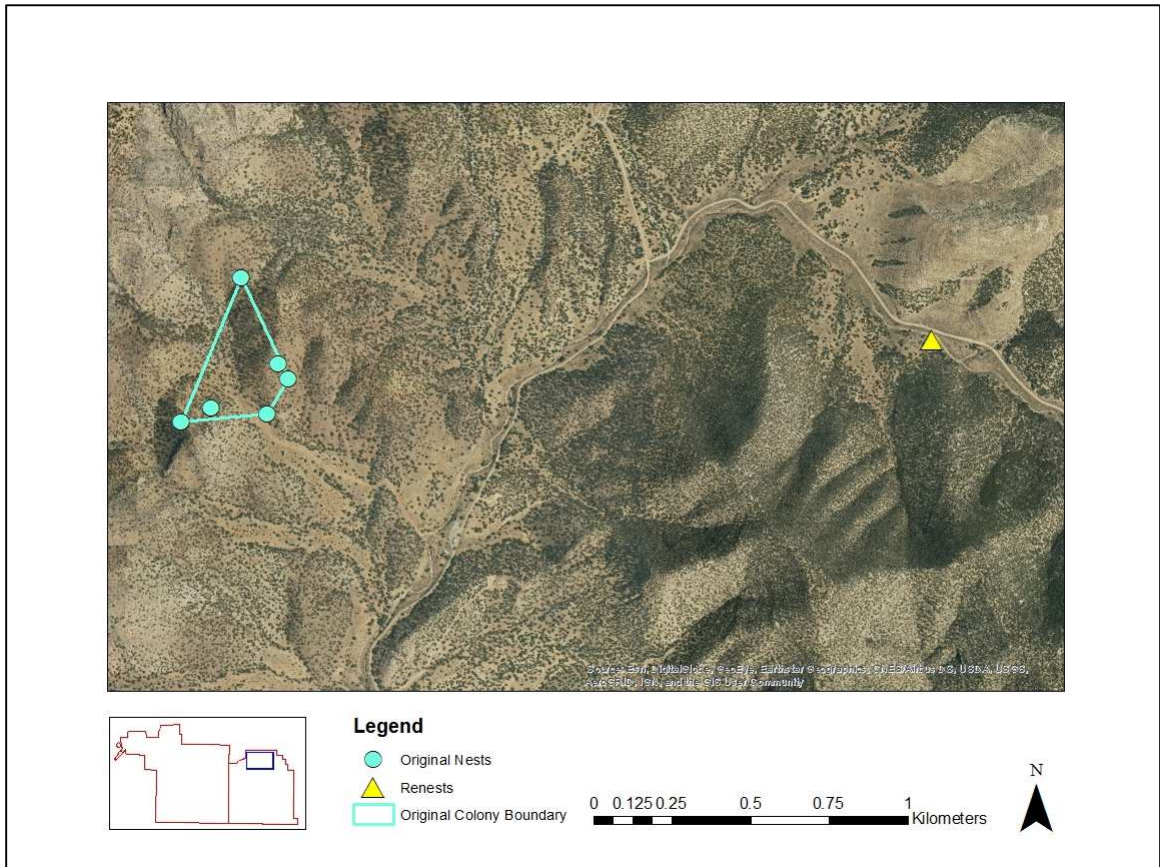
Figure 4.3 – Map of pinyon jay nests at the Starfire1 breeding colony and renests on Kirtland Air Force Base, New Mexico in 2017. Arrows indicate the succession of breeding attempts by two breeding pairs.
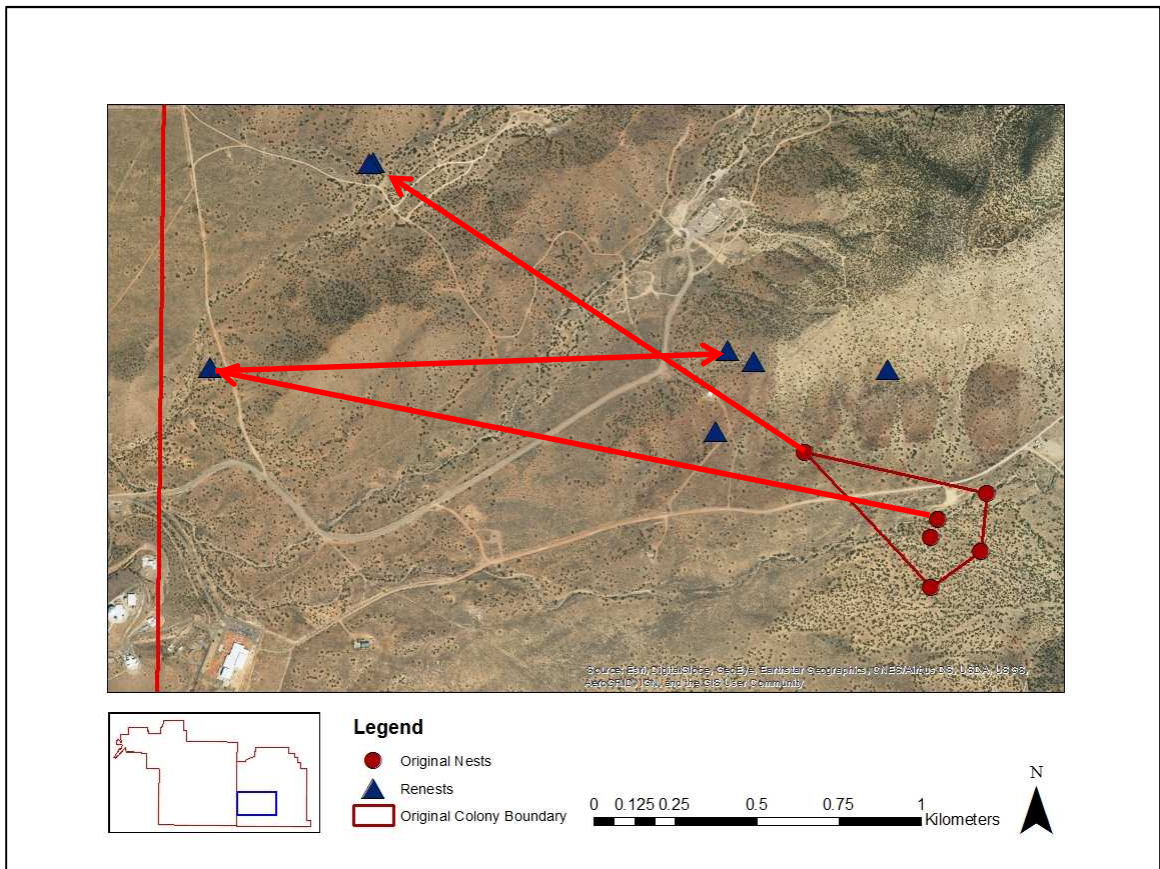
Figure 4.4 – Map of pinyon jay nests at the Starfire3 breeding colony on Kirtland Air Force Base, New Mexico in 2018. The arrow indicates the succession of nesting attempts by one breeding pair. Although the original nests and renests in this colony appear like distinct groups, the distance between the original nests and the nearest renest is approx. 0.4 km. Further, not all of the nests of the original colony were found, so the full extent of the original colony boundary is unknown.
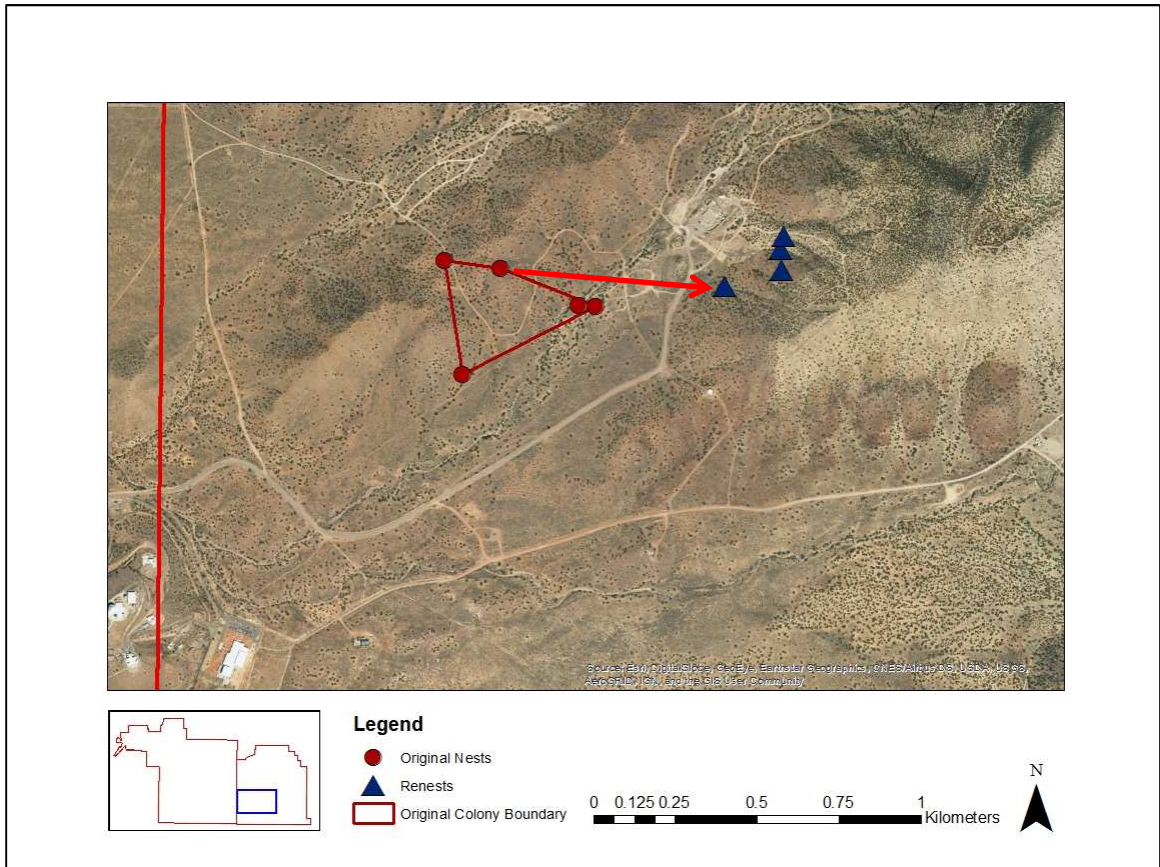
VITA

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